

CDMA2000 Past, Present and Future

Saad Zaman Asif

Telenor Pakistan
38 Paris Plaza, F-11 Markaz, Islamabad, Pakistan
saad.asif@telenor.com.pk

Abstract

The article looked into the possible future of 3GPP2's CDMA2000 1X and CDMA2000 1xEV-DO networks. The 3G CDMA2000 family of standards including EV-DO (Evolution Data Optimized) is in the daily use of more than 600 million customers across the globe. The article first focused on the short term interoperability challenges to LTE and WiMAX and provided some antidotes for addressing these hurdles. The key challenges that were investigated include spectrum planning, authentication and security, end-to-end QoS (Quality of Service), voice enablement and data service continuity. The investigation revealed that a new QoS mapping mechanism between EV-DO and WiMAX similar to the one shown in the article is required for smooth operation. The analysis further indicated that CSFB (Circuit Switched Fallback) and SVLTE (Simultaneous Voice and LTE) were two techniques which could be used to support CS voice on an LTE/CDMA network. However they had different inter-radio access technology interworking requirements. In the following section, the performance aspects both WiMAX and EV-DO were highlighted indicating a deep dip in through put values once the users switches from WiMAX to EV-DO. The article concluded by discussing the future roadmap of CDMA2000 from 1X Advanced and DO Advanced perspectives. A performance comparison between 1X and 1X Advanced and EV-DO and DO Advanced was also presented.

Keywords: CDMA2000, DO-Advanced, EV-DO, LTE, WiMAX

1. Introduction

The continuous downfall of CDMA2000, the death of 3GPP2 UMB (Ultra Mobile Broadband) and the absence of 3GPP2 from IMT-Advanced (4G) are pushing the concern of operators to look for other alternatives. To keep the ball rolling, the CDMA2000 operators are looking for possible migration either towards LTE (Long Term Evolution) or WiMAX (World Interoperability for Microwave Access). CDG (CDMA Development Group), the flagship of CDMA2000, also envisions a path towards LTE which will be an intermediary step before an eventual migration of EV-DO to 4G (LTE Advanced).

The very first step comes to mind for a successful migration involves Mobility Management or Interworking between networks. The mobility management aspects between EV-DO also called HRPD (High Rate Packet Data) and LTE are defined by 3GPP and 3GPP2. The interworking aspects between EV-DO and WiMAX are primarily specified by 3GPP2 and more or less by WiMAX Forum.

After providing the background info (section 2) and the mobility management technicalities (section 3), we will list down the key challenges which the industry facing in this migration in section 4. A performance analysis of WiMAX and EV-DO is shown in section 5, while the future of CDMA2000 including the performance of EV-DO is depicted in section 6.

2. History of CDMA

CDMA came into existence in the telecom world with the inception of 2G IS-95 systems in the mid-nineties. IS-95 was primarily endorsed by US and South Korean operators. Qualcomm was, and still, the key developer of CDMA chipsets, which are incorporated in more than 90% of CDMA2000 devices and networks that are present across the globe.

The 3G CDMA2000 technology was standardized as IS-2000 in 1999 and the first system was deployed by SK Telecom in South Korea in 2000. The journey continues as shown in Figure 1 with the inception of IS-856 EV-DO (Evolution Data Optimized) and till it hit a

roadblock by not getting the endorsement of CDMA2000 EV-DO Rev C (or Ultra Mobile Broadband) from the key industry players. EV-DO Revision A was the last successful endeavour of the CDMA industry and after the discontinuance of UMB from Qualcomm, Sprint and Verizon roadmaps; the industry is look for other alternatives.

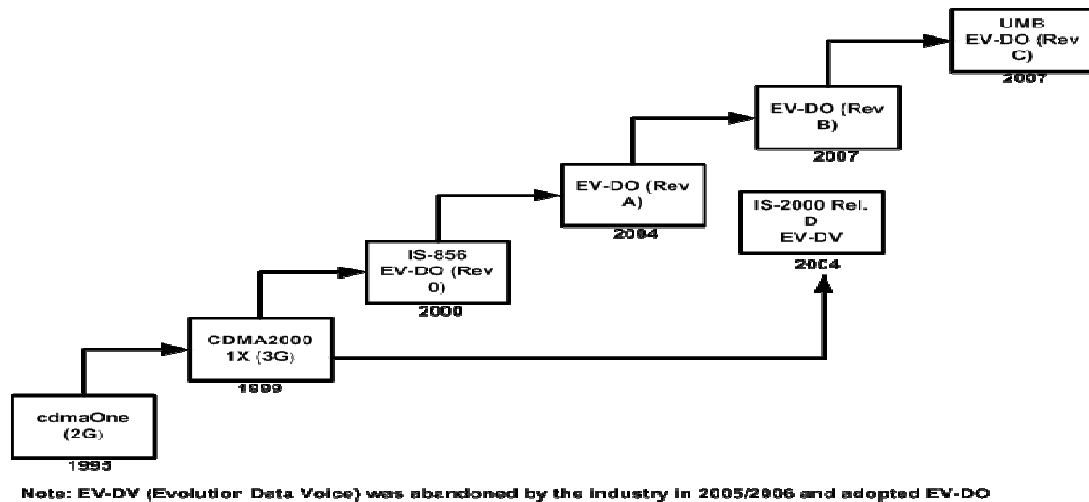


Figure 1. CDMA standardization (1995-2007)

3. Present and Near Future Requirements for CDMA2000

The first question that comes to mind is how to keep the competitiveness for the CDMA2000 industry in the short term. 3GPP2 answered this query by providing interworking specifications for CDMA2000 with LTE and WiMAX. This section will primarily look into the interworking aspects from different standard bodies perspectives.

3.1. Mobility Management

Mobility Management is one of the major functions of cellular systems that allow mobile phones to work across networks. The aim of mobility management is to track where the subscribers are, allowing calls, texting and other mobile phone services to be delivered to them. There are several pieces attached to mobility management including – personal mobility, session mobility, network and terminal mobility [1].

- *Personal Mobility* defines the ability of the user to access his/her personal services (for e.g., bookmarks, calendar, etc.) while away from the home network.
- *Session Mobility* is maintaining seamless in sessions when moving from one network to another (e.g., movement from WiMAX to EV-DO, EV-DO to LTE, etc).
- *Network and Terminal Mobility* defines the capability both the network and the terminal to support roaming.

3.1.1. Mobility Management in CDMA2000

The CDMA2000 systems incorporate Mobile IP to achieve the management mobility. Mobile IP is necessary to maintain sessions in macro-mobility environments. It supports both intra-PDSN and inter-PDSN management mobility. PDSN (Packet Data Serving Node) is a component of CDMA2000 systems that connects radio access with IP networks. Mobile IP is also used to provide seamless connectivity when roaming into a non-3GPP2 network (EPS¹ or WiMAX). CDMA2000 also supports IP micro mobility to handle intra domain mobility without interacting with mobile IP enabled Internet to enhance quality of real-time communications, effectively reducing delay and packet loss during handoffs.

¹ EPS is Evolved Packet System which comprises of E-UTRAN (LTE) and EPC (Evolved Packet Core). E-UTRAN is Evolved UMTS Terrestrial Radio Access Network

3.1.2. Interworking between EV-DO and EPS

3GPP2 has defined an interworking method by evolving existing HRPD networks to be compatible with 3GPP EPC through a step called eHRPD (Evolved HRPD). An eHRPD system consists of HRPD BTS, Evolved Access Network (eAN) and Evolved Packet Control Function (ePCF) that supports evolved mode operation in addition to legacy mode operation. The introduction of eHRPD requires the introduction of a HRPD Serving Gateway (HSGW). The HSGW ensures converged mobility management between eHRPD and LTE networks. The HSGW connects the eHRPD access network with EPC. In some network instances, the existing PDSN can be integrated with or upgraded to the HSGW while the existing HA (Home Agent) can be integrated with or upgraded to the EPC PDN (Packet Data Network) Gateway (or provided as a separate node) [2].

Figure 2 is an example of E-UTRAN and eHRPD interworking architecture in the absence of roaming. Some key reference points are required in the interworking architecture as follows [2]:

- H1 reference point carries signaling information between a source HSGW (S-HSGW) and a target HSGW (T-HSGW) for optimized inter-HSGW handoff.
- H2 reference point carries user traffic between a source HSGW (S-HSGW) and a target HSGW (T-HSGW) for optimized inter-HSGW handoff.
- S101 reference point connects the MME (Mobility Management Entity) in the EPS to the eAN/ePCF in the eHRPD access network. This reference point provides tunnel of signal and data between the UE (user terminal) and the target access network via the source/serving access network.
- S103 reference point connects the Serving Gateway (S-GW) in the EPC to the HSGW. Its function is to forward downlink data between the S-GW and the HSGW to minimize packet losses in mobility from E-UTRAN to eHRPD.
- Gxa reference point connects the Policy and Charging Rules Function (PCRF) in the EPC to the HSGW.
- S2a reference point connects the PDN Gateway to the HSGW. This reference point provides the user plane with related control and mobility support between eHRPD access and the PDN-GW.
- STa reference point connects the AAA (Authentication Authorization and Accounting) in the EPC to the AAA in the eHRPD network.
- Pi* reference point connects the HSGW to the 3GPP2 AAA Proxy.

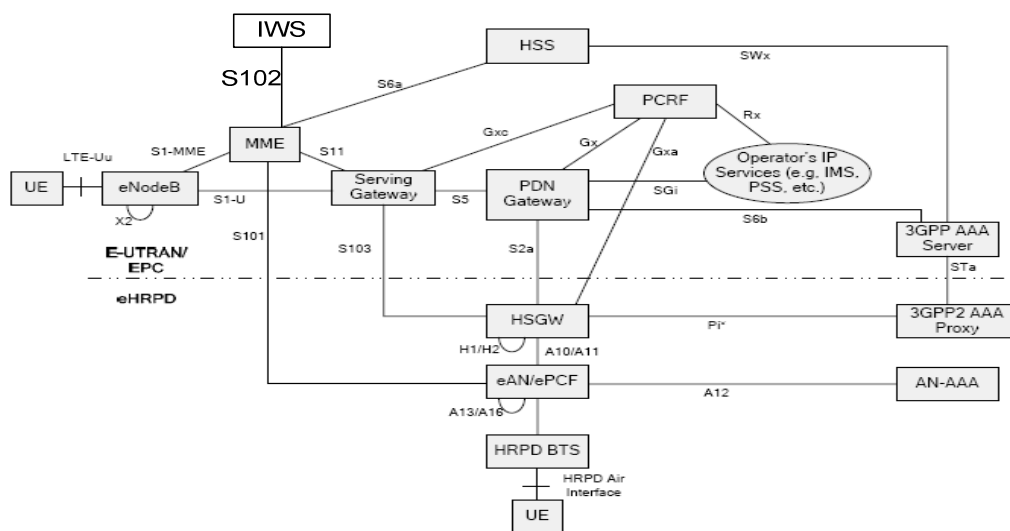


Figure 2 E-UTRAN-eHRPD interworking architecture [2]

Figure 2. E-UTRAN-eHRPD interworking architecture [2]

3.1.3. Interworking between EV-DO and WiMAX

The WiMAX SFF (Signal Forwarding Function) provides a connection between the MS (WiMAX mode) and the ASN-GW. It supports single radio handover from non-WiMAX IP access network to WiMAX. It also facilitates pre-registration and authentication while the MS is connected via the non-WiMAX Access Network prior to active handover to the WiMAX Network.

The HRPD SFF (Signal Forwarding Function) provides a connection between the AT (HRPD mode) and the HRPD AN/PCF. The HRPD SFF is the termination point of secured tunnel between MS/AT and the HRPD SFF [3]. For example, an IPSec tunnel between the access terminal and SFF can be used. The HRPD SFF is a logical entity that supports layer 3 tunnelling of HRPD signalling messages to/from the MS/AT² over the WiMAX air interface.

Further details on the interworking will be discussed in the performance analysis section (section 5).

4. Challenges in Transition – Short term

This section will address the key challenges which the industry will face during this transition.

4.1. Spectrum Planning

The transition from CDMA to LTE requires a thorough spectrum planning. EV-DO primarily operates in 850, 900 and 1900 MHz bands. LTE primarily operate in 900, 1800 and 2600 MHz bands in Europe and in the ‘digital dividend’ 700 MHz band in USA. WiMAX networks are currently operating in 2300, 2600 and 3500 MHz frequency bands.

LTE and WIMAX support multiple channel bandwidths from a minimum of 1.4/1.25 MHz to 20 MHz. Though LTE provides 10 different channel sizes, the current R&D and network deployments are primarily focusing on 10 and 20 MHz carriers. The first two revisions of EV-DO which are deployed worldwide are restricted to a 1.25 MHz channel size. The EV-DO Rev. B which allows multi carrier operation for better performance has not received much support from the industry so far. It allows aggregation of fifteen 1.25 MHz carriers to provide a 20 MHz channel to a single user.

For an effective and gradual transition from EV-DO to LTE, it would be inevitable not to start off with smaller LTE channel bandwidths in LTE-900 (~CDMA 800) and LTE-1800 (~CDMA 1900) bands³, unless a CDMA operator secures additional spectrum in the same band or buys out a new spectrum altogether⁴. At the same time, as these bands fall into each other’s territory spectrum farming is necessary as well. In urban settings, EV-DO cell sites typically use two 1.25 MHz channels to meet the data demand with one channel which is reserved for voice (CDMA2000 1X). Figure 3 shows a possible transition scheme from EV-DO to LTE in a 5 MHz spectrum. EV-DO operators can start from single LTE 1.4 MHz carrier and eventually migrate to full 5 MHz LTE/WiMAX carrier.

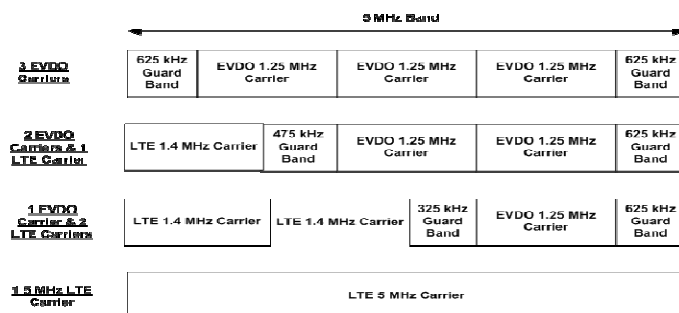


Figure 3. EV-DO migration to LTE [1]

² In standards, the term MS is used for mobile station where as AT is used for Access Terminal.

³ LTE-900 runs from 870-960 MHz while CDMA-800 runs from 824-940 MHz. LTE-1800 lies between 1710-1880 MHz while CDMA-1900 stays between 1850-1990 MHz. AWS Advanced Wireless Services from 1710 to 1755 MHz and from 2110 to 2155 MHz

⁴ Verizon Wireless secured 700 MHz for LTE in addition to 850 and 1900 MHz for CDMA2000.

4.2. Authentication and Security

Each wireless access network has different security mechanism to mitigate security threats. The composition of several security architectures may produce an insecure outcome. This inefficiency occurs due to possibly conflicting security mechanism and the processes that are used to apply a specific security procedure. At the same time, any delay in authentication will impact the performance of high speed sessions. The long authentication delays during handover can be perceived as disruption of services by the user [1].

Different access networks have different link layer network access authentication procedures, different key management mechanisms and also distinct encryption and integrity protection at different layers. When the user performs an inter RAT (radio access technology) handover, the user has to do network specific access authentication procedure, establish the security association to secure the wireless communication and then perform the mobility management procedure. The number of message exchanged during handover for network access authentication imposes heavy burden on both user equipment and network entity and network traffic, which increase the handover latency [4].

For instance, EV-DO uses SHA-1 (Secure Hash Algorithm) and Diffie Hellman as authentication and key-exchange protocol. The EPS, on the other hand, uses EAP-AKA (Extensible Authentication Protocol – Authentication and Key Agreement) to handle the authentication and security needs. Thus to ensure smooth authentication HSGW needs to support EAP and should act as an authenticator in eHRPD. The dual mode UEs (user terminals) also need to support the EAP-AKA protocol.

The UE performs user authentication and authorization in the eHRPD access system using EAP-AKA. The EAP-AKA messages are transferred between the UE and HSGW over PPP. The 3GPP2 AAA server authenticates and authorizes the UE for access in the eHRPD system. The 3GPP AAA server queries the HSS (Home Subscriber Server) and returns the PDN-GW address to the eHRPD system (upon success authentication and authorization). The HSGW stores the PDN-GW IP address and default APN (access point name), QoS profile and other user context information received from the 3GPP AAA/HSS server. As both systems employ EAP-AKA, it is possible to have a smooth transfer of authentication security procedures between serving and target networks. It is further possible that the access specific keys can be derived from the keys (CK and IK) agreed during the AKA (Authentication and Key Agreement) procedure in the previous access system (i.e. security context transfer) [4].

As 3GPP already adopted security context transfer procedures for optimizing authentication during Intra 3GPP network handover, it is reasonable for EPC to enable security context⁵ transfer between the 3GPP and non-3GPP networks to achieve seamless handover. The serving access system security context can be used by the target network and the UE, to mutual authenticate and to derive the target access specific keys for quick connection establishment. And later to impose the required security level, the target access system can perform an access-specific complete authentication procedure in parallel with the data transfer. This requires support of access specific key derivation during handover.

4.3. Quality of Service

EV-DO and LTE employ different sets of QoS mechanism and traffic priority levels. EV-DO supports a device-initiated QoS model whereas the LTE supports a network-initiated model. The QoS classifier is obtained mostly from the UE in EV-DO. In LTE, the UE does not send a QoS classifier to the radio access network, instead this information comes from the network. During handoffs, similar QoS class can only be maintained if there are proper mapping of QoS parameters between the two underlying technologies [5].

EV-DO mainly defines four traffic classes and uses FlowProfileID to identify the QoS needs for an application flow. A FlowProfileID is a scalar value representing a flow description. A flow description specifies all relevant air interface parameters to support a particular packet data service. LTE, on the other hand, supports nine QCI. A QCI (QoS class identifier) is a scalar value which classifies a set of bearer parameters suitable to a particular class of applications. Thus for providing end-to-end QoS, it is necessary that a mapping mechanism is defined when the users are moving from one network to others. In other words, the method

⁵ Security context includes agreed security algorithms between the UE and the serving network, derived encryption and/or integrity protection keys and key identifiers, security association related information like key lifetime, sequence number, count values etc. and the temporary identity issued by the serving network.

used for specifying service parameters for a particular service in eHRPD (namely FlowProfileIDs) should be mapped to the service parameters associated with the same service in EPC (namely QCI). A possible QoS mapping mechanism between eHRPD and EPS is discussed in [2].

Table 1 is the example of QoS mapping between eHRPD and WiMAX. However, no QoS mapping mechanism between CDMA2000 and WiMAX has been defined [6-7] and one possibility is shown in Table 1. This proposed mechanism maps the 4 classes of EV-DO with the six QoS classes of WiMAX into seven distinct priorities. The application like web browsing has been given the lowest priority whereas conversational voice has been assigned one of the highest priorities.

Table 1. Example of QoS mapping between eHRPD and WiMAX

Existing QoS Traffic Classes			Proposed QoS Mapping Mechanism				
QoS Type	WiMAX QoS Value	CDMA2000 QoS Value	Value	WiMAX QoS Type	HRPD QoS Type	Example Services	
Reserved	0		1	BE	Background	FTP, web browsing	↓ lowest Priority
Undefined	1		2	(nrtPS) Non-real-time polling service	Interactive	Interactive Gaming, FTP	
Best Effort	2		3	(rtPS) Real-Time polling service	Streaming	Video Streaming	
nrtPS	3		4	(ertPS) Extended real time polling service	Conversational	Voice with Activity Detection (VoIP), PTT (Push-to-Talk)	
rtPS	4		5	(UGS) Unsolicited Grant Service	Conversational	Conversational Voice, VoIP	
ertPS	5		6	Reserved	Reserved	PTT Control Signaling	
UGS	6		7	Reserved	Reserved	IMS (IP Multimedia Subsystem) Signaling	
Reserved	7						
Unknown		0					
Conversational		1					
Streaming		2					
Interactive		3					
Background		4					
Reserved		5 to 7					

4.4. Voice Enablement

3GPP2 has defined SVDO or Simultaneous Voice and Data operation for CDMA2000 systems. SVDO defines the use of CDMA2000 1X for voice and data via EV-DO. The same principle can be applied with LTE and WiMAX, i.e., using 1X or 1X Advanced voice and LTE/WiMAX data in parallel.

Similarly, 3GPP has defined two methods for enabling voice for the co-existence of two networks. The first option called CSFB (Circuit Switched Fall Back) is used to solely provide data service across LTE networks, while carrying voice service across the CDMA networks. CSFB does not envision the use of IMS (IP Multimedia Subsystem) in the process. The second option can be used to ensure voice between E-UTRAN packet switched access and CDMA2000 1X circuit switched access is Single Radio Voice Call Continuity (SRVCC). SRVCC requires IMS for transitioning LTE VoIP to 1xCS network.

4.4.1 CSFB

CSFB to 1X is supported for both single Rx (receive) and dual Rx user terminals and it is defined in 3GPP TS 23.272 [8]. The UEs with dual Rx can camp in 1X⁶ while they are active in E-UTRAN. However, these terminals may not be able to stay in E-UTRAN when they handle a circuit switched call and/or perform registration signaling, and/or sending or receiving a SMS in 1X. Nevertheless, such handsets will necessitate complex circuitry and will drain battery power.

The single Rx capable terminals, on the other hand, cannot camp in 1X when they are active in E-UTRAN. To address this challenge, the network provides mechanisms in the form of Interworking Solution (IWS) node to perform routine function. The IWS node encapsulates, for example, the paging message from the 1X network into the LTE network message.

⁶ 1X refers to single carrier and it is synonymous to CDMA 1X.

CSFB is supported via S102 reference point (Figure 2) that exists between the MME and the IWS. S102 provides a tunnel between the two entities to relay 1X signaling messages and for supporting SMS in EPS. The SMS are tunneled in EPS and over S102 and does not cause CSFB to 1X. Thus does not require overlapped CDMA 1X coverage.

Unlike 3GPP Release 8, the CSFB in Rel-10 supports simultaneous voice and data (SVD) capability. The support of packet switched handover during CSFB is optimized in R9/R10 of 3GPP. CSFB switches ongoing LTE data services over to the CDMA network to ensure data service continuity when subscribers are using voice services. The SVD capability is not supported in Rel-8 and terminal has to be reconnected to the LTE network to resume data services.

4.4.2 SRVCC

SRVCC allows terminals to utilize LTE's VoIP service in an LTE coverage area and then use the IWS node to handoff the CDMA network to ensure voice service continuity. LTE VoIP has been the focus in the 'One Voice' specifications that defines a voice over IMS profile by listing number of E-UTRAN, EPC, IMS core, and UE features which are considered essential to launch interoperable IMS based voice.

The E-UTRAN architecture needs to be modified with an additional functional entity called 1x CS SRVCC interworking solution function (3GPP2 1xCS IWS) to support voice continuity. This architecture reuses many existing elements from 3GPP2 X.S0042 for 3GPP2 1xCS. SRVCC function is also to support emergency sessions and in limited service mode.

For SRVCC-capable UEs, the call is always anchored at the VCC (voice call continuity) AS (application server) in the 3GPP2's IMS. The 1xCS IWS enables a single radio UE to communicate in parallel both the source system and the target system. From VCC perspective, this mechanism minimizes the voice gap by supporting the transport of signaling for establishment of the target CS access leg while the terminal is connected to the source PS access network. The S102 reference point is used to convey 1xCS signaling messages between the MME and 1xCS IWS. These 1x CS signaling messages are exchanged between the UE and the 1xCS IWS, and S102 is only one link in the overall UE 1xCS IWS tunneling path. On the remaining portion of the tunneling path, the 1xCS signaling messages are encapsulated in E UTRAN/EPS tunneling messages (UE MME) [9].

The role of the 3GPP2 1xCS IWS is:

- To be a signaling tunneling end point towards the MME for receiving/sending encapsulated 1xCS signaling messages to/from the UE; and
- To emulate a 1X BSS (Base Station Subsystem) towards the 1X MSC (reference point A1 between 1xBS and MSC).

4.4.3 SVLTE

Simultaneous Voice and LTE means support for voice via CDMA 1X or 1X Advanced and for data via LTE. SVLTE (Figure 4) allows users to access the web, send emails, watch videos, etc while simultaneously communicating on a phone call.

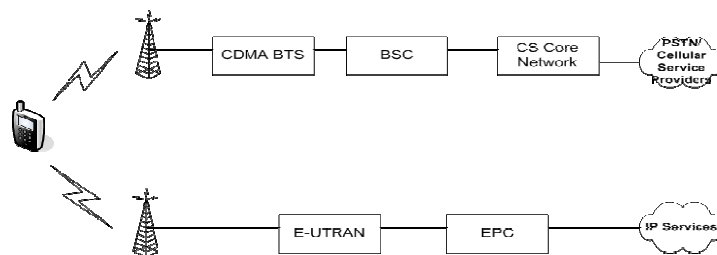


Figure 4. SVLTE architecture

This option does not require interworking between the two networks. However, the phones will require two radios – one for 1X and one for LTE. A high level architecture of SVLTE

is shown in Figure 4. SVLTE is the only option that has been commercialized so far and was first launched on Verizon Wireless network in 2010.

4.4.4 Voice Analysis

At this moment, SVLTE seems to be a more viable solution for the near future and it may replace CSFB down the road. SRVCC requires IMS core which is only deployed in handful of commercial networks. A high level analysis of supporting voice with CDMA2000 network and data with LTE is shown in Table 2.

Table 2. CDMA/LTE voice analysis

Solution	2010-2014	2015 onwards	Comments
SVLTE	Use in CDMA2000/LTE networks	Perhaps a replacement for CSFB	Battery impact but provides good QoE (Quality of Experience)
CSFB	Scale of deployment depends on the success/failure of SVLTE	Perhaps replace by SVLTE	Political choice by 3GPP/GSMA
SRVCC	Scale of deployment depends on the success/failure of SVLTE and CSFB	Scale of deployment depends on the scale of deployment of IMS	Call quality could be compromised as compared to CS voice

4.5. Data Service Continuity

To provide data coverage not only in LTE hot spot areas but also outside EPS coverage zones by utilizing wide-coverage CDMA networks, handovers are required for data continuity. To achieve seamless handovers, dual mode devices, appropriate signaling interfaces and suitable backhaul are the key ingredients that are required.

4.5.1 Infrastructure Upgrades

The key element addition comes in the form of HSGW in the eHRPD network. HSGW as described earlier provides interworking eHRPD access network and EPS packet gateway. Further to support end-to-end QoS and services seamless, proper facilitation of FCAPS (Fault, Configuration, Accounting, Performance, and Security) of the network will be required. The facilitation of FCAPS will primarily require software upgrades in the relevant operations support systems.

There is also a pattern in favour of Multi-mode BTSs that supports multiple radio technologies. Though, not required for interworking but will eventual allow easy and cost effective migration towards 4G.

4.5.2 Mobile Backhaul

The backhaul, area between BTS/eNodeB and first or second traffic aggregation level or between BTS/NodeB and BSC/RNC (depending on operator's network topology) will have a significant impact on the performance of data as the users' handoff to EV-DO networks. The users will get lower data rates when they transitioned to EV-DO networks. This is not just due to EV-DO technology but also due to the absence of fibre or Gigabit radios that operate in 70/80 GHz bands in the backhaul of such networks. HRPD systems transport data via low capacity microwave radios or E1/T1 leased lines. LTE, on the other hand, requires either fibre enabled or Gigabit Ethernet enabled all-IP backhaul network which is not the case in 3G networks.

4.5.3 Devices

Devices are required to operate not only in multiple bands but also need both EV-DO and LTE/WiMAX functionalities. The delay in early 2010 from the main chipset vendor Qualcomm negatively impacted the commercialization efforts of LTE and LTE/EV-DO dual mode devices (primarily USB dongles) by roughly two quarters. The very first EV-DO/LTE dual mode handset SCH-R900 from Samsung was launched by Metro PCS, USA in 3Q'2010.

At the time of writing, very few devices are available that operates in both LTE/EV-DO and WiMAX/EV-DO modes. These high-end devices include smart phones, personal hotspots, and data modems. Sprint was the first operator to launch EV-DO and WiMAX dual mode

devices in 2010. Verizon Wireless announced four LTE and EV-DO dual mode devices during the 2011 Consumer Electronics Show.

4.5.4 Handovers

The handoffs can be provided either using non-optimized handover or optimized handover procedures. Both of handover types are applicable to both active and idle (dormant) modes.

- Non-optimized Handover: Non-optimized handoff involves the movement of the UE from E-UTRAN to eHRPD or vice-versa without the use of tunnelled signalling (i.e., S101 signalling) between the source access network and the target access network. The UE leaves the radio environment of the source access network and performs a radio-level attachment to the target access network (e.g., creates an eHRPD session for the case of the UE moving from E-UTRAN to eHRPD), and then performs a handover attach procedure to the Packet Data Network(s), it had been communicating with over the source access network [2].
- Optimized Handover: Optimized handoff involves the movement of the UE from E-UTRAN to eHRPD or vice-versa using tunnelled signalling (i.e., S101 signalling) between the source access network and the target access network. While still on the source access network, the UE tunnels signalling to the target access network to pre-register through the source access network, i.e., to create both a radio and an IP context on the target system. The optimized handoffs between E-UTRAN and HRPD involve two phases, pre-registration and the actual handoff. After pre-registration, the UE performs a radio-level handoff to the target technology per specified procedures [2].

5. WiMAX and EV-DO Performance Analysis

The performance of WiMAX and EV-DO in field and lab environments will be the topic of discussion in this section. As discussed in section 3, SFF is required to perform handovers between the two networks. A common IP core can be used for the WiMAX-HRPD interworking. A set of common elements like DHCP (Dynamic Host Configuration Protocol) and DNS (Domain Name Server), Home Agent (HA), and AAA is also required. The key interfaces and the interface in the architecture are as follows [3, 10]:

- Ty: The Ty interface carries policy, charging, and control information between the PDSN and the PCRF.
- X1: The X1 interface carries HRPD signalling information between the MS/AT and the HRPD SFF.
- X2: The X2 interface carries control information via a layer 3 tunnel between the WiMAX SFF and the MS/AT.
- X3: The X3 interface carries IP traffic between the PDSN and the LMA/HA. It uses PMIPv6 (Proxy Mobile IPv6) for IP traffic between the PDSN and the LMA.
- R6: R6 is interface between the WiMAX SFF and an ASN-GW. The R6 is the same as the interface between the WiMAX BS and ASN-GW.
- R9: R9 is a new reference point between the UE/MS and the WiMAX SFF. It is used to tunnel IEEE 802.16 MAC layer signalling and WiMAX messages to/from the UE/MS over the non-WiMAX Access Network.

5. 1. Analysis

We have evaluated WiMAX and EV-DO systems in both lab and field environments. A setup is shown in Figure 5 depicting five 3-sector cell sites roughly covering the area of 5 sq km. The cell sites were connected to ASN (in case of WiMAX) and to a BSC (in case of EV-DO) which is then connected to the core network where consisted of AAA, DHCP and DNS servers and HA [1]. The common core network was then to the Internet (IP services). The tests on the WiMAX system were conducted with a 5-MHz channel using a 512 FFT⁷ at 3.5 GHz in TDD (Time Division Duplex) mode. The EV-DO test network was operating at 1900 MHz supporting

⁷ Fast Fourier Transform is the size of FFT; in WiMAX FFT size varies (128, 256, 512, 1024, 2048) with the different channel bandwidth sizes (1.25, 2.5, 5, 10, 20 MHz) respectively

1.25 MHz channel in FDD (Frequency Division Multiplexing). During the entire testing exercise, the traffic ratio was 4:1 (downlink: uplink).

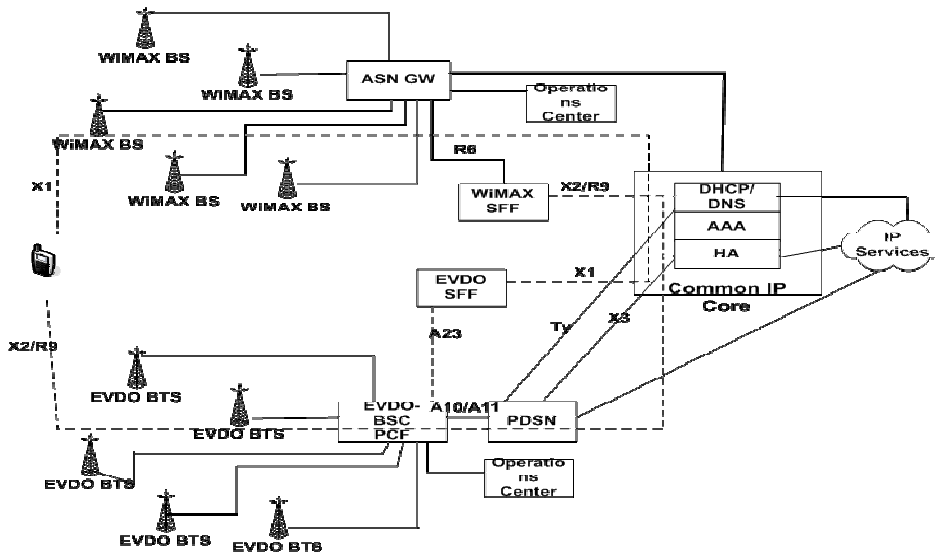


Figure 5. Evaluation setup

Figure 6 shows one of the capacity test results that were started with a single stationary CPE (Customer Premise Equipment) which was download files using a profile of 2 Mbps downlink and 512 kbps in uplink. Then a second subscriber station was added to the picture but the throughput was still increasing. The subscriber stations were added till the total throughput of the sector start to degrade from 5.9/4.1 Mbps in the downlink and uplink respectively in WIMAX. In our case, the throughputs started decrease with the addition of the eighth user with both 16-QAM and 64-QAM modulation techniques. Thus, maximum capacity (5.9 Mbps) can be achieved by eight users in parallel in downlink using the stated profile.

The case was repeated when the user was handed off to EV-DO network using SFF. The throughputs started decrease with the addition of the sixth user with both 8-PSK and 16-QAM modulation techniques.

During testing, it was also noticed that VoIP call quality was noticeably degraded as the user's handoffs to EV-DO because of the absence of a QoS mapping mechanism. The users from the highest UGS QoS type of WiMAX falls to unknown QoS type of EV-DO. Thus, the proposed QoS mapping mechanism as shown in Table 1 would be helpful in dealing with such issues.

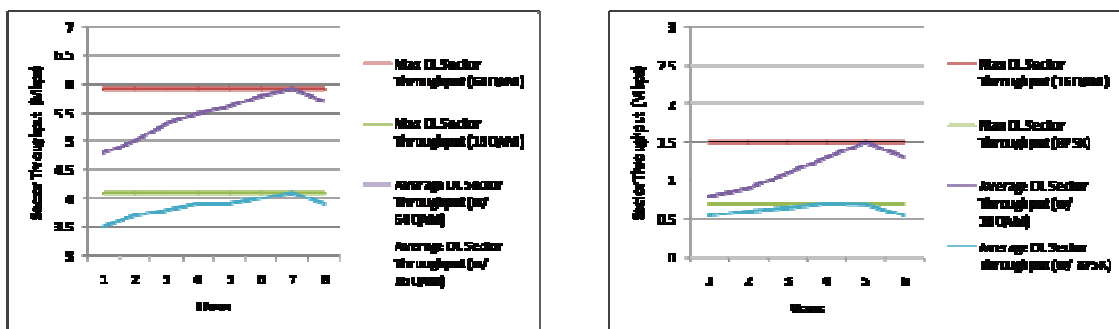


Figure 6. Capacity Results

**6. What's Next?
EV-DO Evolution**

To keep the CDMA2000 ball rolling, the CDG in 2011 provided a revised roadmap (first version came in 2009) for CDMA2000 which includes technological enhancements to both CDMA 1X and EV-DO as shown in Figure 7. CDG also claims that CDMA2000 will interoperate with wider-bandwidth OFDM (Orthogonal Frequency Division Multiplexing) based technologies such as LTE, LTE-Advanced (4G) and WiFi for additional broadband capacity in densely populated hot-zones/hot-spots where the demand for data is extremely high. The jury is still out there to determine the success or failure of these two different sets of roadmap.

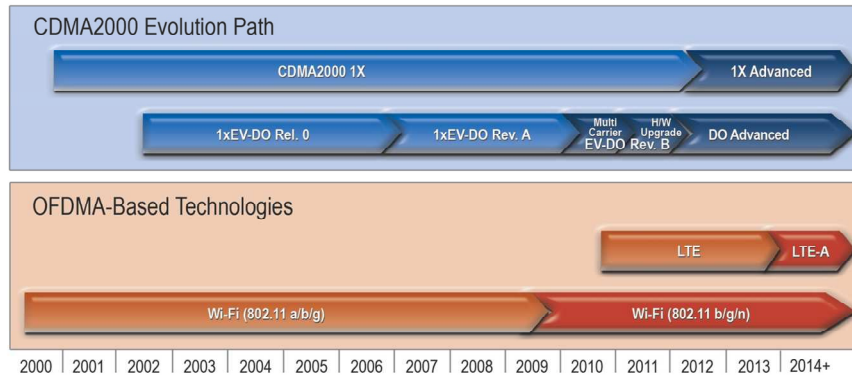


Figure 7. CDMA2000 evolution [11]

6.1.1. 1X Advanced

CDMA2000 1X Advanced was standardized as 3GPP2 C.S000X-E in September 2009. It is an evolution of CDMA2000 1X and can provide up to four times increase in voice capacity as compared to today's capacity of 35 simultaneous calls in 1.25 MHz of spectrum while delivering the same level of voice quality. This increase is primarily due to uplink and downlink interference cancellation, mobile receives diversity and several radio link enhancements that are included in 1X Advanced. The peak data rates will remain the same as IS-2000 Rel-A that is 307 kbps in both directions. Table 3 shows some of the key differences between CDMA2000 1X and 1X Advanced.

Table 3. 1X vs. 1X Advanced [12-26]

OSI Layers	1X Advanced	1X
Physical	12 Radio Configurations for downlink and 8 in uplink Additional Common and Data channels both in downlink and uplink for improving voice performance	9 Radio Configurations for downlink and 6 in uplink ---
MAC (Medium Access Control)	Broadcast/Multicast MAC multiplex sublayer which is used by broadcast services to transmit data to the mobile station via the broadcast logical channels.	BMAC is not present
LAC (Link Access Control)	Additional Message Integrity Procedures which is only applicable to a set of Layer 3 messages passed by it to LAC layer	Absence of specific message integrity procedures

6.1.2. DO Advanced

DO Advanced is the evolution of EV-DO Rev. B and was standardized by 3GPP2 in April 2010 as C.S0024-XXX-C (expected as TIA-856 Revision C) [22-26]. A number of key

features of this standard can be introduced in EV-DO Rev. A and EV-DO Rev. B networks primarily via software upgrades. However, in order to support OFDM, MIMO (Multiple Input Multiple Output) and MTD (Mobile Transmit Diversity) hardware upgrades will be required. To sum up, DO Advanced is comprised of three basic building blocks namely Smart Networks, Advanced Topology Networks and Advanced Devices as defined by CDG which shown in Figure 8.

A high level description of some of these features is as follows:

- *Network Load Balancing*: This feature off-loads users on the edge of heavily loaded sectors to lightly loaded neighboring sectors. The efficiency of traffic off-loading is not only alleviate congestion over the radio access network, but also within the backhaul network which in turn improves the overall network capacity.

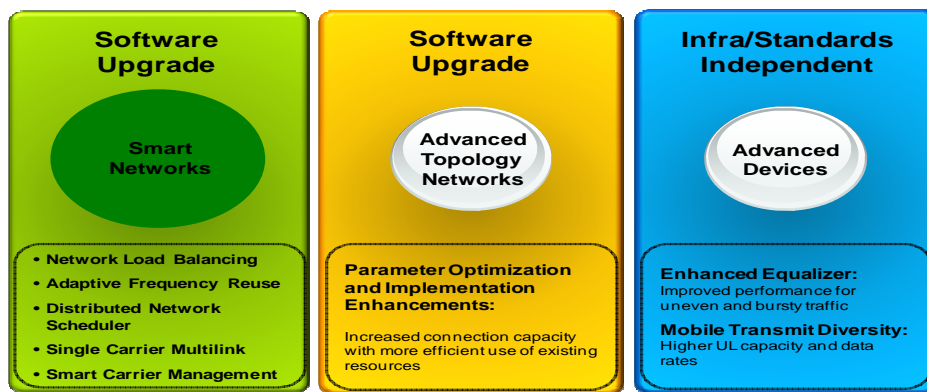


Figure 8. DO Advanced [11]

- *Adaptive Frequency Reuse*. Also known as Demand Match Configuration allows controlling the power level of the different sectors and also the different carriers. The power level is based upon the amount of load which they carried. The capacity is increased by lowering the transmit power of lightly loaded sectors to minimize interference.
- *Distributed Network Scheduler*. This feature increases data rates for users, especially at the edge of the cell by assigning the most suitable carriers to them, without sacrificing the gain achieved through Multicarrier. The users are preferentially served by carriers that maximize capacity.
- *Advanced Topology Networks*. It manages more interactive applications such as push/pull mobile email. It optimizes the process of allocation and de-allocation of resources to such applications and improves the usage of access and paging channels, resulting in support for a large number of simultaneous connected devices.
- *MTD*. MTD provides higher uplink capacity and data rates.

6.1.2.1. DO Advanced Performance

The peak data rates in DO Advanced and Rev. B are equal, i.e. 14.7 Mbps in downlink within a 5 MHz channel. However, with Forward MIMO-OFDM Traffic Channel and 64-QAM the rate can go as high as 56.22 Mbps in the downlink. In the uplink, the peak data rate is 12.9 Mbps in a 5 MHz channel.

The performance of DO Advanced is better than the previous revisions of EV-DO as shown in Figure 9. The figure shows the improve user experience with DO Advanced for web browsing at highly loaded conditions for an uneven load cluster of cells. This is due to the use of network load balancing functions of smart networks and ECM. The actual increase in capacity is based on demand distribution and implementation [27].

EV-DO enables advance, bandwidth hungry, elastic and non-elastic applications to enhance operators' profits. Table 4 provides a summary of the technical and performance attributes of the different EV-DO revisions. The data rates and data throughputs are provided on a single 1.25 MHz carrier in the table 4.

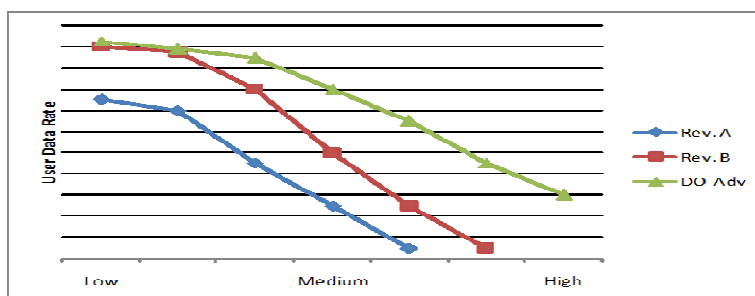


Figure 9. Performance Improvement with DO Advanced

Table 4. Comparison of EV-DO Revisions [1]

Attribute	1xEV-DO Rev 0	1xEV-DO Rev A	EV-DO Rev B (expected)	DO Advanced (expected)
Duplex Scheme	FDD	FDD	FDD	FDD
Multiple Access	CDMA	CDMA	CDMA	CDMA
Multicarrier Operation	No	No	Yes	Yes
Channel Bandwidth	1.25 MHz	1.25 MHz	Multiple 1.25 MHz carriers	Multiple 1.25 MHz carriers
Peak Data Rates	2.4 Mbps (downlink) 153.6 kbps (uplink)	3.1 Mbps (downlink) 1.8 Mbps (uplink)	4.9 Mbps (downlink) 1.8 Mbps (uplink)	18.74 Mbps (downlink) 4.3 Mbps (uplink)
Average Data Rates	300-500 kbps (downlink) 60-90 kbps (uplink)	400-900 kbps (downlink) 300-500 kbps (uplink)	800-1000 kbps (downlink) 400-700 kbps (uplink)	1000-1200 kbps (downlink) 600-800 kbps (uplink)
Downlink Sector Throughput	700 kbps	1000 kbps	1200 kbps	1500 Mbps
Uplink Sector Throughput	200 kbps	600 kbps	700 kbps	1000 Mbps
Average Data Call Setup Time	< 3 seconds	< 1 second	< 1 second	< 1 second
Average One way Latency	150 ms	50 ms	40 ms	30 ms
Fast Call Setup (< 1 second)	No	Yes	Yes	Yes
Spectral Efficiency	0.56 b/s/Hz (downlink) 0.16 b/s/Hz (uplink)	0.8 b/s/Hz (downlink) 0.5 b/s/Hz (uplink)	0.96 b/s/Hz (downlink) 0.56 b/s/Hz (uplink)	1.2 b/s/Hz (downlink) 0.8 b/s/Hz (uplink)
Voice	No	Supports VoIP	Supports VoIP	Supports VoIP
Simultaneous Voice and Data	No	Yes with 1X/1X Advanced	Yes with 1X/1X Advanced	Yes with 1X/1X Advanced
Quality of Services	No	Yes	Yes	Yes
MIMO	No	No	No	Yes
Broadcast Multicast	No	Yes	Yes	Yes
Support for cdma2000 1X	No	Yes, with hybrid terminals	Yes, with hybrid terminals	Yes, with hybrid terminals

7. Conclusions

The migration either to LTE/LTE-Advanced or WiMAX/WiMAX-Advanced seems to more plausible than to CDG recommended 1X-Advanced/DO-Advanced technologies. Before this eventual migration, these networks will exist in parallel and interoperate if the operators decide to do so. Nevertheless, the interoperability or interworking comes with a number of challenges.

First part of the article was focused on identifying and addressing some of these key challenges namely:

- It would be inevitable for many EV-DO operators not to start off with smaller channel bandwidths for LTE in LTE-900 (~CDMA 800) and LTE-1800 (~CDMA 1900) bands
- Support for EAP-AKA is mandatory to support authentication and ensuring security
- Mapping of QoS parameters as shown in this article will be required to ensure data continuity
- SVLTE will be necessary to ensure voice continuity in the short term
- For data service continuity infrastructure upgrades in the form of HSGW and operations support systems will be needed. Dual band and multi-band devices will also be required.

The performance analysis of WiMAX and EV-DO revealed that EV-DO will require multicarriers to have a comparable performance. Further, 1X Advanced and DO Advanced are better equipped than their predecessors to deal with the never-ending demands of operational excellence and broadband.

However, in the end CDMA2000 1X and EV-DO networks can continue to survive for sometime but will ultimately cease to exist, unless there is a considerable drive from 3GPP2 and CDG for the continuation of EV-DO in upcoming 5G discussions.

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