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# 1x EV-DO Forward Link Physical and MAC Layer Overview

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# 1x EV-DO Forward Link Physical and MAC Layer Overview

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# 1 Introduction

The past decade sees the rapid growth of mobile Internet technologies. Accessing the Internet from smart phones or from laptops with mobile Internet access cards has gained unprecedented popularity. The increasing bandwidth and responsiveness offered by mobile technologies to end users foster a wider variety of Internet applications. Applications such as video streaming, online gaming and file sharing that were not available but now widely supported on mobile devices. The gap between consumer mobile and wireline Internet access has been increasingly closer, giving end users great flexibility to stay connected without constraints of venues, time, and selection of applications.

Among these mobile Internet technologies, Evolution-Data Optimized (EV-DO) is currently the most widely used technology in North and South America, Europe, Japan and South Korea [4]. EV-DO is standardized by the 3rd Generation Partnership Project 2 (3GPP2) as part of the CDMA2000 family of standards and has been adopted by many mobile phone service providers around 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.

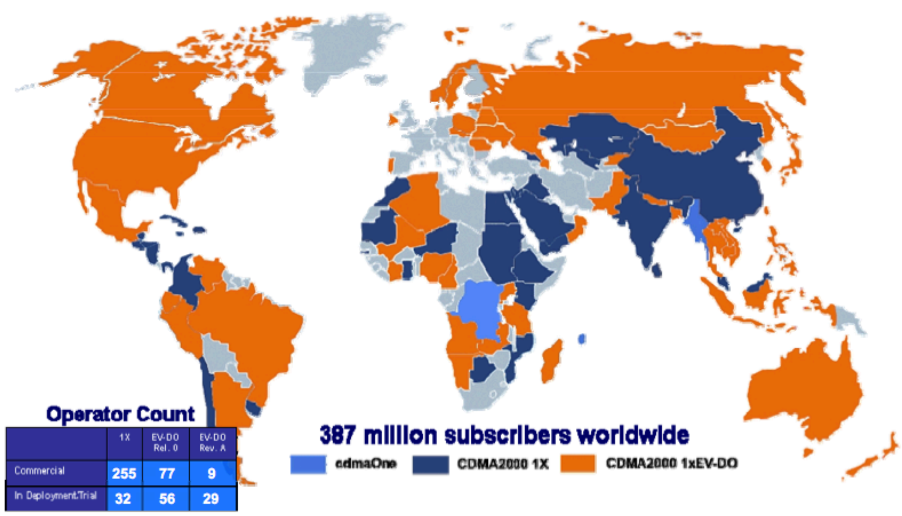


Figure 1: World Wide Coverage of EV-DO [4]

The EV-DO standard has three revisions: Rev. 0, Rev. A and Rev. B. The first revision or Rev. 0 was developed by Qualcomm in 1999 and initially called High Data

Rate (HDR), but was renamed to 1xEV-DO after the ratification by the International Telecommunication Union (ITU) and given the numerical designation TIA-856 (also written as IS 856 TIA/EIA). The 1x prefix indicates 1xEV as the direct successor of the 1xRTT (1 times Radio Transmission Technology) air interface standard, but then was conveniently dropped due to marketing purposes. EV-DO Rev. 0 supports data rates of up to 2.45Mbps on the forward link (or downlink) and 153Kbps on the reverse link (uplink). EV-DO Rev. A introduces a few additional forward link data rates and support for delay-sensitive low-rate applications such as VoIP by Packet Division Multiply Access (PDMA), one-to-many Data Rate Control (DRC) index mapping, and seamless server handoffs. EV-DO Rev. B is a multi-carrier version of Rev. A which further increases link capacity and reduces packet delays; however, due to commercial reasons it is not widely deployed.

EV-DO uses a CDMA frequency carrier of 1.25 MHz separate from 1xRTT for the forward link and shares the carrier with CDMA2000 1xRTT for reverse link. The forward link design is based on the premise that any combining of data and voice results in inefficiency due to their different nature. The design of the reverse link comes in with the observation that the reverse link and forward link bandwidth usage of broadband subscribers is usually asymmetric, with more bandwidth required on the forward link and much less on the reverse link.

This white paper primarily focuses on the forward link of EV-DO and assumes Rev. A. A comprehensive comparison of EV-DO Rev. A and Rev. 0 can be found at [5]. The rest of this paper abbreviates EV-DO by DO as other literatures do.

# 2 DO network architecture

Figure 2 shows the network architecture of DO network. Access terminals (ATs), typically handsets and laptops with data cards, connect to an access point (or AP, in this figure the Radio Node) to access the DO network. Each AP typically serves one cell[1] and supports three sectors[2]. Higher layers of the 1xEV-DO protocol are processed at the Radio Network Controller (RNC), which also manages handoffs and passes user data between the APs and the Packet Data Switch Network (PDSN). The PDSN is a wireless edge router that connects the Radio Access Network (RAN) to the Internet.

[1] The radio coverage area a fixed-location cellular tower provides.

[2] A division of radio coverage area by using directional antennas. Typically a cell has 3 sectors.

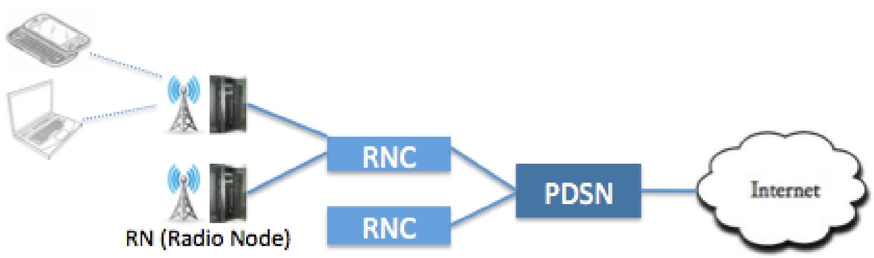


Figure 2: An EV-DO Network Architecture

# 3 DO forward link

The peak rate of DO forward link is 3.1 Mbps [3]. This peak rate is the highest physical layer packet rate an Access Terminal (AT) can receive, or the highest rate a sector can transmit. A cell can produce a maximum throughput of 3.1Mbps $\times$ n, with n being the number of sectors in this cell.

A DO sector is capable of supporting a maximum of 60 simultaneous users in the "connected" state, i.e., actively requesting and receiving packets. This number does not include dormant users that are in the network but do not have any network activity. For instance, if the users in a sector use the network 20% of the time, then in effect 300 users can be served by this sector.

The 60 active users restraint is imposed by the DO power control scheme. In a DO sector, every user is power controlled by a distinct Reverse Power Control bit (RPC). The RPC bits are sent in parallel to all mobiles with an open connection. In the DO protocol, there are 64 such bits. 4 out of these 64 are used for other purposes, which leaves 60 reverse power control bits that can actually be assigned to users. Note that power control only happens on the reverse link, as the forward link is always transmitted at full power for use by all the ATs.

## 3.1 Forward link structure

The DO forward link uses 1.25MHz bandwidth and a separate carrier to transmit packets. The channels on forward link are Time Division Multiplexed (TDM). This results sheer difference in the way transmit power is used by channels comparing to precedent CDMA technologies such as IS-95. When the AP has data or control traffic to send, it sends the traffic at its full power, while IS-95 divides power among all channels. Figure 3 demonstrates the transmission power scheme of IS-95 and DO.

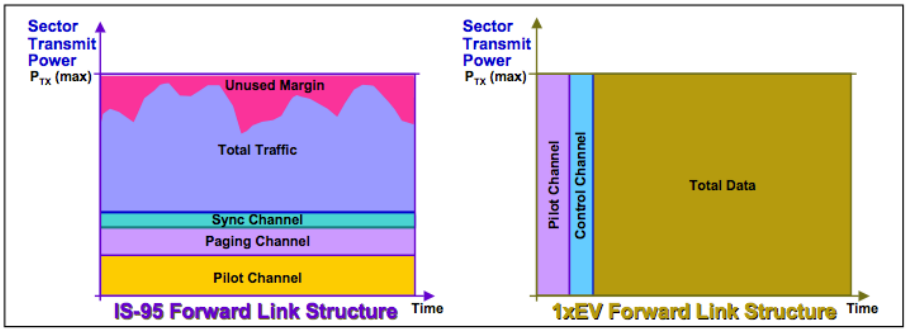


Figure 3: EV-DO transmits at full power to maximize data throughput [3]

The 1xEV forward channel consists of the following time-multiplexed channels: pilot channel, Medium Access Control (MAC) channel, traffic channel, and control channel, as shown in figure 4. The pilot channel helps ATs to determine their channel Carrier-to-Interference ratio (C/I). The MAC channel is seen with traffic or control channel; with traffic channel, it addresses addressing and rate control, while with control channel, it provides the procedures and messages required for an access network to transmit and for an access terminal to receive the control channel. The traffic channel carries user data packets. The control channel carries control messages, and it may also carry user traffic.

The forward link is defined in terms of frames of length 26.67 ms. Within a frame, there are 16 slots, each of length of 2048 chips[3] or 1.67 ms duration. Each frame is composed of two half-frame units of 8 slots and each slot is further divided into two half-slots.

The control channel occurs every 426.67ms, or 16 frames, for 13.33ms, or half a frame (see figure 5. Every slot has the same structure that contains pilot, MAC, and Data (control data or user traffic). Each pilot burst has a duration of 96 chips and is centered at the midpoint of the half slot. Figure 6 shows the structure of a slot.

As opposed to traditional TDMA, no predetermined time slots are allocated to ATs.

[3]A chip is the fundamental transmission unit in Code Division Multiple Access (CDMA) networks.

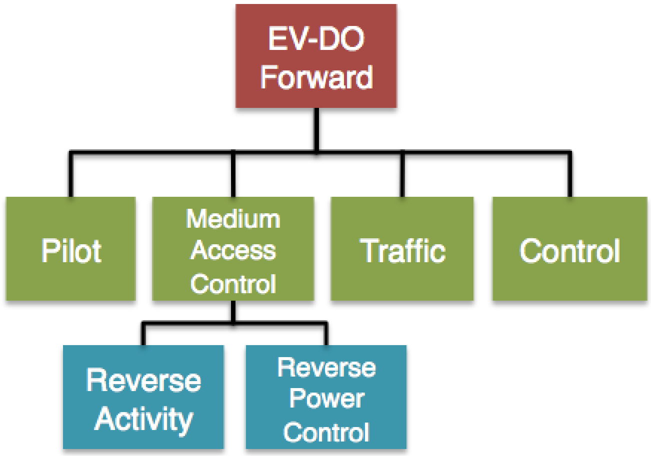


Figure 4: EV-DO Forward Link Structure

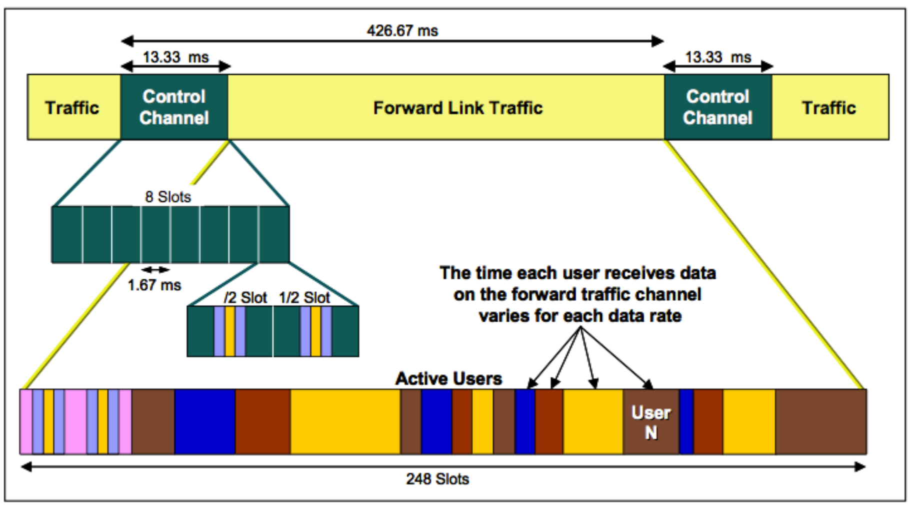


Figure 5: EV-DO Forward Link Demonstration [3]

| 1 slot, 1.667 ms | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1/2 slot, 1024 chips | | | | | 1/2 slot, 1024 chips | | | | |
| **Data 400 chips** | **MAC 64 chips** | **Pilot 96 chips** | **MAC 64 chips** | **Data 400 chips** | **Data 400 chips** | **MAC 64 chips** | **Pilot 96 chips** | **MAC 64 chips** | **Data 400 chips** |

Figure 6: EV-DO Forward Link Slot Structure

When an AT is actively using the link (sending and receiving data), it keeps listening to all time slots for possible incoming data.

### 3.2 Physical Layer Packets

EV-DO forward link physical layer packets are defined by their transmission formats. The triple (s, t, p) defines the transmission format, in which s is the physical layer packet size in bits, t is the nominal packet duration in slots, and p is the preamble length in chips. For example, (256, 8, 1024) defines packets with 256-bit payload, 8-slot nominal duration and a 1024-chip preamble. DO supports packet size of 128, 256, 512, 1024, 2048, 3072, 4096, and 5120 bits, with nominal spans of one through 16 slots, resulting in data rates ranging from 4.8 kb/s to 3.072 Mb/s.

### 3.3 Packet Data Rate

The 1xEV forward link supports dynamic data rates. ATs constantly measure the channel C/I, then requests the appropriate data rate for the channel conditions every 1.67 ms. The AP receives the ATs request for a particular data rate, and encodes the forward link data at the highest rate that promises less than 1% Packet Error Rate (PER) at the requested instant. With the maximum rate information being updated so frequently, the AP makes sure the data is sent to ATs at the maximum rate their varying channel conditions allow at any instant. For a DRC request, the following steps are performed [3]:
(a) AT measures received C/I's from available sectors
(b) AT selects the best serving sector
(c) AT requests transmission at the highest possible data rate that sustains less than 1% PER based on measured C/I
(d) The selected sector transmits data to the AT at the requested data rate.

The Access Terminal continuously updates the Access Point on the DRC channel, indicating a specified data rate to be used on the forward link. Figure 7 shows the process of a DRC request.

Transmission formats, data rate, nominal slot duration, associated multi-user transmissions formats for each DRC index value are listed in table 1.

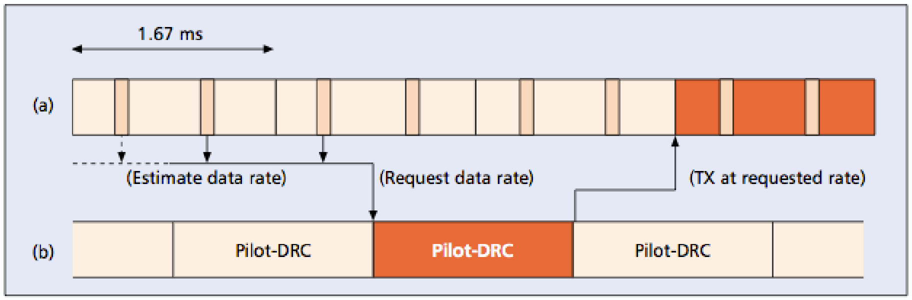


Figure 7: Process of a DRC request [6]

## 3.4 Early Completion and Incremental Redundancy

As defined in physical layer transmission formats, Forward traffic channel and control channel can be transmitted in a span of 1 to 16 slots. If a packet is transmitted in more than 1 time slot, the encoding redundancy makes successful reception of one slot possible for decoding the whole packet. Moreover, the reception of each successive slot improves the likelihood of successful decoding after combining. With such an incremental redundancy coding scheme, the AT notifies the AP to terminate the transmission as soon as the packet is decoded correctly. A 3 slots interleaving between such consecutive redundant slots allows AT to try decoding the packet and notify the result to the AP. These 3 slots can have no data (contain only pilots) or have data for other ATs. For example, a packet of format (1024, 4, 256) that has a nominal slot duration of 4 could be sent and decoded correctly by the AT receiving only the first two slots. This gain in transmission efficiency is called early completion.

Early completion gain exists because the estimation of the RF (Radio Frequency) environment at the handset is not perfect. The DRC index requested by the AT is computed from an estimated channel condition which is in turn calculated by a long-range fading channel prediction algorithm [7]. This algorithm produces conservative estimations (to ensure less than 1% PER), and the mismatch between the data rate that should be transmitted and the data rate that is requested by the handset is effectively mitigated by early completion.

Table 1: Rate, Span, and list of Associated Transmission Formats [1]

| **DRC Index** | **Rate Metric (kbps)** | **Span (slots)** | **Transmission Formats** |
|---|---|---|---|
| 0x0 | 0 | 16 | (128, 16, 1024), (256, 16, 1024), (512, 16, 1024), (1024, 16, 1024) |
| 0x1 | 38.4 | 16 | (128, 16, 1024), (256, 16, 1024), (512, 16, 1024), (1024, 16, 1024) |
| 0x2 | 76.8 | 8 | (128, 8, 512), (256, 8, 512), (512, 8, 512), (1024, 8, 512) |
| 0x3 | 153.6 | 4 | (128, 4, 256), (256, 4, 256), (512, 4, 256), (1024, 4, 256) |
| 0x4 | 307.2 | 2 | (128, 2, 128), (256, 2, 128), (512, 2, 128), (1024, 2, 128) |
| 0x5 | 307.2 | 4 | (512, 4, 128), (1024, 4, 128), (2048, 4, 128) |
| 0x6 | 614.4 | 1 | (128, 1, 64), (256, 1, 64), (512, 1, 64), (1024, 1, 64) |
| 0x7 | 614.4 | 2 | (512, 2, 64), (1024, 2, 64), (2048, 2, 64) |
| 0x8 | 921.6 | 2 | (1024, 2, 64), (3072, 2, 64) |
| 0x9 | 1228.8 | 1 | (512, 1, 64), (1024, 1, 64), (2048, 1, 64) |
| 0xa | 1228.8 | 2 | (4096, 2, 64) |
| 0xb | 1843.2 | 1 | (1024, 1, 64), (3072, 1, 64) |
| 0xc | 2457.6 | 1 | (4096, 1, 64) |
| 0xd | 1536 | 2 | (5120, 2, 64) |
| 0xe | 3072 | 1 | (5120, 1, 64) |

## 3.5 Proportional fairness scheduling algorithm

A proportional fairness scheduling algorithm decides the order ATs receive data on the forward link. The algorithm tries to maximize total network throughput while at the same time provide a certain level of fairness to allow all users at least a minimal level of service. To achieve this goal, data transmissions are prioritized by the requested data rate (implied by DRC index) and the moving average of the destination AT's throughput [2].

Suppose a DO system with one AP and $N$ ATs currently associated with the AP. Let $R_i(t)$ be the estimate of the average rate for AT $i$ at slot $t$, $i= 1,..,N$. Also, suppose that at slot $t$, the current DRC (i.e., requested rate) from user $i$ is $DRC_i(t)$, again $i=l,..,N$. The algorithm works as follows:

1. Scheduling: The AT with the highest ratio of $DRC_i(t)/R_i(t)$ out of all $N$ ATs will receive transmission at each decision time. Ties are broken randomly. Any AT for whom there is no data to send is ignored in this calculation.
2. Update Average Rate: For each AT $i$ $R_i(t+1) = (1\text{-}1/t_c)\ R_i(t) + 1/t_c * r_i$, where an AT that is not currently receiving service has 0 for its current rate of transmission. Even ATs for whom the scheduler has no data to send get their average rate updated.

Note that the scheduling step is executed each time a new transmission begins but the update average rate is done in each slot, even if the slot is in the middle of a multi-slot transmission. The update of the average rate as specified here is done using a low pass filter with a time constant of $t_c$ slots. $t_c$ determines how much impact past throughput has on current likelihood of being served. With this scheduling algorithm, ATs that are moving towards a better location are preferred, resulting in a total throughput gain by trying to serve each AT at its peak rate. This gain is also known as multi-user diversity. Under the circumstances when user mobility is high, this scheduling algorithm exploits the channel condition variation and produces pronounced gains. When users are stationary and their channel condition variation is low, the scheduling algorithm behaves closely to round-robin (except that the order of each round of serving is determined randomly).

# 4 Other Features

## 4.1 Packet-division multiple access

PDMA, or packet-division multiple access, is the technique of packing and transmitting packets from multiply users in a single physical layer packet. Such a physical layer packet that contains data for multiple AT's (up to eight) is also called multi-user packet (MUP). PDMA enables DO to support a large number of low-rate delay sensitive applications. The forward link scheduler serves single-user packets (SUPs) using opportunistic scheduling to exploit multi-user diversity and decides when to serve MUPs.

## 4.2 Soft Handoff

DO supports soft handoff to another AP without interrupting existing connections. This is necessary to support delay-sensitive applications such as VoIP, Gaming, and video streaming. The key to achieve this goal is keeping a low packet latency and avoiding packet drop during handoffs.

During handoffs, a data queue is set up at the new AP for the AT and packets destined to the AT are rerouted to the new AP. The new AP will transmit packets to the AT until this process is done. In DO, this is achieve by early notification from AT to AP about the handoff event.

The Data Source Channel (DSC) is a physical layer channel from the AT to the access network that provides an early indication of handoff. When an AT decides to handoff to a new AP, it signals the network by changing the DSC 64 slots before formalizing the handoff. The advance notice allows the network to queue data at the new AP while continuing to serve the mobile from the original AP. When the handoff is triggered, the AP is not served for 16 slots in a typical configuration. The outage during handoff of typically 16 slots translates to a delay of 27ms, a typical tolerable delay by delay-sensitive applications.

# 5 Summary

1xEV provides wireline equivalent bandwidth to mobile users, giving them greater freedom in acquiring information from Internet. The standard efficiently makes use of a 1.25MHz frequency by adopting variable data rate, incremental redundancy, and a multi-user diversity scheduler for increasing throughput and by employing PDMA, flexible packet sizes, and soft handoff for delay-sensitive application optimization.

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