NUST Journal of Engineering Sciences, Vol. 9, No. 1, 2016, pp. 23-28

Performance Evaluation of CDMA 2000 1x EV-DO Rev A/ Rev B Network

Muhammad Naveed Mughal and Muhammad Ali*

Electrical Engineering Department, University of Engineering & Technology (UET), Lahore, Pakistan
*Corresponding author: m.ali@uet.edu.pk
Received: 04 November 2015 Accepted: 30 September 2016

Abstract

CDMA2000 1x EVDO Rev A is a 3rd Generation (3G) wireless solution for high-speed mobile Internet access (also known as IS 856-A). This paper provides insight into key enhancements of 3G EV-DO Revision A and Revision B which are not previously reported and demonstrated through experimentation and measurements. It provides statistics of EV-DO Rev A under different measurement environments and its comparison for performance evaluation. The results of this paper can be useful for building EV-DO simulators as well as preparing correct/fine-tuned simulation model for 3G EV-DO Rev A/ Rev B.

Introduction

Code Division Multiple Access (CDMA) 1x EV-DO Rev A [1] has been finalized by the 3GPP2 (3G partnership project 2) and has been published by TIA (Telecommunication Industry Association) as IS-856-A. As per statistics updated on 1st August 2016 [2], 314 telecom operators had deployed CDMA 1x EV-DO networks in 118 countries/territories including 302 commercial 1x networks and 175 EV-DO Rev A and 12 EV-DO Rev B networks worldwide.

CDMA 2000 1x EV-DO Revision 0 was a high rate wireless packet data system (2.4 Mbps/153 kbps for downlink/uplink) having improved forward link capacity and coverage over traditional CDMA 1x system (IS-95/ IS-2000). The rapid growth of EV-DO customers is observed in recent years due to amassed demand of high-speed Internet access over a wireless link, includes delay sensitive applications (video telephony, wireless gaming, VoIP) as well as downlink demanding applications (file transfers ,web browsing).

EV-DO Rev A

To cope up with new low latency applications, few enhancements approved by 3GPP2 in CDMA2000 1x EV-DO Rel 0 (IS-856) resulting in a new standard CDMA2000 1x EV-DO Rev A (IS-856-A). These enhancements in IS-856 Rev A to meet new applications' requirements are as follows:

- Hybrid automatic repeat request (H-ARQ) is implemented at a uplink physical layer in addition to the introduction of higher order modulation schemes (QPSK and 8PSK) resulting higher uplink data rate up to 1.8 Mbps in comparison of 153.6 kbps in Rel. 0
- In 1x EV-DO, Rise over thermal (ROT) is measured periodically during the silence period, when no access terminal (AT) is allowed to transmit. ROT is an indicator of sector loading and system stability. ROT operating point can be set to adjust sector throughput and capacity. In 1x EV-DO Rev A, further improvement can be achieved in ROT by decreasing the delay in ROT control loop using quick reverse activity bit (QRAB), updated in every slot (after 1.66 ms) instead of per frame (after 26.66 ms) in Rel. 0.
- To support low latency applications and downlink intensive applications in 1x EV-DO Rev A, some key enhancements are done on forward physical and media access control (MAC) layers.
    - At forwarding physical layer, short packets (128, 256, 512 bits) are introduced for low latency applications as well as to achieve packing efficiency, while large packet (5120 bits) to support higher data rates and bigger payloads.
    - At forwarding MAC Layer, following enhancements are implemented:
        - Packet division multiple access (PDMA): In addition to time division multiplexing (TDM), transmission and opportunistic scheduling under fairness constraint, an access network (AN) may serve multiple ATs within the same physical layer packet results in improved packing efficiency and improved latency performance. Use of PDMA allows 1x EV-DO Rev A to support Multi-User Packet (MUP) containing data for multiple ATs.
        - 1x EV-DO Rev A allows flexible mapping between the requested Data Rate Control (DRC) index and transmitted packet size/data rate.
        - Adaptive server selection: In 1x EV-DO Rev A, AT uses Data Source Control (DSC) channel to provide an early indication of serving cell changes to AN. Due to the prior knowledge of the instant of server changes, transmit delay is minimized.
        - Null-rate conversions support in 1x EV-DO Rev A. Null-rate DRC sent by AT can be mapped to transmission formats (256, 16, 1024), (512, 16, 1024) and (1024, 16, 1024) which is used in MUP.

The peak data rates of downlink/uplink are 3.1 Mbps/1.8 Mbps in EV-DO Rev A and 9.3 Mbps/5.4 Mbps in EV-DO Rev B Phase I. However, the user-experienced application layer throughput has not been much reported for these EV-DO networks. In CDMA 2000 1x EV-DO Rev A, many enhancements have been done to decrease latency as compared to EV-DO Rel. 0. However, due to the time-variant behavior of wireless channels (poor radio conditions) and support of mobility feature, some losses are still observed which could decrease the throughput.

Related Work

Despite widespread deployment worldwide, low-level 3G EV-DO analysis is not well established and very minor quantity of literature is available on EV-DO especially Rev A and Rev B. The available literature is subdivided into two categories. First category [3],[4-7] involved simulation based study of EV-DO Technology at vendor based R&D (Qualcomm and R&D, Zhengzhou, China) centres due to unavailability of EV-DO network simulators. In second category [8], [9-12], sparse measurement-based analysis is published due to restricted access to proprietary cellular network by researchers and complications in controlled measurements management over cellular network infrastructure etc.

Naga Bhushan et. al., [3] presented key enhancements of EV-DO Rev A over Release 0, intended for both delay-sensitive (not supported in Release 0) and delay tolerant applications support. Overview of physical and MAC layer of EV-DO Rev A is presented which involves multi-user packets (MUP) and short packets on forwarding link and multi-flow reverse link MAC layer, H-ARQ on the uplink with full backwards compatibility with Release 0. EV-DO Rev, A physical layer reverse link performance is evaluated by Mingxi Fan et. al [4]. Reverse link capacity of EV-DO Rev A is achieved both via system based simulations as well as analysis. Due to the use of H-ARQ on the forward link, early completion technique provides gain over the reported DRC channel data rate on the fully loaded system. In adjacent cells of the live network which are not completely loaded, early completion gain based on field measurements averages to 35%. Yuanbo Chai et. al., [5] suggested a novel adaptive rate control algorithm of EV-DO Rev A system for the reverse link. Channel quality of the reverse link is considered as influencing factor of T2P (traffic to pilot) flow adjustment and degree of influence are adjusted by a weighting factor introduced in this algorithm. This new algorithm can reduce the system load and improve the system throughput as shown by simulation results. System stability, however, is not well improved in the new algorithm and needs to be studied further. Mehmat Yavuz et. al., [6] analysed the performance of VoIP services over EV-DO Rev A network and had shown that high-quality VoIP with high capacity and unrestrained mobility can be achieved. To improve the quality of service and capacity for voice processing, new concepts and techniques proposed such as adaptive dejitter buffer, time warping, and smart blanking. In addition to VoIP services, a substantial amount of delay tolerant traffic, as well as multicasting, is also simultaneously supported in EV-DO Rev A. Deepak Das et. al. [7], proposed a framework which includes a Quality of service loop for power control on the reverse link of EV-DO Rev A in the presence of H-ARQ. He showed that it is possible to achieve the desired trade-off between delay performance and rise over thermal or delay performance and throughput.

Qi Bi [8] provided a field measurement based comprehensive performance analysis of EV-DO Release 0 system. Based on analysis and measurements, he discussed some simulation assumptions which leads to performance results consistent with the field measurements. Kumar and Rakesh [9] [10] addressed call processing performance in a field environment for EV-DO radio access network (RAN). It included call detail record (CDR), call setup success rate (CSSR), RF failure rate (RFFR) and call drop connection rate (DCR). Best effort (BE) throughput was also analyzed for different user counts. Zhe Zhou et. al., [11] presented measurement studies on commercial EV-DO network by investigating EV-DO characteristics. His study will support for developing effective bandwidth estimation techniques or facilitate the development of EV-DO simulators which are not publicly available. After exploration of some of EV-DO parameters in his research, some parameters are still untouched and this can be explored by taking measurements such as urban vs. suburban performance comparison or mobile vs. stationary performance characteristics. Fengyi Yang [12] presented a statistical analysis on subscriber behaviors in EV-DO Rev A network of commercial Telecom operator of china and proposed some solutions. P2P services and limitless or boundless download package plan make the network resources exhausted and unbalanced network load. 3% to 5% data users have used about 40% of total traffic volume and engaged 50% online time as per statistical results are shown in the paper. To manage network traffic in an effective way multiple schemes are suggested such as Fair Usage policy (FUP) to restrain the traffic volume, subscriber classification to improve VIP subscriber's experience, and P2P restriction/throttling to limit the data rate of P2P service.

Measurement Model

The previous studies [3], [4-7], are mainly based on computer simulations and theoretical predictions that depends on assumptions about many characteristics of the radio frequency (RF) environment, including the propagation models, the antenna characteristics, cells layout, , the number of paths ,the handoff status, the channel types (e.g., Rayleigh, additive white Gaussian noise [AWGN] and Ricean), the nature of the time correlation of the RF channel, and applications details of the base station and the terminal device. Due to this elongated list of dependencies, predictions established on simulations and theoretic analysis leads to forecast results that may differ extensively (from inadmissibly low to extraordinarily high) contingent on the assumptions that are used in the study. Substantial hands-on experience is essential to select assumptions analogous to field conditions to make an accurate prediction of system performance. Performance validation by field measurements is, therefore, desirable and essential, very few studies [8], [9-12] exist in the literature on CDMA 2000 1x EV-DO due to the difficulty of interpreting and analysing the results and the cost of taking measurements on live networks . This research carried out measurement-based performance evaluation of key technologies/features used in EV-DO Rev A at real world commercial 3G CDMA 2000 1x EV-DO network at Pakistan Telecommunication Company Limited, Pakistan. The infrastructure is shown in Figure 1 and RF condition, parameters and assumptions are shown in Table 1. For this measurement-based analysis, following software/tools are used:

- Airbridge
- iManager M2000

- Qualcomm eXtensible Diagnostic Monitor (QXDM)

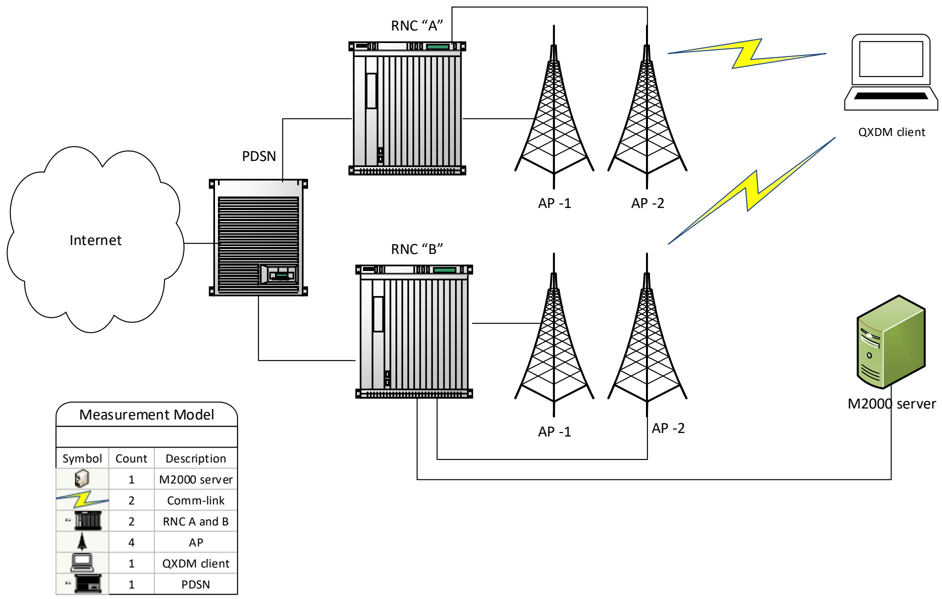

Fig. 1: Measurement Model

Table 1: System model parameters

RF Conditions and parameters	
Geographical Region	**Urban**
Technology	EVDO A
Frequency Band	1900MHz
Sectorization	3 Sectors
AP Antenna Gain (dBi)	18
AP Antenna Height (m)	30
RX Noise Figure of AP (dB)	3.2
AP Max. TX Power (dBm)	43
AT Max Tx Power (dBm)	23
AT Antenna Gain (dBi)	2
AT Antenna height (m)	1
AT Noise figure (dB)	8
Penetration loss (dB)	18
Pathloss Model	Hata Model PCS Extension

Results

Reverse Link

Rev A introduces a new set of packet sizes and data rates with peak forward-link rate going from 2.4 Mbps to 3.1 Mbps and a peak reverse-link rate 153.5 kbps to 1.8 Mbps.

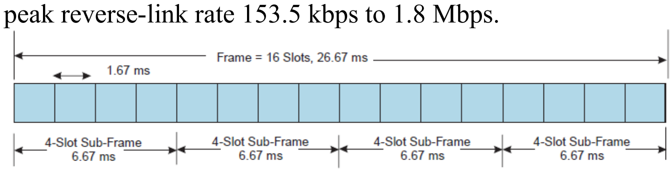

Fig. 2: Frame structure of Rev A. reverse link

As shown in Figure 2, Rev A shortens the frame size from 26.67 msec (full frame) to 6.67 msec (sub-frames) and divides packet into subpackets allowing early termination which increases reverse link throughput. The early termination phenomenon is illustrated in next results.

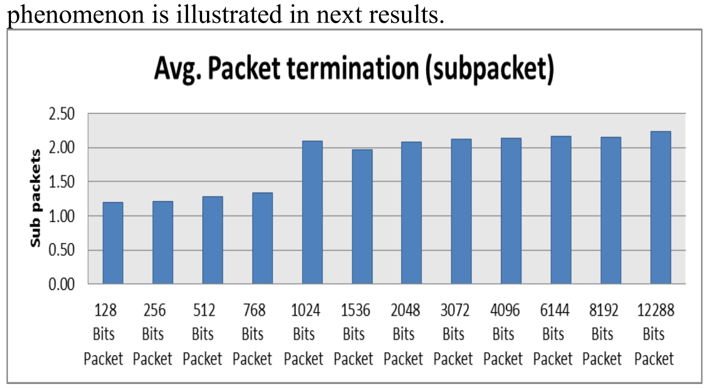

Fig. 3: Reverse link Avg. packet termination (user level)

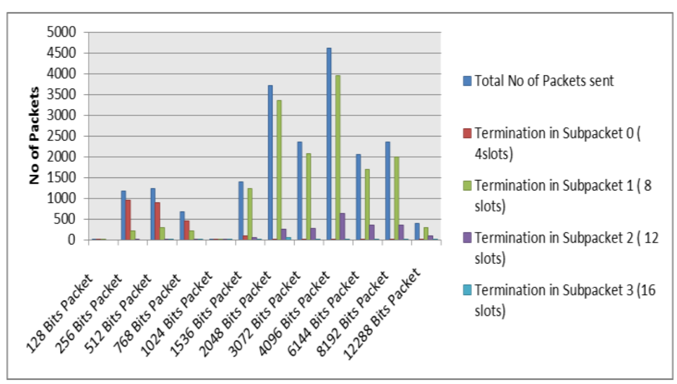

Fig. 4: Reverse link early termination effect (user level)

Figure 3 and Figure 4 show that packets of a size less than 1024 bits mostly terminated in one sub-packet (four slots), while larger packets (size greater than 1024 bits) terminated mostly in two sub-packets. The more favorable the RF

environment, the sooner early termination occurs (after the third, second, or first sub-frame). This effectively increases the data rate and reduces the repetition rate.
Reverse link transmission format is shown in Table. 2. The data rates highlighted yellow are newly introduced in Rev A and were not available in Rev 0.

Table 2: Reverse link data rates in EV-DO

Payload Bits	Effective Rate Kbps after:			
	4 slots	8 slots	12 slots	16 slots
128	19.2	9.6	6.4	4.8
256	38	19.2	12.8	9.6
512	76	38.4	25.6	19.2
768	115	57.6	38.4	28.8
1024	153	76.8	51.2	38.4
1536	230	115	76.8	57.6
2048	307	153	102.4	76.8
3072	461	230	153.6	115.2
4096	614	307	204.8	153.6
6144	921	461	307	230.4
8192	1228	614	409	307.2
12288	1843	921	614	460.8

When the RF conditions are improved, the Rev 0 AT must wait up to one frame time (26.67 ms) before the AT can increase its reverse link data rate to take advantage of the improved RF environment. Conversely, if the RF conditions worsen, it may take up to 26.67 ms before the AT reduces its data rate, possibly causing retransmission delays. So due to rapid changes in RF conditions, reverse link data rates also change very rapidly resulting transmission of packets having different packet sizes according to RF channel conditions. Figure 5 shows session percentage of different packet sizes according to wireless channel condition for a single user.

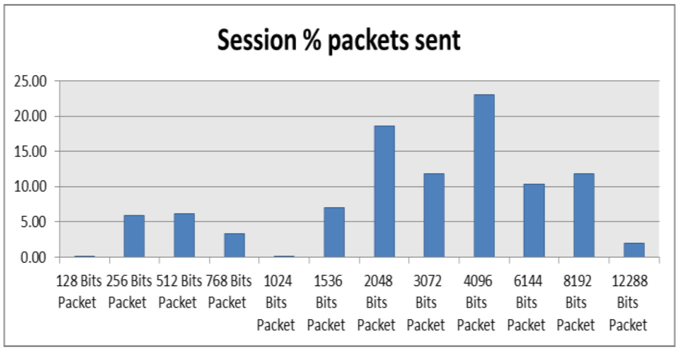

Fig. 5: Reverse link packet session %age (user level)

Figure 6 shows the carrier level reverse link packet size percentage. It can be seen that 85 to 90% of total packets have payload length up to 2048 bits. The results are taken from two radio network controllers (RNC) and four access points (AP). However, it can be seen that the trend is almost same irrespective of AP and RNC and service area.

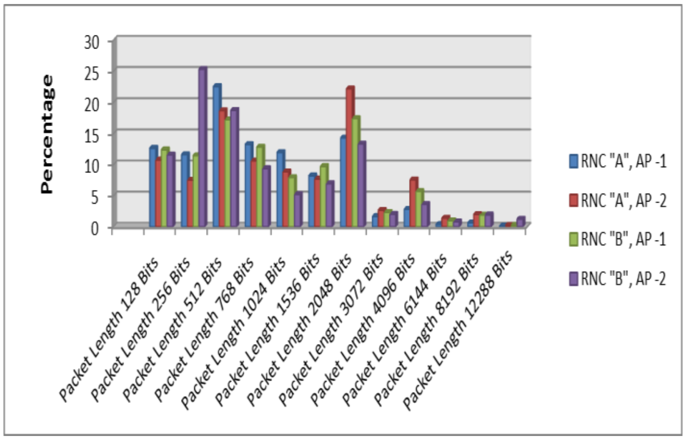

Fig. 6: Reverse link packet %age (carrier level)

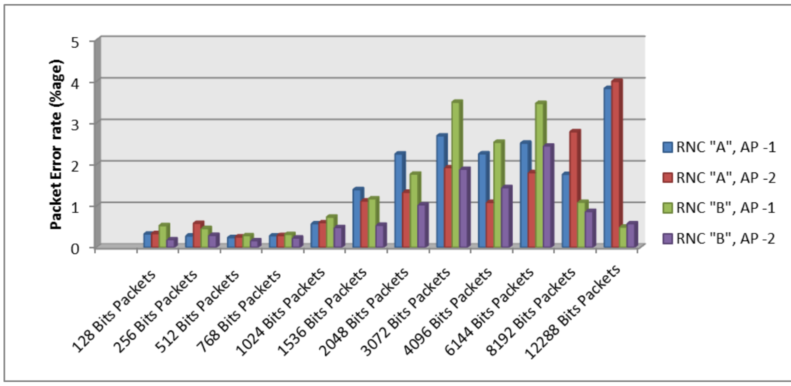

Fig. 7: Reverse link PER (carrier level)

Figure 7 shows the relation of PER on reverse link with packet size. PER is high for bigger packet size. The trend is almost same for two RNC's and four AP's. High PER is the main indicator of low percentage of bigger packet size contribution shown in Figure 6.

Forward Link

The different data rates available in 1x EV-DO Rev A are achieved by varying the transmitted signal modulation schemes via forward link adaptive modulation and other physical layer characteristics. Rev A transmission formats (Packet Size, Span, Preamble Chips, Length) for DRC values 0x0 through 0xe are shown in Table 3.
The rate at which data is transmitted to the AT is a function of the AT RF environment. The AT continuously monitors the quality of received pilot pulses from all sectors in the active set (all neighbouring sectors). In response, the AT sends back a data rate control (DRC) report to the base stations in the active set. The DRC report identifies the sector with the highest C/I ratio and the highest rate in which the AT can receive quality data from the sector. Fig 8 shows the different data rates achieved by a single user according to variation in RF channel.
Fig 9 shows the carrier level data rates taken from measurement setup having two RNC's and four AP's. It can be seen that about 70% to 80% packets sent on newly added data rates i.e. 1536 kbps and 3072 kbps (highlighted yellow in Table 3).

Table. 3: Forward link transmission format in EV-DO

DRC Index	Slots	Modulation	Preamble Chips	Payload Bits	Raw Kb/s
0x0	n/a	QPSK	n/a	0	null rate
0x1	16	QPSK	1024	1024	38.4
0x2	8	QPSK	512	1024	76.8
0x3	4	QPSK	256	1024	153.6
0x4	2	QPSK	128	1024	307.2
0x5	4	QPSK	128	2048	307.2
0x6	1	QPSK	64	1024	614.4
0x7	2	QPSK	64	2048	614.4
0x8	2	QPSK	64	3072	921.6
0x9	1	QPSK	64	2048	1,228.80
0xa	2	16QAM	64	4096	1,228.80
0xb	1	8PSK	64	3072	1,843.20
0xc	1	16QAM	64	4096	2,457.60
0xd	2	16QAM	64	5120	1,536.00
0xe	1	16QAM	64	5120	3,072.00

These new data rates are included in Rev A and were not available in old Release 0. To maximize the carrier level throughput and to increase carrier efficiency, the majority of the packets sent to the users served by this carrier on high data rates.

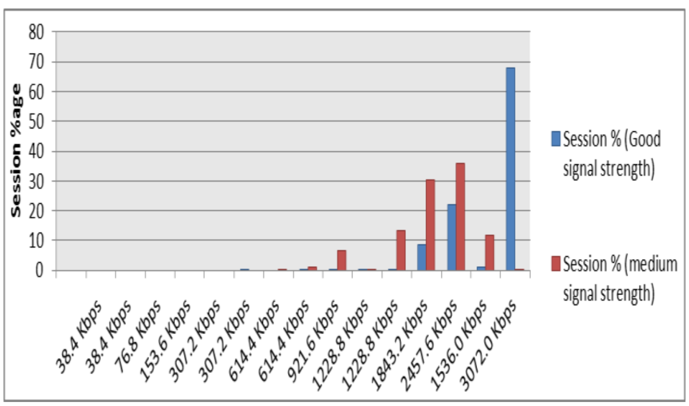

Fig. 8: Forward link data rates session %age (single user)

If during the packet data transmission cycle, the AT RF environment improves, the AT could validate the correctness of the packet data information after the first, second or third time slot. In this case, an early packet transmission termination occurs where rather than receiving an NAK signal after the first, second or third time slot the base station receives an ACK signal, indicating that the packet is successfully validated at the AT. At this time, the base station cancels transmission of the packet during the remaining time slots in the packet transmission cycle, and in their place initiates the transmission of a new packet or packets. Fig 10 shows that in the case of good RF environment, average slot termination in forward traffic channel is reduced.

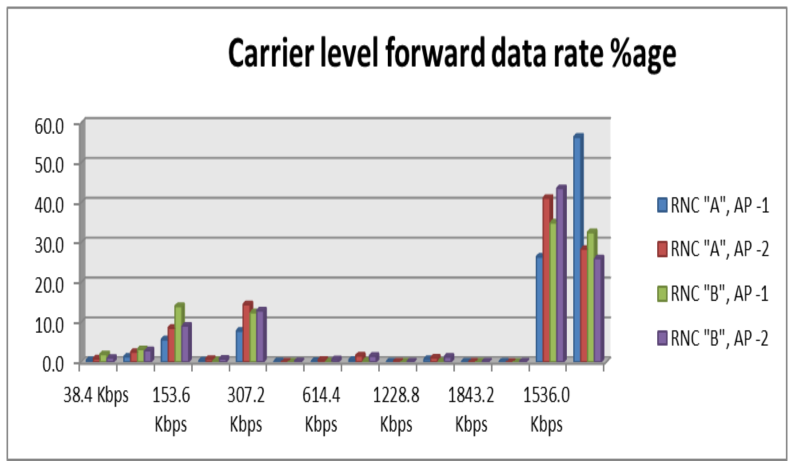

Fig. 9: Forward link data rates session %age (carrier level)

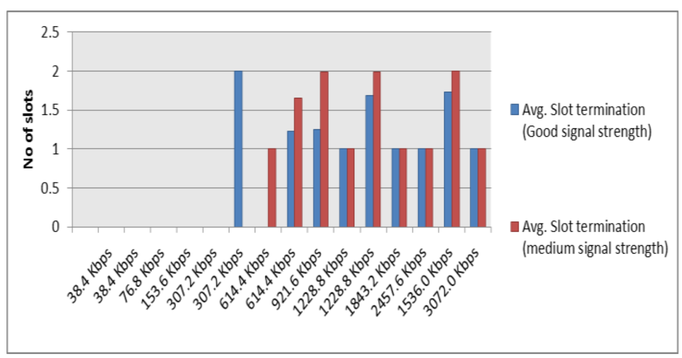

Fig. 10: Early termination effect in forward link

Conclusion

This paper evaluated the performance of forward and reverse link enhancements in EV-DO Rev A which were not available in old release 0. The reverse link peak data rate has increased from 153.5 kbps to 1.8 Mbps in Rev A by introducing new packet sizes. These new packet sizes enhance the early termination effect in reverse link due to improved RF conditions, hence, increasing the reverse link data rates. Forward link data rate has also increased from 2.4 Mbps to 3.1 Mbps in EV-DO Rev A by introducing two new DRCs for higher data rates. Irrespective of AP, RNC and coverage area, packets are sent on higher data rates to maximize the carrier throughput and efficiency. Early termination effect is also observed for the forward link which demonstrates that average slot termination is reduced in good RF conditions, hence, increasing the forward link data rates.

References

1. "3GPP2 C.S0024-A v.3.o, cdma2000 High Rate Packet Data Air Interface Specification," 2006.
2. "CDMA Statistics." http://www.cdg.org/resources/cdma_stats.asp
3. N. Bhushan, et al., "CDMA2000 1× EV-DO revision a: a physical layer and MAC layer overview," IEEE Communications Magazine, vol. 44, no. 2, 2006, pp. 37-49.
4. M. Fan, et al., "On the reverse link performance of cdma2000 1× EV DO revision A system," Proc. IEEE International Conference on Communications, 2005. ICC 2005. 2005, IEEE, 2005, pp. 2244-2250.
5. Y. Chai, et al., "An adaptive algorithm for the reverse link of cdma2000 1x EV-DO Rev. A system," Proc. 2010 International Conference on Computer, Mechatronics, Control and Electronic Engineering, IEEE, 2010, pp. 491-494.
6. M. Yavuz, et al., "VoIP over cdma2000 1xEV-DO revision A," IEEE Communications Magazine, vol. 44, no. 2, 2006, pp. 50-57.
7. D. Das, et al., "Power control for CDMA with hybrid-ARQ," Proc. 2007 IEEE 65th Vehicular Technology Conference-VTC2007-Spring, IEEE, 2007, pp. 996-1000.
8. Q. Bi, "A forward link performance study of the 1xEV-DO rev. 0 system using field measurements and simulations," Bell Labs Technical Journal, vol. 10, no. 2, 2005, pp. 5-19.
9. K. Venkata and R. Hanumantha, "Call processing performance evaluation in a prototyped field environment for EV-DO system," Proc. TENCON 2012-2012 IEEE Region 10 Conference, IEEE, 2012, pp. 1-6.
10. Z. Zhou, et al., "Characterization of a 3G EV-DO network-A measurement study," Proc. Local Computer Networks Workshops (LCN Workshops), 2012 IEEE 37th Conference on, IEEE, 2012, pp. 790-798.
11. K. Venkata and R. Hanumantha, "A Performance Study of Multi-carrier EV-DO Data Traffic Using Field Data and Simulations," Proc. Computer Modelling and Simulation (UKSim), 2013 UKSim 15th International Conference on, IEEE, 2013, pp. 745-749.
12. F. Yang and X. Lu, "QoS and Traffic Management for CDMA Network," Proc. Cyber-Enabled Distributed Computing and Knowledge Discovery (CyberC), 2011 International Conference on, IEEE, 2011, pp. 170-173.
13. "3rd Generation Partnership Project 2 (3GPP2) C.S0024-B v1.0, cdma2000 High Rate Packet Data Air Interface Specification,," 2005.