1xEV-DO System-Level Simulator Based on Measured Link-Level Data†

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***Abstract*— 1xEV-DO systems are being deployed widely for high speed wireless data communications. A 1xEV-DO system-level simulator is developed to evaluate the forward link capacity in an environment of multi-cell, multi-user, and mixed traffic of HTTP, FTP, NRV, and WAP, using measured link-level data, such as data rate transition thresholds and FER from HPEOS†† (High rate packet data Performance Evaluation & Optimization System for cdma2000 1xEV-DO). The performance of the 1xEV-DO system is evaluated in terms of utilization, service throughput, over-the-air (OTA) throughput, and packet delay for four different traffic types, by using the system-level simulator.**

I. Introduction

As demand for high speed wireless data increases, 3GPP2 published 'cdma2000 High Rate Packet Data Air Interface Specification' in Oct. 2002[1]. Now, thousands of users subscribe 1xEV-DO services such as video on demand (VOD) and audio on demand (AOD). However, the maximum forward link throughput, the number of maximum users and the packet delay were not evaluated precisely. These are important factors to operate 1xEV-DO system efficiently from the viewpoint of radio resource management and to meet quality of service (QoS) requirements.

Paranchych and Yavuz[2] derived closed-form expressions for packet error probability and throughput of a 1xEV-DO system. Jalali et al.[3] evaluated the sector throughput performance of HDR. These results can give an insight to estimate system performance. However, both studies did not take into account mixed traffic environment and did not consider measured link-level data.

In order to develop a system-level simulation, The HPEOS†† is used to obtain the measured link-level data such as FER and data rate transition thresholds. HPEOS system plays a role of access terminal (AT) and measures link-level data by receiving traffic packet from access point (AP). A test AP on SKT††† networks is used for measuring the data. Through this system-level simulator, we evaluate the forward link capacity and the packet delay of each traffic in multi-cell, multi-user, and mixed traffic environments.

This paper is organized as follows. In Section 2, important factors for modeling 1xEV-DO system and key features of HPEOS system are explained. Traffic, system modeling methodology and key features of simulator are described in Section 3. In Section 4, We compared the maximum throughput of simulator with the measured maximum throughput from HPEOS and evaluated simulation results. Finally, conclusions are presented in Section 5.

II. 1xEV-DO System and HPEOS

A. 1xEV-DO System

In the 1xEV-DO system, forward link packets are time-multiplexed so that there is no interference from other users in the same cell. Downlink packet data are transmitted with full power. Variable data rate, which is determined according to the user's channel conditions, is a more efficient method than power control for packet data transmission. When all ATs in a cell have no data to receive and AP only transmits short pilot bursts and MAC information, Forward traffic channel mean power is reduced up to 30% of full power. Hence, a decrease in transmit power effectively reduces interference to other cells. The 1xEV-DO system uses an Adaptive Modulation and Coding (AMC) technique to adaptively change the required data rate according to channel conditions. The requested data rate of AT is changed accordingly as radio channel varies and this information is fed back to AP via the reverse link data rate request channel (DRC) and is updated as frequently as a single slot(1.67ms). Commonly DRC means the requested data rate from ATs. We will alternately use DRC and the requested data rate from ATs[4].

B. HPEOS (High rate packet data Performance Evaluation & Optimization System)

HPEOS developed by HFR Company measures mobile diagnosis measure (DM) parameters, including received SINR, FER and throughput in a radio channel environment.

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††HPEOS system, developed by HFR company is a High rate packet data Performance Evaluation & Optimization System for cdma2000 1xEV

†††SKT is a 1xEV-DO service provider in Korea

Fig. 1. The first mode HPEOS measurement

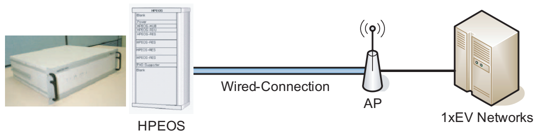

Fig. 2. The second mode HPEOS measurement

HPEOS supports two modes to analyze CDMA radio channel conditions. First, it can measure wireless environment itself, acting like AT. Fig 1 shows the first mode HPEOS measurement system. We use this mode to obtain the required data. Second, it connects to an AP and generates radio channel environments as shown in Fig 2. In the second mode, pathloss, fading, noise, and mobility are generated and controlled by HPEOS. Furthermore, traffic load and user service type can be controlled. It is possible to make various radio channel environments with many scenarios in HPEOS. Diverse test environments can be generated so that the test results are generalized.

As mentioned before, HPEOS receives data from AP in order to measure radio link condition and we obtain data rate transition thresholds and FER of each data rate from mobile DM. Link-level measured data are appropriate for system-level simulation parameters.

III. Traffic Models and System Model

A. Traffic Models

To make a common simulation environment, four types of traffic: HTTP, FTP, WAP and Near Real-Time Video (NRV) are used. In a mixed traffic environment, the traffic is distributed with 24.4%(HTTP), 9.29%(FTP), 56.43%(WAP), and 9.85%(NRV). Each traffic model parameter is described in [5]. Traffic model parameters represent packet characteristics and affect packet delay. Packets of each traffic type are fragmented into frames and each frame is transmitted accordingly as a requested data rate.

B. System Model

The objective of this study is to evaluate the 1xEV-DO system downlink capacity and packet delay in multi-cell, multi-user and mixed traffic environments. A 1-tier multi-cell with hexagonal seven cells is considered and each AP accommodates the same number of ATs. In order to develop a 1xEV-DO system simulator, we set up five steps : initialization, traffic generation, scheduling, radio channel propagation, DRC update & reception. All ATs and seven APs are operated every time slot. Data transmission unit is MAC frame with a size of 1024 bits. The procedure of simulation is show in Fig 3.

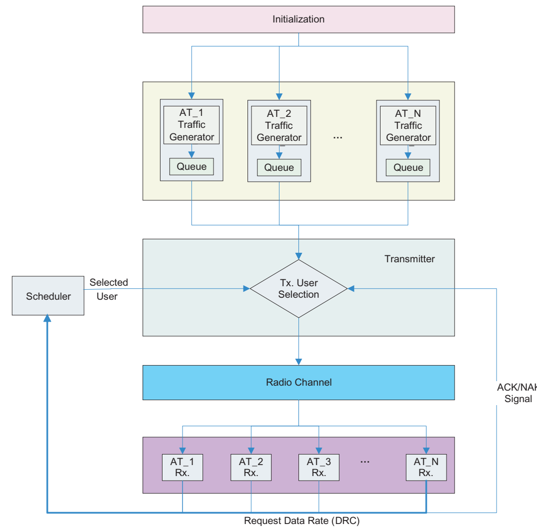

Fig. 3. 1xEV-DO system simulator block diagram

1) Initialization: After determining the number of users in a cell, ATs are uniformly distributed in seven cells and AT's propagation losses and shadow fading from each cell are predicted. Each AT selects its home-cell that has the best channel quality among seven candidates and determines one traffic type among HTTP, FTP, WAP, and NRV according to the given traffic distribution. We assume the number of ATs in each cell is identical and the traffic type of each AT is fixed during simulation time.

2) Traffic Generation: According to the previously determined traffic type, each AT generates data packets randomly based on traffic parameters[5]. The basic time unit of traffic generator is a slot length. Bursty traffic data are generated in a slot time basis. A unit size of packets is 1024 bits(MAC frame size). When packet size is smaller than MAC frame size like WAP and NRV traffic, for example, the maximum packet size of NRV traffic is 125bytes(1000bits), traffic generator uses 1 MAC frame as a minimum unit of packet size.

3) Scheduling: A proportionally fair(PF) algorithm is used for scheduling. In this algorithm, a user with the largest ratio of $DRC_k/\overline{R}_k$ is selected for transmission, where DRC_k is the data rate requested by user k, t_c is the window size expressed in the number of slots, and $\overline{R}_k$ is the average transmission rate to user k over the previous window. The average rate is updated in each slot prior to selecting a user according to the following equation:

$$\overline{R}_k(n) = (1-\frac{1}{t_c})\overline{R}_k(n-1) + \frac{1}{t_c}R_k(n-1) \qquad (1)$$

The value of $R_k(n-1)$ is identical to the DRC value of user k in slot $n-1$ in cast that user k was selected for transmission in slot $n-1$, and $R_k(n-1)$ is zero, otherwise.

TABLE I

DATA RATE OPTIONS IN 1XEV-DO AND MEASURED DATA

Data rate (kb/s)	Number of slots, bits	Measured DRC selection threshold(dB)	Measured 1% FER Ec/Nt(dB)	Rx. data repetition factor
38.4	16, 1024	.	-30	9.6
76.8	8, 1024	-10.45	-12	4.8
153.6	4, 1024	-7.45	-8.5	2.4
307.2	2, 1024	-4.45	-5.5	1.2
614.4	1, 1024	-1.45	-2.5	1
921.6	2, 3072	1.55	0	1.02
1228.8	2, 4096	4.55	4.5	1.02
1843.2	1, 3072	8.55	8	1
2457.6	1, 4096	10.55	9.5	1

This iteration is also updated within a multi-slot transmission. The PF algorithm attempts to serve each AT at the peak of its condition or lower $\overline{R}_k$. We use a time constant t_c of 1000 slots which is a typical value widely used. With this algorithm, the total throughput increases with the number of users due to a multi-user diversity gain.

4) Transmission: Before transmission, if there is a NAK signal in the past slot, AP retransmits the stored data to the previous receiver. Although the scheduler selects a different user, AP gives a priority to the AT transmitting the NAK signal. A hybrid-ARQ (H-ARQ) technique with chase combining is used for retransmission. In H-ARQ schemes, errored packets have a considerable energy that can enhance system performance[6]. Each AT updates its requested data rate and feedbacks this information to AP in every slot time. AP establishes the number of slots and bits using the updated feedback information of a selected user in scheduler. Data rate options are classified in Table I. When the repetition factor of selected AT is over 1, AP uses early ACK signal to increase throughput and efficiency. If an AT receives sufficient SINR for ACK signal and the repetition factor is over 1, the AT transmits early ACK signal to AP before all granted slots for transmitted AT flow and then scheduler updates user information to transmit new data.

5) Radio Channel Propagation: Propagation delay is not considered in simulation. Propagation loss constant is assumed to be 4. We assume shadow fading has a log-normal distribution. For a fixed location of ATs, shadow fading is time-invariant. Shadow fading per AT from seven AP's is generated in the initialization stage. This shadow fading has some correlation because shadow fading depends on geographical environments. When shadow fading is given by $x_1, x_2, .., and\ x_{m-1}$, the distribution of shadow fading x_m with a correlation coefficient of 0.5 is recursively calculated by

$$f(x_m)\mid_{x_1,..,x_{m-1}} = \frac{f(x_1,\ldots,x_m)}{f(x_1,\ldots,x_{m-1})} \sim N\left(\frac{x_1+\ldots+x_{m-1}}{m}, \frac{m+1}{2m}\sigma^2\right), \quad (2)$$

where σ has a standard deviation of 10dB and m=2,3. . .n[7]. Finally, Jake's fading is used for small-scale fading.

6) DRC Update and Reception: Each AT estimates a received SINR value considering pathloss, fading, noise, and other cell interference at each slot time. Since 70% of full power in a slot is used for data transmission, transmission power is decreased up to 30% of full power, when AP has no data to send. After calculation of the received SINR, AT updates a DRC value using measured DRC threshold data from HPEOS. In general, AT determines the maximum data rate while achieving a target packet error rate of typically 1-2%. If the requested data rate is determined, the AT sends this information back to AP transmitter and scheduler.

AT estimates a received SINR value considering the repetition factor of each DRC value and checks if the received frame have errors. Receiver generates errors based on the received SINR and measured FER from HPEOS. If the repetition factor is over 1, an early ACK signal is considered as mentioned before. When an early ACK signal occurs, AT send ACK signal to AP before all granted slots for transmitted user are exhausted. When an error occurs, AT send an NAK signal to AP. Upon retransmission from AP, AT calculates the received SINR using chase combining with the past SINR. Table I summarizes the SINR required to achieve a FER value of 1%.

In a real environment, we can not control radio channel environment and other factors like traffic load to test many types of scenarios. Hence, it is impractical to estimate capacity in different radio channel environments. However, using this simulator, we can predict system capacity and QoS in various radio channel environments by varying traffic model, scheduling algorithm, and channel conditions.

IV. PERFORMANCE EVALUATION

We evaluate the performance of 1xEV-DO system in terms of four measures such as average packet delay, service throughput, OTA throughput, and utilization. Four measures are defined as follows:

$$\begin{array}{c}\text{Average}\\ \text{packet delay}\end{array}\ (\text{s}) = \frac{\sum_i \begin{array}{c}\text{elapsing time for successive}\\ \text{transmission of packet } i\end{array}}{\text{the number of total packets}}, \quad (3)$$

$$\begin{array}{c}\text{Service}\\ \text{throughput}\end{array}\ (\text{bps}) = \frac{\text{total good bits during } T}{T}, \quad (4)$$

where 'total good bits' means the successfully transmitted data bits and T is the total simulation time.

$$\begin{array}{c}\text{OTA}\\ \text{throughput}\end{array}\ (\text{bps}) = \frac{\text{total good bits during } T}{T_{\text{tx}}}, \quad (5)$$

where T_{tx} is the total transmission time during the total simulation time, T.

$$\text{Utilization } (\%) = \frac{T - T_{\text{no\_tx}}}{T} \times 100, \quad (6)$$

TABLE II

SIMULATION PARAMETERS

Environment	Value or Method
Cell layout	Hexagonal grid
Cell radius	1 km
Shadow fading standard deviation	8.9 dB
User speed	3 km/h
Carrier frequency	900MHz
Fast fading	Jake's 1 path fading
H-ARQ scheme	Chase combining
AP total transmission power	15W
Feedback delay of requested data rate	1 slot

where $T_{\mathrm{no\_tx}}$ is the total idle period during the total simulation time, T.

A. Assumptions for System Simulation

In the initialization stage, we assume that ATs have a uniformly random spatial distribution over seven cells. User speed is 3km/h. Maximum transmission power is 15 watts. We also assume that feedback information for required data rate from ATs, is received without errors. Detailed simulation parameters are summarized in Table II.

B. Comparison of maximum throughput and measured data

To verify the system-level simulator, simulator results are compared with the measured data from HPEOS. FTP traffic is selected for test traffic. FTP traffic is full-loaded to observe the maximum throughput. All users have an SINR value of 5dB in average. Simulation environment and measured environment of HPEOS are identically configured for comparison. The maximum service throughput of simulator is 1.043Mbps and the measured data from HPEOS is 1.114Mbps.

C. Simulation Results

Using the simulation parameters as shown in Table II, simulation is performed in a homogeneous traffic environment in which all ATs have only one traffic type among HTTP, FTP, WAP, and NRV services during simulation. Traffic parameters and the results are shown in Table III.

If the number of HTTP and FTP users is 30 and 8, the packet delay of HTTP and FTP is 0.5s and 25s, respectively, in the homogeneous traffic environment. If the number of WAP and NRV users is 100 and 6, the packet delay of WAP and NRV is 3ms and 30ms, respectively.

Packet size and traffic burstiness are approximately proportional to packet delay from simulation results and Table III, and the number of maximum available users is approximately inverse proportional to packet size and utilization per user from Table III. Hence, we can make sure that packet size, traffic burstiness, and utilization per user are important factors of system performance.

In a mixed traffic environment, simulation is performed with 30 seeds and simulation time per seed is 1900 seconds. Since one slot length is 1.67ms, simulator has approximately 34 millions slots for evaluation. In this subsection, forward link performance is evaluated in terms of utilization, throughput and packet delay as a function of the number of total users in a cell.

TABLE III

TRAFFIC PARAMETERS AND SIMULATION RESULTS IN A HOMOGENEOUS TRAFFIC ENVIRONMENT

Component	HTTP	FTP	WAP	NRV
Mean packet size(bytes)	8200	2M	256	50
Mean reading time(s)	30	180	5.5	0.1
Traffic burstiness	6.36	3.43	2.33	1.48
Utilization per user(%)	1.5	7.1	0.07	12
Max. available user	67	14	1493	8

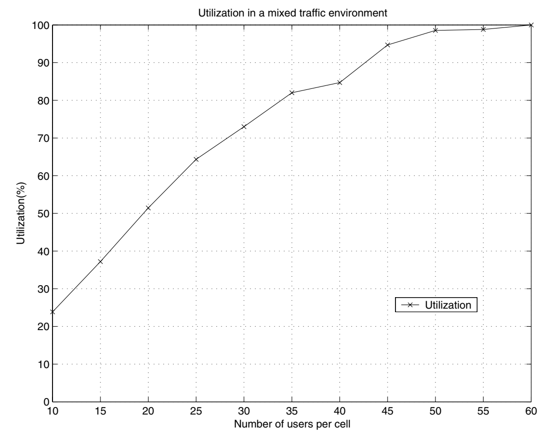

Fig. 4. Utilization vs. the number of users per cell

1) Utilization: As the number of users in a single cell increases, utilization linearly increases as shown in Fig 4. If the number of users is 50, the 1xEV-DO system is full-loaded. Since we assume the mixed traffic environment is unchangeable during simulation time, the maximum number of accommodated users is approximately 50.

In fact, user's traffic type is the most primary factor of utilization. In a homogeneous traffic environment, one NRV connection occupies approximately 12% of system utilization and one WAP service occupies approximately 0.07% of system utilization, as shown in Table III. If the mixed traffic pattern changes, the maximum number of accommodated users can be changed.

2) Service throughput and OTA throughput: For examples, as the number of users in a single cell increases, service throughput also linearly increases like utilization in Fig 5. If the number of users is 50, the 1xEV-DO system is full-loaded and has approximately 1Mbps service throughput. Each user's actual service throughput varies with traffic type. Simulation results show NRV and FTP users have 40% of total service throughput respectively, HTTP users have 18.6%, and WAP users have 1.4% in a typical mixed traffic proportion from simulation.

OTA throughput represents the real over-the-air throughput during actual transmission time. From service provider's

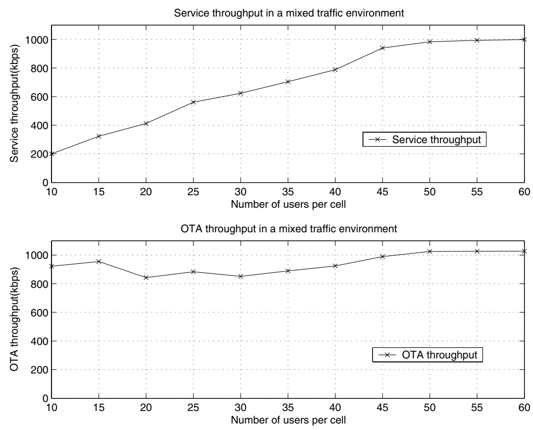

Fig. 5. Service throughput and OTA throughput

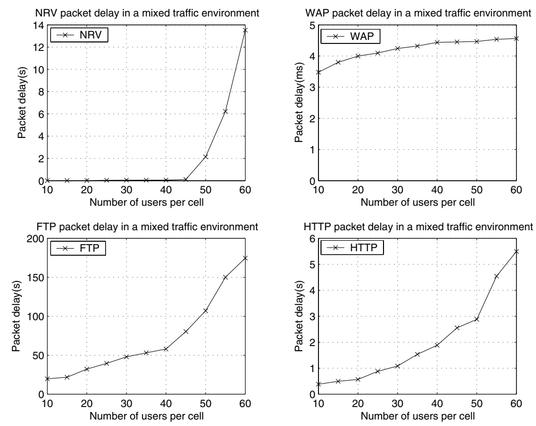

Fig. 6. Packet delay of each traffic type

viewpoint, OTA throughput is a very important factor because OTA throughput means the maximum throughput through the air interface. Fig 5 shows the service throughput and the OTA throughput in a mized traffic environment. Users in a poor radio channel condition decreases the OTA throughput. The average OTA throughput is approximately 1Mbps which is the same as the saturated service throughput.

3) Packet delay: Packet delay of each traffic type is affected by packet size and burstiness given in Table III. Fig 6 shows the packet delay of each traffic type in a mixed traffic environment. Packet delay of NRV traffic increases exponentially as the number of users in a single cell increases. NRV traffic users have less than 50(ms) packet delay under 40 users in a mixed traffic environment. This delay value can guarantee QoS of NRV traffic. NRV yields small packet delay under 40 users because NRV traffic has a small packet size and low burstiness. However, if the number of users is over 40, packet delay increases exponentially. The average packet delay of WAP traffic is approximately 4.2(ms) because WAP traffic has a small packet size and low burstiness, WAP traffic yields a relatively small packet delay so that WAP users can not identify packet delay. FTP traffic users have an exponentially increased packet delay due to a large packet size. HTTP traffic users also have exponentially increased packet delay. If the number of users is under 30, packet delay is about 1 sec. This value is acceptable for internet web browsing. From these results, we can estimate the expected packet delay of each traffic and the maximum number of users for guaranteeing QoS.

V. CONCLUSIONS

A 1xEV-DO system-level simulator using measured link-level data is developed to evaluate the forward link capacity and packet delay in an environment of multi-cell, multi-user, and mixed traffic of HTTP, FTP, NRV, and WAP. The maximum throughput of system simulator is compared with the measured maximum throughput for verification and the performance of 1xEV-DO system is evaluated in terms of utilization, service throughput, OTA throughput and packet delay of four types by using the system-level simulator. This simulator can be utilized in system management and performance evaluation in various traffic environments.

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