# Performance of Lucent CDMA2000 3G1X Packet Data Experimental System

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## Abstract

*The cdma2000 3G1X system is one of the first members of the IMT-2000 family of third generation wireless systems to reach field trial status. The cdma2000 3G1X system will provide service providers with increased voice capacity for their networks as well as high-speed packet data services. An experimental system based on the cdma2000 3G1X standard has been successfully developed by Lucent Technologies. In this paper, we will report the packet data performance results obtained from both lab and field tests of the experimental system.*

*The measurements of packet data performance concentrate on high-speed packet data throughput. Peak user data rates of 144 kbps are demonstrated and the measured throughput performance is compared with simulation results. Good agreement was found between predicted/simulated performance and the empirically observed behavior of the trial system.*

## I. Introduction

The cdma2000 3G1X system [1] is one of the first members of the IMT-2000 family of third generation wireless systems to reach field trial status. The cdma2000 3G1X system will provide service providers with increased voice capacity for their networks as well as high-speed packet data services. In the spring of 2000, the Wireless Network Group of Lucent Technologies began field tests of a cdma2000 3G1X experimental system. The overall performance of the 3G1X experimental system has been tested and measured over coaxial cable in a lab environment, as well as in an over-the-air vehicular environment, using cell sites of several service providers. This paper summarizes the measured results and characterizes the packet data service performance of the trial system.

The outline of the paper is as follows. Section II gives a brief overview of the implementation of the cdma2000 high-speed packet data service in the experimental system. Sections III and IV present performance of packet data service over forward link and reverse link, respectively. The concluding remarks are made in Section V.

## II. 3G1X Experimental System Overview

The experimental system supports the packet data service defined in cdma2000 system, and is compliant with the IS-2000 standard [1][2]. The key air interface channels and network elements for the packet data service are implemented.

### A. Air Interface Channel Characteristics

In the first phase of the trial system, the following radio link traffic channels are supported and are used for packet data transmissions:

- **The Fundamental Channel** (FCH), which can support 9.6 kbps of packet data transfer in the forward and reverse directions. This FCH is also used for signaling and power control.
- **The Forward Supplemental Channel** (F-SCH), which can transport data at channel rates of 153.6 and 38.4 kbps.
- **The Reverse Supplemental Channel** (R-SCH), which can transport data at channel rates of 38.4 kbps.

In the trial system, both forward and reverse link channels support radio configuration 3 (RC 3) with convolutional coding, as defined in the IS-2000 standard. Packet data service at other data rates, as well as voice service, were added in the next phase of the trial and are not discussed here.

The rates of user payload (user information bits over the air, including RLP retransmission) are somewhat less than the full channel rates due to channel overhead as shown in Table 1. The calculations in the table assume the SCH uses double size data block format.

**Table 1 3G1X Trial System Channel Characteristics**

| | Channel (kbps) | Overhead (kbps) | User at RLP (kbps) |
|---|---|---|---|
| FCH | 9.6 | 1.6 | 8 |
| F-SCH(Low) | 38.4 | 4.8 | 33.6 |
| F-SCH(High) | 153.6 | 19.2 | 134.4 |
| R-SCH | 38.4 | 4.8 | 33.6 |

### B. Burst Modes of Operation

During the entire time a data call is up, the forward and reverse FCH are available for transporting data and signaling control messages. Whenever the transmit queue exceeds 1000 bytes, a burst request is generated to increase the available transmission rate. Burst requests result in the allocation of an SCH at the highest rate the physical link can support. During a burst, both the FCH and SCH are used to transport data, providing a capacity to the user as shown in Table 2. Once a burst is established, it is maintained until all data has been transmitted or until the maximum burst duration is reached (set to 5.12 seconds for the tests reported).

The projected user rates observed at PPP and TCP/IP are shown in Table 2. The user data rates at PPP are calculated by assuming a 1% FER for both FCH and SCH channels, a 1-2-3 RLP retransmission scheme, and burst length of 5.12 seconds and a 0.5 seconds interval between bursts. The calculation of

TCP/IP layer throughput assumes an IP packet size of 1000 bytes and TCP/IP header compression. At the TCP/IP layer, higher values are observed because TCP/IP headers are compressed by PPP before being sent over the air. Therefore the TCP/IP data rate, after decompression, can be slightly higher than the actual rate of user data transmitted over the air.

**Table 2 3G1X Trial System Burst Modes**

| | Operational Channels | User at PPP (kbps) | | TCP/IP (kbps) | |
|---|---|---|---|---|---|
| | | infinite burst | finite burst | infinite burst | finite burst |
| Burst Off | FCH | 7.8 | 7.8 | 8 | 8 |
| Burst Low | FCH+F-SCH(Low) | 40.8 | 37.8 | 42 | 39 |
| Burst High | FCH+F-SCH(High) | 139.6 | 127.8 | 144 | 132 |

## C. Network Architecture and Packet Data Protocol Stack

The trial system network architecture is illustrated in Figure 1. All over-the-air signaling between the network and the mobile station are compliant with the IS-2000 standard.

The 3G1X trial system supports data applications on top of classical IP over PPP. The packet data protocol stack supported in the trial system is shown in Figure 2.

A mobile data user gains access to the Internet by connecting his PC to the Mobile Station (MS) using a high speed serial connection. A PPP link is established between a mobile PC and the IWF-LNS after setting up a P1 packet data service. The IWF-LNS assigns a dynamic IP address to the mobile host. The PPP link is retained when P1 service is Dormant. The IWF-LNS serves as the interface to the Internet, and sends and receives IP datagrams to and from the mobile using the appropriate PPP link.

The SDU maintains RLP connectivity with the mobile for an active packet data service. There is an IS-634 A3 user traffic connection between the SDU and a BTS for each active leg. RLP frames between the SDU and BTS are carried in IS-634 frames.

PPP layer traffic are measured with the PPP monitor at the PC-MS and LAC-LNS interfaces to assess packet losses, errors, and delays through the system. (Delays and packet losses in the LNS are negligible and are not measured on a continuous basis.)

# III. Forward Link Performance

## A. Lab Test - AWGN Channel

With a good RF link, and with applications which generate steady data traffic, such as FTP, the data burst operations will appears as a series of bursts with fixed rate, duration and interval between two consecutive bursts.

A non-fading environment with AWGN represents a static RF environment and is ideal for establishing a baseline performance characterization.

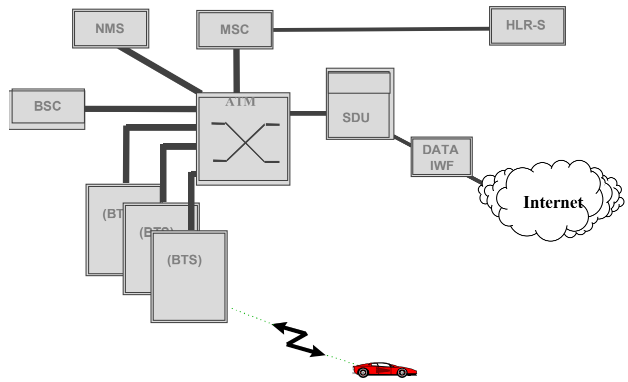


**Figure 1 3G1X Trial System Network Architecture**

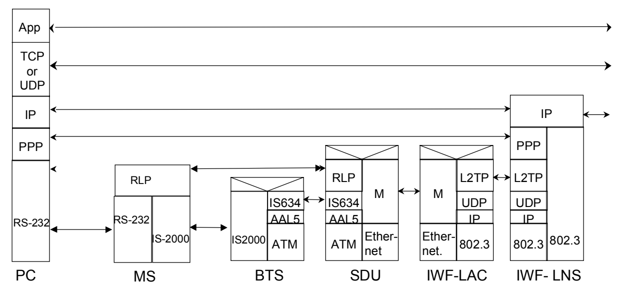


**Figure 2 Packet Data Protocol Stack in 3G1X Trial System**

Figure 3 shows throughput to the user for an FTP download using the high speed SCH under favorable RF conditions – i.e. a signal in AWGN at a low FER. The figure clearly shows that during the 5 second bursts the throughput peaks at about 142 kbps and drops significantly during the intervals between bursts. The mean throughput for the data transfer in Figure 3 is 118 kbps, which is about 9% below the mean of 128 kbps which was observed under error free conditions.

Also visible in Figure 3 are times during bursts when throughput falls momentarily (e.g. 10 seconds into the run) by 20-40% (30-60kbps). These are cases when frame errors are not recovered by RLP through the automatic retransmission request (ARQ) scheme and one or more IP data packets are lost or corrupted. Since about 20 packets per second are transmitted at the full rate, a loss of a single packet amounts to a 5% loss in efficiency. The reason that the actual reduction in throughput is higher is due to the way the TCP protocol recovers from errors.

The FTP application uses TCP/IP to provide reliable data transfer by retransmission of packets which are missing or received with errors. All TCP transfers begin with the "slow start procedure" during which receiver acknowledgments are used to gradually increase the rate of data transmissions until the full capacity of the channel is reached. The slow start procedure is also used whenever a packet error or data flow interruption occurs and this results in a much larger impact on throughput than the inefficiency of IP packet retransmission alone.

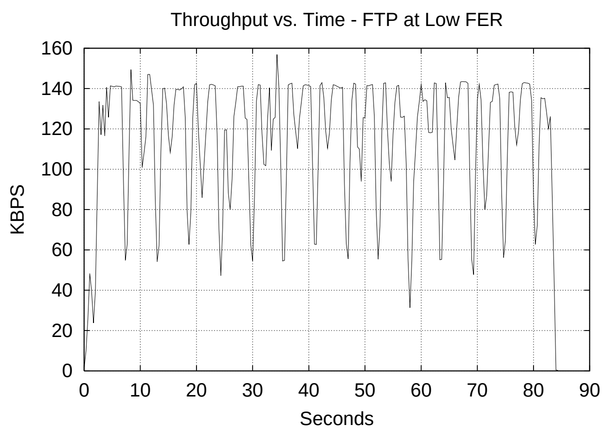


**Figure 3 Forward Throughput vs. Time for AWGN FTP at Low FER**

Forward link throughput at various FER values was measured by downloading a large (>5 Mbit) file via FTP. The cumulative probability of the PPP packet throughput is plotted in Figure 4. It can be seen that peak throughput, at the 90th percentile, is reaching 142 kbps. Note that 142 kbps is the peak payload (PPP packets) throughput that can be achieved with 153.6 kbps SCH and 9.6 kbps FCH delivering data simultaneously. This demonstrates that the system can achieve the designed target peak rate.

The average throughput with different channel FER from lab measurement and simulations are listed in Table 3. Simulation results from an end-to-end Wireless Packet Data Simulation Tool are also presented in Figure 4.

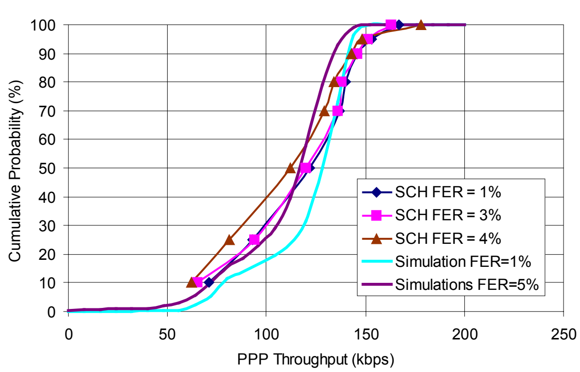


**Figure 4 Forward PPP Packet Throughput in AWGN Channel**

In the simulations, the throughput is measured at the output of PPP. The throughput is measured over TCP/IP traffic with full TCP/IP headers (i.e., traffic after decompression of TCP/IP header). Under typical conditions, this throughput is about 3-4% higher than the throughput measured over traffic with compressed TCP/IP headers, which is measured by the PPP Monitor. Taking this factor into consideration, the simulation results show close agreement with lab measurements. System performance is observed to be within about 10% of the predicted performance from simulations.

**Table 3 Average PPP Throughput in AWGN Channel**

| | F-SCH FER (%) | PPP throughput (kbps) |
|---|---|---|
| Lab | 1 | 115 |
| Lab | 3 | 114 |
| Lab | 4 | 106 |
| Sim,5.12s burst | 1 | 132 |
| Sim, infinite burst | 1 | 143 |

## B. Lab Test - Flat Fading Channel

Figure 5 shows the throughput versus time for an FTP download to a pedestrian (3 km/hr) in Rayleigh fading conditions with a 7% measured FER. Under these conditions the peak channel rate is lowered and the burst on-and-off character so obvious in Figure 3 is barely evident here.

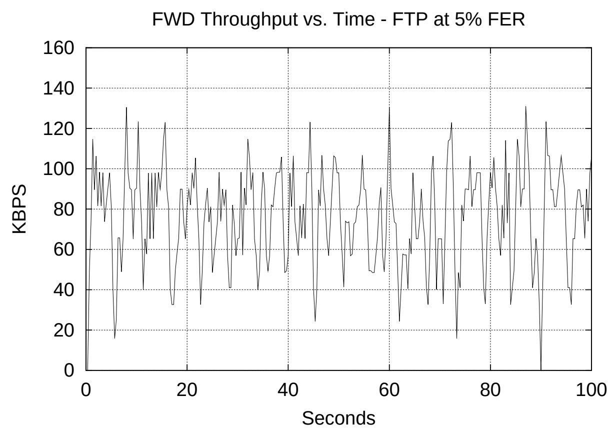


**Figure 5 Forward Throughput vs. Time for Pedestrian FTP at 5% FER**

Runs were made under varying user speeds ranging from 3 to 100km/hr and a summary of results is collected in Table 4.

**Table 4 Summary of Forward Throughput Results in Fading Conditions**

| Speed (km/hr) | F-SCH FER | Avg (kbps) | Median (kbps) |
|---|---|---|---|
| 3 | 7% | 79 | 74 |
| 10 | 5% | 85 | 88 |
| 30 | 4% | 88 | 90 |
| 100 | 3% | 92 | 91 |

The cumulative probabilities of the PPP packet throughput in flat Rayleigh fading channel with various vehicle speeds are plotted in Figure 6. For each speed, the measured FER is also shown. The cumulative probability of the PPP packet throughput in AWGN channel (without fading) is also shown in the figure as a reference.

These results obtained for fading channels show that throughput is primarily a function of FER and depend only weakly on the precise statistics of the fading channel, which are a function only of mobile speed in these experiments. When compared with the performance in AWGN only, it can be seen that the burstiness of the fading in the RF channel causes some degradation on the packet data performance.

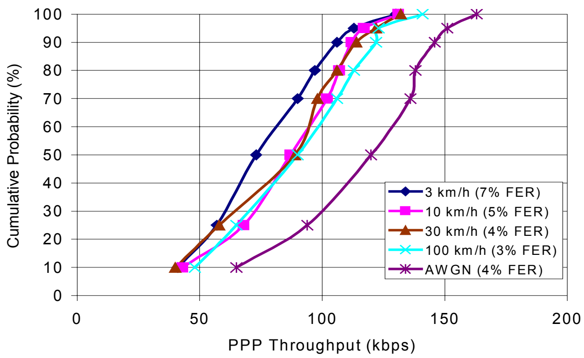


**Figure 6 Forward PPP Throughput in Fading Channel**

## C. Field Tests – Stationary

The data below is presented for stationary mobile testing at the middle and edge of the cell. The results show performance for a single mobile as well as for two simultaneous users. The FSCH for both mobiles was configured to transmit at 153.6 kbps.

The application layer throughput is shown for each mobile over the entire duration of data transfer. The PPP layer throughput as well as the RF parameters tabulated below present data for the first mobile only.

The throughput numbers, as shown in Table 5, are consistent within the range of results observed over various lab test conditions. Some key RF parameters are tabulated in Table 6

**Table 5 Over the air throughput performance for 153.6 kbps FSCH transmission**

| Mobile Conditions | Application layer Throughput (kbps) | PPP layer Throughput (kbps) |
|---|---|---|
| Stationary, middle cell | 101.6 (M1), 108.8 (M2) | 110.0 (M1 only), 113.7 (M1, with M2 present) |
| Stationary, cell edge | 93.7 (M1), 101.8 (M20 | 110.1 (M1 only), 112.9 (M1, with M2) |
| Pedestrian | 102.7 | 115.7 |
| Vehicular, sector route | 94.2 | 109.4 |

**Table 6 Over the air physical layer performance for 153.6 kbps FSCH transmission (single user test only)**

| Mobile Conditions | Best Pilot Ec/Io (dB) | FCH FER (%) | SCH FER (%) | Mobile Rx pwr (dBm) | FSCH transmit gain (dB) |
|---|---|---|---|---|---|
| Stationary, middle cell | -2.4 | 1.2 | 5.3 | -84.5 | -27.8 |
| Stationary, cell edge | -8.9 | 0.86 | 3.7 | -96.8 | -17.9 |
| Pedestrian | -8.1 | 1.0 | 4.2 | -66.5 | -19.8 |
| Vehicular, sector route | -7.0 | 1.6 | 6.5 | -63.0 | -20.7 |

The FSCH target FER was set to 5%and both of the mobiles were able to achieve FER close to the targets on their respective channels. The average of the total cell site power for the 2-mobile test was roughly 4 dB above the pilot level.

## D. Field Tests – Pedestrian and Vehicular

These tests were also configured for 153.6 kbps FSCH. Orthogonal interference was utilized to reduce the transmit Pilot Ec/Ior by 3dB. The average performance over the test interval is shown in Table 5 and Table 6. Note that the pedestrian test was executed with the FSCH target FER set to 2.5%, and the vehicular test at 5% target FER. Throughput was comparable with the stationary test results.

Lower throughput for the vehicular test occurs in an area of RF impairment on the drive route, about 12 seconds into the run. This problem area is evident from the plot for RF parameters (Figure 7).

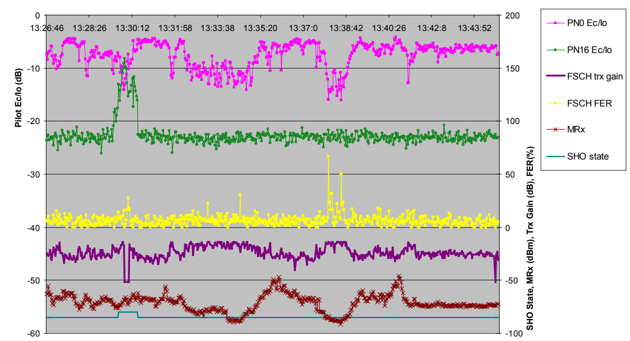


**Figure 7: Physical layer performance for 153.6 kbps FSCH transmission – Sector Route Vehicular mobility**

# IV. Reverse Link Performance

## A. Lab Tests – AWGN Channel

Reverse link tests were made using an FTP upload of a large file from the user PC to an FTP server on the Internet. Figure 8 shows the throughput versus time from one of the runs. Average throughput is 41 kbps when operating normally. The throughput cumulative distribution shows that at the 90th percentile, the throughput is reaching 41 kbps, the peak payload (PPP packets) that can be achieved with a 38.4 kbps SCH and a 9.6 kbps FCH delivering data simultaneously.

It is noticed that the data flow stoppages at 20 and 60 seconds into the run are caused by TCP timeouts. A TCP time-out occurs when a packet is lost and TCP is left in deadlock while the transmitter waits to receive an ACK and the receiver waits for a new data packet to ACK. Note that TCP errors on the reverse link have a much different effect on throughput than those observed on the forward link (see Figure 5).

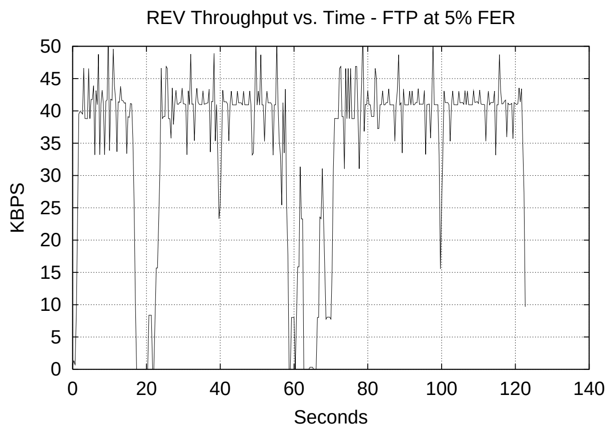


**Figure 8 REV Throughput vs. Time at 5% FER**

The average throughputs seen in the lab, together with end-end packet data simulation results, are listed in Table 7.

**Table 7 R-SCH average PPP throughput in AWGN channel**

| | R-SCH FER (%) | PPP throughput (kbps) |
|---|---|---|
| Lab | 1 | 32 |
| Lab | 3 | 26 |
| Sim | 1 | 41 |
| Sim | 5 | 40 |
| Sim | 10 | 37 |

## B. Field Tests – Stationary and Pedestrian

Three mobile users were configured to, transmit data at 38.4 kbps on the RSCH. The second mobile began transmitting 3 minutes after the first, and the third mobile 6 minutes after the to allow performance comparisons as a function of the number of reverse link users. These tests were also executed at the middle and edge of the cell. The application and PPP layer throughputs and RF parameters are tabulated in Table 8.

The measured RF parameters show that the RSCH FER is close to 0% and there is no apparent increase in the mobile transmit power of the first mobile as additional users are added.

The throughput performance is consistent with performance at the middle of the cell and cell edge. This is because there was sufficient mobile transmit power to keep the RSCH FER close to 0%. Even with the three users, the RSCH mobile transmit power is around 10 dBm, significantly lower than mobile maximum transmit power. This suggests there was room for additional users.

The pedestrian test was conducted at the same location as the forward link test. In addition, 4 dB attenuation was inserted in the mobile transmit path. The application and PPP layer throughputs, as shown in Table 8, are close to best case results achieved on a static link. The average RSCH FER was 0.22%.

**Table 8 Over the air throughput performance for 38.4 kbps RSCH transmission**

| Mobile Conditions | Application layer Throughput (kbps) | PPP layer Throughput (kbps) |
|---|---|---|
| Stationary, middle cell | 34.1 (M1)<br>36.7 (M2)<br>36.7 (M3) | 40.1 (M1 only)<br>40.8 (2 mobiles)<br>40.7 (3 mobiles) |
| Stationary, cell edge | 33.9 (M1)<br>36.2 (M2)<br>36.8 (M3) | 40.5 (M1 only)<br>40.7 (2 mobiles)<br>41.0 (3 mobiles) |
| Pedestrian | 35.5 | 39.5 |

# V. Conclusions

This paper reports the performance of the Lucent 3G1X experimental system. The performance measurements cover both physical link performance and packet data performance in both cabled and over the air environments, with emphasis on characterizing the packet data performance under various physical channel conditions. The performance measurement results compare favorably with simulation results.

The major packet data results are summarized in the following:

**Table 9 The average PPP throughput (measured with traffic from FTP based applications, kbps)**

| Link | Sim AWGN | Lab AWGN | Lab Veh (100km/h) | Air Ped | Air Veh |
|---|---|---|---|---|---|
| For (153.6) | 132 | 115 | 92 | 112 | 109 |
| Rev (38.4) | 42 | 32 | N/A | 40 | 41 |

Based on the performance measurement results, the following conclusions can be made:

1. The peak throughput of the experimental system can reach the peak available channel rates on both the forward and reverse links.
2. Packet data performance of the experimental system demonstrates that 3G1X system can provide high quality end-end packet data service.
3. Performance data observed in the lab and over-the-air show reasonable agreement with predictions from theoretical simulations.
4. The trials have successfully demonstrated interoperability between cdma2000 network infrastructure and mobile station stations from multiple vendors.

# References

[1] TIA/EIA, IS-2000, *a family of standards for cdma2000 Spread Spectrum Systems*.

[2] TIA/EIA, IS-707-A-1, *Data Service Options for Wideband Spread Spectrum Systems – Addendum 1*.