Uplink CDMA2000 Performance Evaluation With Mobile Clients

J. Arturo Pérez-Díaz, J. Miguel García-Ramos, Miriam Calderon-Reyes and Luis G. Riojas-Mandujano

Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM),
Campus Cuernavaca, México.

Abstract

In this paper we present an analysis of the CDMA 2000 performance with mobile clients, the analysis includes tests at different speeds and transfer rates. We are using the evolution of CDMA2000 called 1xEV-DO, which is the first massively provided service in Mexico, by Iusacell Company.

Due to carrier security constraints, our test focuses on the up-link (reverse link) communication. We used two computers with Windows XP SO sending traffic from the mobile client to the static host at different transfer rates (30, 60, 90 Kbps). In each test the mobile client sent traffic at different vehicular speeds (40, 60, 90 Km/h).

In general, we notice that the technology looses performance when the speed and the transfer rate increases. Initially, at low speed, the performance decreases linearly, reaching an apparent exponential decreasing trend at higher speeds. At low speed the transfer rate were almost the same 100 % and at high speed the transfer rate decreased between 27-33 %.

Key words:
Throughput, CDMA2000, Transfer Rate, Uplink, Mobile clients

1. Introduction

During the last decade there has been a marked commercial explosion regarding the improvement, usage and marketing of wireless communication technology, mobile devices and end-mile service delivery, both for data and voice exchange. From these technologies, CDMA2000 has established itself as one with the biggest acceptation rates, especially in the Asian Pacific and the Americas. It is said that CDMA2000 subscribers surpass, globally, the number of 373 million. CDMA2000 constitutes as well the technological basis for UMTS [1], the most popular mobile telephonic system in Europe.

Given the forecasted acceptance peak for this technology in the fields of cellular phones and internet access, is very interesting to analyze the related TCP behavior and performance with a fixed throughput and with mobile clients [2].

A version of CDMA2000 called 1xEV-DO (Evolution-Data Only) is claimed to provide service to mobile nodes traveling at maximum speed of 120 km/h. We focus this work on the measurement of the up-link (communication from mobile node to the CDMA2000 antenna) throughput variation for this technology, at various common speed values for intra and inter-city vehicular transportation.

Unpredictable throughput variation is an undesired condition for commercial telecommunication providers, since it prevents them to guarantee with certain degree of quality the continuity of service on a given channel.

As we know TCP is a protocol that was created for wired networks, where the packet loss is rarely caused by unreliability of the physical media, but by congestion in the network. TCP protocol reacts accordingly, reducing the slide window size to prevent this congestion. In wireless networks, however, the packet loss could be caused for different atmospheric aspects like *rain, wind speed and cloudiness*, just in the same fashion it occurs within the Wimax Technology context [3].

Because of the unsteady TCP performance over wireless media, a lot of improvements had been suggested, for example: to create a parallel layer reusing the existing information in other OSI model layers [4], to use additional layers of OSI model [5] and improvements in algorithms and general performance [6].

In the context of computer networks, "throughput" is defined as the amount of data per time unit that is delivered to a certain terminal from a network node, or from one node to another. Digital data throughput is usually measured in bits per second (bps).

Data throughput achieved from one computer to another usually is lower than the maximum bandwidth and than the network access channel capacity due to factors as network shared usage, the presence of flow control and congestion avoidance policies as well as scheduling routing algorithms that may favor certain kind of traffic above others (QoS policies).

In this paper we present a technological overview of the CDMA2000 system components and interfaces, as well as the results obtained during the measurement of reverse (up-link) throughput variation from a mobile CDMA2000-

Manuscript received May 5, 2007
Manuscript revised May 20, 2007

enabled source traveling at 40, 60 and 90 km/hr. Interesting observations are obtained and explained.

The rest of this paper is organized as follows: section 2 provides a high-level technological description of CDMA2000 and particularly, of its 1xEV-DO “flavor”. Section 3 describes the characteristics, scope and boundaries for the Testing Environment used for measuring the up-link throughput variation. Following, section 4 enlists the results obtained during the tests, as well as interesting observations about them. Finally, we present in section 5 the conclusions for the present work, as well as the perspectives for future work on this topic.

2. CDMA2000 Technology

Being the technology selected by the first massive provider of CDMA2000 services in Mexico, it is of our interest to describe the main features and advantages of 1xEV-DO, one of the most widely accepted CDMA2000 flavours.

1xEV-DO is a 3G technology for mobile communication, that provides not only down-link data transmission rates over 2.4 Mbps (average rate: 700 Kbps, depending on network conditions) and up-link rates around 350 Kbps (average rate: 153 Kbps); but also good capacities for managing multimedia data services [7].

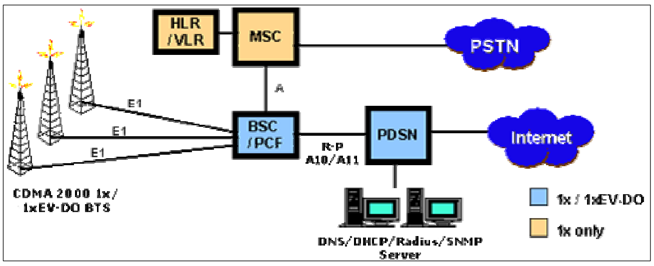

Fig. 1 High-level architecture for a CDMA2000 1xEV-DO network.

Moreover, 1xEV-DO is a cost-effective technology, since it is able to deliver more than 4Mbps of capacity using a 1.25MHz channel [8]. The spectrum usage efficiency, joint with the provision of value contents has guaranteed demand and success for the technology in the last years around the world.

Among its marketing-competitive technical features, 1xEV-DO designates a frequency channel used exclusively for the transport of IP packets [9]. 1xEV-DO is able to operate at frequency of 1900 MHz, expanding its possibilities of implementation for the carrier company.

The referred asymmetric nature of 1xEV-DO down-link and up-link channels reduces complexity in the network equipments and devices, and is aligned with today's services and applications available over the internet.

Figure 1 depicts roughly the elements that constitute a 1xEV-DO network. A group of BTS (Base Transceiver Station) is controlled by a BCS (Base Station Controller) that acts like the hand-off manager and interfaces the BTS with the PDSN (Packet Data Serving Node).

The PDSN is the element interfacing the wireless access network with the Internet. Not only it establishes the user sessions with PPP protocol (packet compression and filtering features), but also routes IP datagrams with differentiated service support.

For the scope of the current work, it results useful to outline the main characteristics of the 1xEV-DO aerial interface and, in particular, of its up-link (reverse) path, that is, the one going from the terminal to the BTS.

Performance of the 1xEV-DO reverse link surpasses the ones obtained in cdmaOne and CDMA2000 1X [10] by using innovative techniques such as *BPSK advanced modulation* and *turbo code-enabled packages* [11] with code rates of 1/2 and 1/4. Moreover, 1xEV-DO reverse link transmission uses a pilot channel, which improves the system performance through the *coherent signal detection* technique.

Transmission rate allowed by each terminal is determined by a distributed MAC algorithm, which provides terminals with certain autonomy to “decide” whether they want or not to transmit at a higher rate [12]. The BTS, however, controls the total load amount for the reverse link by changing its own status from “not busy” to “busy” and vice versa. Terminals are encouraged to increase or decrease their transmission rates accordingly, passing, through “valid” pre-defined transmission rates with values in Kbps of: 9.6, 19.2, 38.4, 76.8 and 153.6

The market share of this technology in Mexico is growing slowly. By now, only one massive effort to commercialize the CDMA2000 technology is supported by the Iusacell Company. The commercial name for it is BAM.

We have performed some experiments with this technology in the area of Cuernavaca, Morelos. The test environment and the results for them will be shown in part 3 and 4.

3. Testing Environment

Because of our interest is to analyze the behavior of TCP over a wireless CDMA2000 network segment, we used an existing card named BAM. The general characteristics for the referred BAM card and service are the following: *Technology 3G Evolution (EvDO), Data rate 2.4 Mbps (downlink) and 153 Kbps (Uplink), Dual Band equipment CDMA 800 MHz/1.9 GHz, PCMCIA II Card, Software required Windows 2000/XP and Mac[13]*.

Our testing environment is formed by a static host accessing the Internet trough a conventional cable modem, and a mobile host that reaches the Internet through a BAM Card (see Figure 2).

The computers that we used for the test had the following characteristics: the *static host* 512 MB RAM, Intel Pentium M 1500MHz 1.5 GHz, 40 GB HD, Windows XP Professional and the *mobile client* 1 GB RAM, Intel Pentium Centrino 1.7 GHz, 80 GB HD, Windows XP Professional.

As stated before, our tests were focused on the up-link communication of our testing set. That is, the CDMA2000-enabled mobile host sending packets to the static host.

To perform our tests we used a free-licensed software tool called "IPTraffic Test & Measure" [14] to generate the needed traffic. This tool controls the transfer rate and helped us to obtain the Transfer throughput (Tx) and Reception throughput (Rx) information saving it automatically in a file.

As a starting baseline, the CDMA2000-enabled client was left static and its performance was measured at three different transfer rates: *30Kbps*, *60Kbps* and *90 Kbps*. Each test was performed three times with a time period of 5 minutes. Information regarding transmission and reception throughput was obtained on every second with the help of the referred free-licensed software. Following, the test was performed with the CDMA2000-enabled client moving at three different vehicular speeds (*40Km/h*, *60Km/h* and *90Km/h*).

As shown in Figure 2, the wire segment was connected to a conventional coaxial cable modem with a downlink speed of 128 Kb/s, wide enough for the scope of our experiment. The static host was connected to Internet passing through fifteen routers to get communication with the CDMA2000 antenna.

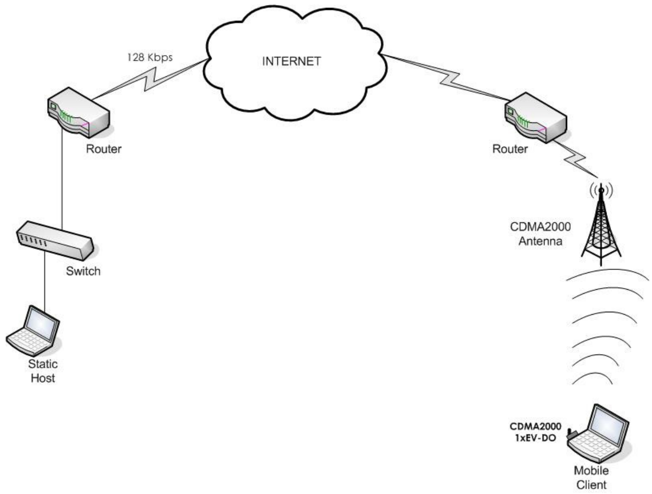

Fig. 2 Testing environment schema

First of all we needed to know if the computers had communication, the number of routers between both computers and their IP address. For that we used the *tracert windows* command getting a total of 15 routers. With the *ping* command we sent packets from the mobile client to the first router and to the static host. We performed this test several times and the RTT average were: Wireless segment: **263.66 ms** and Total segment: **301.66 ms**.

4. Preliminary Results

Each of the referred tests, 3 different throughput rates, 4 different speeds (0 km/hr included), was repeated three times.
Thus, we obtained 36 different data files with the metrics of our interest: transmission throughput, reception throughput, packets sent and received, and so on.

In order to obtain the best performance in the CDMA2000 network, we performed the test later than 21:00 and in the same geographical area (Mexico City – Acapulco Highway, Kms. 90 – 97. approximately, southbound).

In the following tables, we can observe that in some of our test the transfer rate values obtained are bigger than the specified one, the possible reason may find its origin on the traffic generation tool we are using and it associated algorithms.

Transfer Rate (Kbps)		Vehicular Speed			
		Fija	40 Km/h	60 Km/h	90 Km/h
30 Kbps	*Max*	35.59	34.7	35.16	33.12
	Average	**34.02**	**33.37**	**33.72**	**32.35**
	Min	31.59	31.18	31.48	13.24
60 Kbps	*Max*	61.35	62.27	57.82	55.76
	Average	**57.03**	**56.85**	**51.36**	**40.36**
	Min	45.24	46.96	42.97	16.61
90 Kbps	*Max*	86.3	89.24	89.97	78.36
	Average	**78.87**	**79.25**	**84.29**	**64.81**
	Min	68.58	62.91	74.12	58.12

Table 1: Tx performance (Kbps)

Table 1 shows our Tx results in Kbps, the maximum, the minimum and in bold you can see the average for all test.

Table 2 shows our Tx results in percentage, the maximum, the minimum and in bold you can see the average for all tests performed for that throughput and vehicular speed conditions.

Here you can observe an obvious tendency that at a greater vehicular speed, the transfer rate losses performance exponentially. However, when the mobile client is static or in a low vehicular speed the performance is almost the same or decreases linearly.

Transfer Rate (%)		Vehicular Speed			
		Fija	40 Km/h	60 Km/h	90 Km/h
30 Kbps	*Max*	**118.63**	**115.67**	**117.20**	**110.40**
	Media	**113.40**	**112.63**	**112.40**	**107.83**
	Min	**105.30**	**103.93**	**104.93**	**44.13**
60 Kbps	*Max*	**102.25**	**103.78**	**96.37**	**92.93**
	Media	**95.05**	**94.75**	**91.60**	**77.27**
	Min	**75.40**	**78.27**	**71.62**	**27.68**
90 Kbps	*Max*	**95.89**	**99.16**	**99.97**	**87.07**
	Media	**88.18**	**88.06**	**83.66**	**72.01**
	Min	**76.20**	**69.90**	**82.36**	**64.58**

Table 2: Tx performance (%)

In Figure 3 we can observe this information graphically. An exponential tendency is clearly identify.

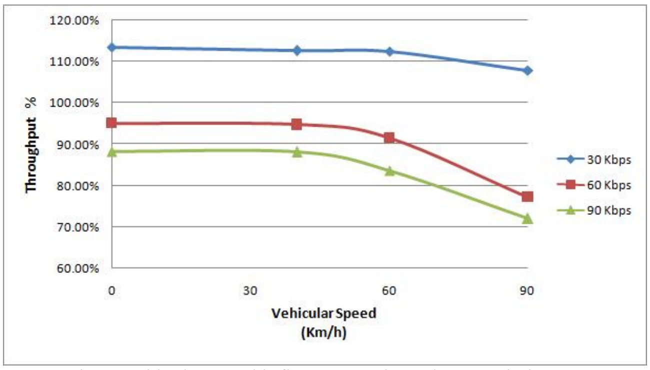

Fig. 3 Vehicular speed influence on Throughput Variation

An interesting observation is the one obtained when comparing side-by-side the most opposite situations of our tests. That is, the best performance obtained versus the worst performance at the same transfer rate. As a visual aid, we present also the graphics that compare the fluctuation between Tx vs Rx.

Figure 4 shows the performance at 60 Kbps-Static, we can observe that the transmission average throughput is 57.03 Kbps, reaching almost the total desired transfer rate. And the oscillation had its maximum at 61.35 Kbps and the minimum at 45.24 Kbps, meaning just an increment of 7% and a decrement of 20% from the average.

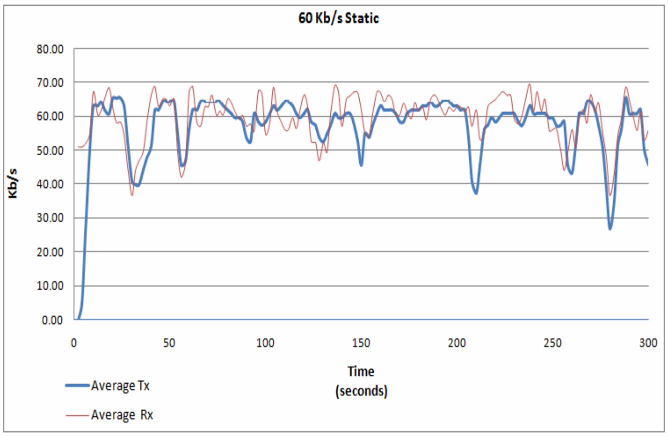

Fig. 4 60Kbps-Static average Transfer Rate

On the other hand the Figure 5 shows the performance at 60Kbps–90Km/h, we can observe that the average slow down to 40.36 Kbps. And the oscillation had its maximum at 55.76 and the minimum at 16.61, which mean an increment of 25% and a decrement of 40% from the average.

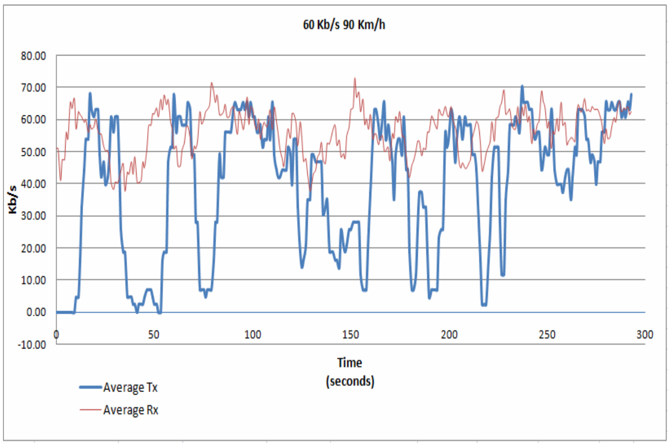

Fig. 5 60Kbps-90Km/h average Transfer Rate

Doing the same comparison at 90 Kbps, the results can be observed at Figure 6, that shows the performance at 90Kbps-Static. The average throughput is of 78.87 Kbps, close to the total transfer rate. And the oscillation was maximum 86.30 and the minimum was 68.58, that means just an increment of 8% and a decrement of 11% from the average.

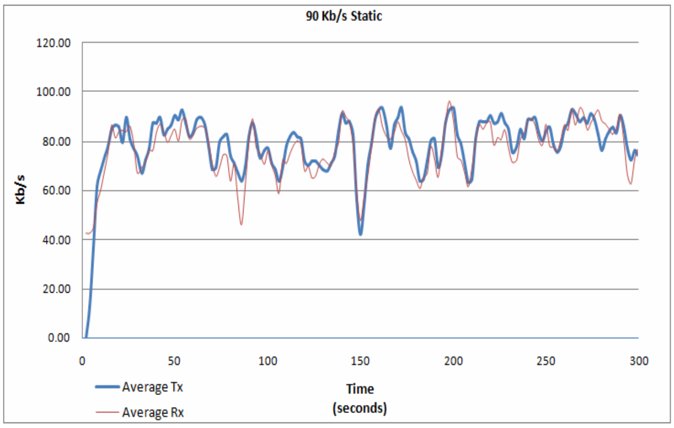

Fig. 6 90Kbps-Static average Transfer Rate

On the other hand, Figure 7 shows the performance at 90Kbps–90Km/h, we can observe that the average throughput decreases to 64.81 Kbps. And the oscillation finds its maximum value at 78.36 and its minimum at 58.12, which means an increment of 15% and a decrement of 8% from the average, respectively.

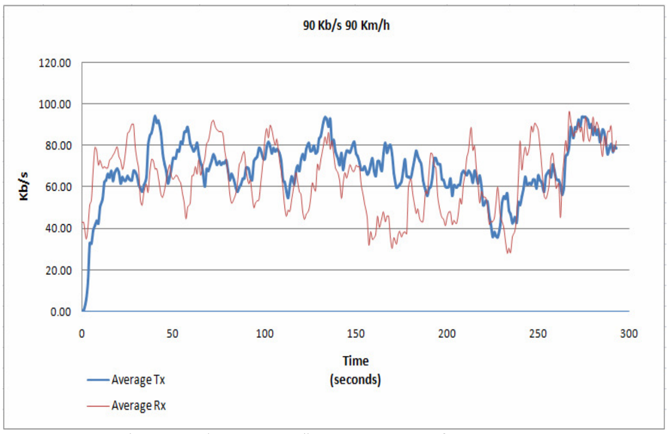

Fig. 7 90Kbps-90 Km/h average Transfer Rate

Even if further information was obtained with these tests, we think that the presented here is the most relevant to illustrate the main trend: CDMA2000 technology looses performance at high speeds. As stated before, the throughput decreases in a linear manner at speeds up to 60 km/hr, and decreases exponentially in speeds around 90 km/hr.

Talking about the behavior of transfer rate Transmition (Tx) versus Reception (Rx), we note that in general at a low vehicular speed the difference between Tx vs Rx is minimum; but, as we increment the vehicular speed the difference gains significance.

5. Conclusion

As a main conclusion from our results we can state that, when the mobile host was static or in low speed (*40KM/h, 60Km/h*), the throughput is very similar or had a lineal decrease. In the other hand, when the speed is higher (*90Km/h*) the throughput decreased exponentially.

We noticed that if we increase the speed up to 90 Km/h, (i.e. 110 km/h), the throughput rate continues decreasing more and more. We have decided not to include that kind of tests, given that we were unable to maintain such a high speed constantly for a long period of time, because of the traffic in the highway.

Something to note here is that the original intention of this work was to study the down-link performance. However, we found that, due to understandable commercial restrictions, the company who provides the service has a firewall to detect and avoid massive traffic flow operations, like the one we needed to implement for this test.

Thus, a possible future work could include an analysis of the down-link performance, once an agreement with the carrier company is reached or a different way to implement the test is found. A possibility would be starting the downlink request from an internal node of the CDMA2000 network.

This kind of test would allow us to perform measurements at higher throughput rates, given that for CDMA2000 the down-link limit is broader than the up-link (2.4 Mbps versus 153 Kbps, respectively).

References

[1] Ai-Chun Pang; Jyh-Cheng Chen; Yuan-Kai Chen; Agrawal, P.; "Mobility and session management: UMTS vs. cdma2000" Wireless Communications, IEEE [see also IEEE Personal Communications], Volume 11, Issue 4, Aug. 2004 Page(s):30 – 43, Digital Object Identifier 10.1109/MWC.2004.1325889

[2] Kandukuri, S.; Chaponniere, E.; Hamdy, W.; "Impact of TCP and RLP parameters on CDMA2000 performance " Vehicular Technology Conference, 2003. VTC 2003-Spring.The 57th IEEE Semiannual ,Volume 1, 22-25 April 2003 Page(s):626 - 631 vol.1

[3] Jesus A. Perez, Bonoit Donnet, Olivier Bonaventure, "Preliminary Analysis of the TCP behavior in 802.16 Networks". ITESM-Campus Cuernavaca, Department of Electronics,Temixco, México. Universite Catolique de Louvain, CSE Department, Louvain-la-Neuve, Belgium

[4] Madhav Chinta, Abdelsalam (Sumi) Helal and Choonhwa Lee. "ILC-TCP: An Interlayer Collaboration Protocol for TCP Performance Improvement in Mobile and Wireless Environments Department of Computer & Information Science & Engineering. University of Florida, Gainesville, FL 32611-6120, USA. helal@cise.ufl.edu

[5] Dzmitry Kliazovich and Fabrizio Granelli, Giovanni Pau and Mario Gerla. "APOHN: Subnetwork Layering to Improve TCP Performance over Heterogeneous Paths "University of Trento, UCLA Via Sommarive 14, I-38050 Trento, Italy, Computer Science Department, CA 90095, USA. [klezovic,granelli]@dit.unitn.it

[6] Milan Todorovi´c, No´e L´opez-Benitez, N-Com, LP, " Efficiency Study of TCP Protocols in Infrastructured Wireless Networks" Department of Computer Science Texas Tech University Lubbock, TX 79424-4957, Lubbock, TX 79409-3104. mtodorovic@n-com.us, nlb@cs.ttu.edu

[7] Poole, I. "What exactly is ... ... cdma 2000?"
This paper appears in: **Communications Engineer**
Publication Date: Feb./March 2006,Volume: 4 , On page(s): 46 – 47, ISSN: 1479-8352

[8] Esteves, Eduardo; Swart, Hugo. "CDMA 2000 1xEVDO: Technologies, Services and Marketing Last updated: January 5, 2004. Available.in: ttp://www.teleco.com.br/es/tutoriais/es_tutorialcdma2000 Teleco, Brazil

[9] Ramachandran Ramjee, Li Li, Tom la Porta, Sneha Kasera , "IP paging service for mobile hosts " September 2002. Wireless Networks, Volume 8 Issue 5 **Publisher:** Kluwer Academic Publishers

[10] Rao, Y.S.; Kripalani, A.; "CDMA2000 mobile radio access for IMT 2000" Personal Wireless Communication, 1999 IEEE International Conference on17-19 Feb. 1999 Page(s):6 - 15
Digital Object Identifier 10.1109/ICPWC.1999.759574

[11] Tüchler, Michael; Koetter Ralf and Singer, Andrew C. "Turbo Equalization: Principles and New Results" IEEE Transactions on Communications. Vol. 50, No. 5, May 2002. Pages 754-767

[12] Gurelli Mehmet and Etkin, Raul.. "Capacity Simulation of cdma2000 1xEV-DO Forward Link with Opportunistic Beam Forming". QUALCOMM Incorporated. University of California, Berkeley

[13] http://www.iusacell.com.mx/iusacellEmpresarial/content/html/datos/videosBAM.html. IUSACELL Company

[14] http://www.zti-telecom.com/pages/iptraffic-test-easure.htm. ZTI Telecomunicaciones

Jesús Arturo Pérez-Díaz [jesus.arturo.perez@itesm.mx] obtained his B.Sc. degree in Computer Science from the Autonomous University of Aguascalientes (1995). He worked as a system and network administrator in the Aguascalientes city hall. In 1997 he started his PhD degree in the University of Oviedo, Spain. He studied the program New advances in Computer Science Systems, and during these years he researched in mobile agents and published around 12 research papers in magazines and international conferences. During the same period of time he took part in a couple of European research projects and became a full associate member of the European founded research project AgentLink. He got his PhD Degree in Computer Science in the University of Oviedo in 2000, afterwards he became associate professor of the Computer Science Department in the same University from 2000 to 2002. During these years he gave courses and made research in network and Internet security. Nowadays he is a researcher and professor in the ITESM – Campus Cuernavaca México and member of the Researchers National System, his research field focus in network security and wireless communications. Currently Dr. Pérez-Díaz has gotten the recognized Cisco certifications CCNA and CCAI, which allows him to give Cisco certification courses. Additionally he is giving courses on wireless communications and network security in the postgraduate programs in the ITESM, also he has supervised master and PhD theses in the same field. He has given security courses in some European and South American Universities.

José Miguel García-Ramos [A00439529@itesm.mx] obtained his B.Sc. degree in Electronics and Communications Engineering from the Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Estado de México (1995). He worked as a Service Coordinator in Siemens de México from 1994 to 1997 and as a Maintenance Manager in Elevadores Schindler de México from 1997 to 2002. During these years he supervised some important installations of high speed elevators like Torre Mayor, the biggest building in Latin America. In 2006 he started his M.C degree in the Instituto Tecnológico y de Estudios Superiores Campus Cuernavaca, México in Computer Science Systems, nowadays he is still studying his M.C and researching in Wireless networks, specifically in CDMA2000 networks.

Miriam Calderón-Reyes [A01126648@itesm.mx] obtained his B.Sc. degree in Computer Science from the Technologic Institute of Zacatepec (2003). She worked as a Software Developer in the Autonomous University of Morelos State in the Cuernavaca city hall from 2003 to 2006. During the same period of time she was computer teacher in the Universitary College of Americas. In 2006 she started his Master degree in the ITESM – Campus Cuernavaca and currently she is in the second semester.

Luis Guillermo Riojas-Mandujano [A00373476@itesm.mx] obtained his B.Sc. degree in Computer Systems Engineering from Tecnológico de Monterrey (ITESM) Campus Cuernavaca in 2000. He is currently studying a M.Sc. in Computer Science in the same institution, where his main area of research is Spontaneous Networking. He accumulated experience on software engineering and IT project leadership during nearly five years of working experience for General Electric Headquarters in Fairfield, Connecticut and Softtek, Inc. in Aguascalientes.