RAMON: Rapid-Mobility Network Emulator

Edwin Hernandez and Abdelsalam (Sumi) Helal

Computer and Information Sciences and Engineering Department
University of Florida, Gainesville, FL, 32611-6120, USA
helal@cise.ufl.edu
http://www.harris.cise.ufl.edu/projects/rapmobile.htm

Abstract

In wireless networks, as in many areas of engineering, simulation has been the *de-facto* standard for testing, dimensioning and analyzing mobile protocols. Emulation, which presents a lower cost, more accurate, yet more complex engineering alternative to simulation, has not been widely used in mobile computing studies. RAMON is a software/hardware emulator tailored to mimic the realistic characteristics of wireless networks. RAMON is especially designed to study how mobile protocols cope with high vehicular speeds. The main advantage of RAMON is the rapid, cost-effective and accurate testing it provides. This ranges from proper identification of protocol bottlenecks, to testing of newly available wireless networks and hardware and software devices.

Keywords: *Network emulation, rapid-mobility, RAMON, Mobile-IP, wireless LAN, simulation.*

Introduction

Mobile computing networks provide environments and scenarios, which challenge and overturn the current paradigms of computing. Nomadic data and devices make the current network protocols insufficient and unable to cope with mobility. Simulation environments have been developed by the research community to study and improve the performance of mobile network protocols, determine bottlenecks, and reduce the cost of hardware implementations. The most widely used simulator is the Network Simulator (ns) [Fla00] which provides simulation environments for wired and wireless networks.

Although simulation of mobile networks of moderate speeds can be easily achieved using ns, rapid mobility conditions and complex propagation models challenge the utility and suitability of the simulation approach. In particular, the duplication of the software development process of the simulator, to include new operating system platforms and/or newly introduced wireless technologies, is costly and unpractical. For example, in the case of Wireless LAN technology currently, the 802,11b is currently implemented in ns. The 802.11a, however, is not and hence significant coding needs to be done before ns is ready for use with the 11a network. A hybrid approach that pieces together existing ns software modules with emerging wireless network hardware is needed. Such approach seems to be a more cost-effective and faster way to test and develop mobile network protocols. This paper introduces RAMON, a Rapid-Mobility Network emulator, which is a hybrid approach to simulation and emulation.

Simulation versus Emulation

Simulation environments and specifically network simulators have been widely used throughout the past few decades. Wire-line emulators have also been used to replicate the conditions of end-to-end network delays found on. For example, the End-to-End Emulator, ENDE [Bott93], developed at the Texas A&M University, is aimed to imitate the Internet by providing end-to-end network delay using ICMP packets as a real time traffic source. In the same way, the Ohio Network Emulator ONE [All97] is able to emulate transmission, queuing, and propagation delay between two computers interconnected by a router. Finally, The National Institute of Standards and Technology (NIST), NET or NISTNET [NIST01] emulator allows an inexpensive PC-based router to emulate numerous complex performance scenarios, including: tunable packet delay distributions, congestion and background loss, bandwidth limitation, and packet reordering and duplication. There are also other emulators that are commercially available.

RAMON extends currently available wired-network emulators by adding wireless extension features. It glues together pieces of hardware and software to allow the replication of realistic mobile networks and mobile connection scenarios. RAMON emulates mobility in wireless networks by affecting the actual network physical parameters. It also emulates mobile unit speed, acceleration and trajectory changes, by controlling the causality between actual network parameters and network behavior perceived by the moving computer. In the subsequent subsections, we describe the architecture of RAMON and the methodology used to emulate a wireless network.

Networked application can be easily tested in an emulation environment without needing to go through the intermediate steps done in a simulator. First of all, applications can be tested without changing their API by isolating the network and transport layers of the system as an independent variable. Secondly, by using actual hardware components instead of modeling them, the complexity of coding the algorithms and the computation time required to simulate radio-wave fading, antenna propagation, or base-station implementation details, can be avoided. This amounts to a significant savings in time and cost of developments. For instance , a Mobile-IP simulation involving 1-mobile unit and 20 base-stations required 500 Mbytes of trace file running for more than 3 hours on a very powerful server to process a 600 second long simulation scenario. On the contrary an emulation code would use exactly 600 seconds of the real-time clock (6% of 3 hours) to accomplish the same study.

The simplification of systems parameters required in a simulator (e.g., propagation models) is another reason to question the simulation approach and to embrace emulation. Even though simplification reduces simulation time as well as implementation complexity, obtained results and drawn conclusions could be quite misleading due to oversimplification.

In fact, most experimental work on networks (especially, wireless) has been conducted using purely a simulation approach. In a recent study by Pawlikowski et al [Pawk02], it was pointed out that 76% of the authors in IEEE journals who used a simulation-based approach were not concerned with the random nature of the results, and made statistical mistakes during the initial setup of the experiments. The randomness of the experiments and the assumptions made in many research publications were difficult to replicate. It is our motivation that the combination of network simulation and emulation can potentially lead to better practices and faster and more reliable and replicable results than a simulation-only approach.

A New Mobile Network Emulator

We have toyed with the idea of replacing parts of the ns simulator with actual components. In particular, we focused on emulating the L1/L2 layers of the wireless network, as well as capturing the relative effect of mobility across a predetermined path. Figure1 depicts the architecture of RAMON and the wireless and wired components. The emulator consists of three nodes used for mobility management and routing. Each node is composed of an Access Point (AP), which is also called Base Station, and a Pentium server loaded with the mobility management software. The operating system platform used is Linux kernel 2.4.18 and the Access Points are Cisco's, loaded with IOS version 11.03. Any mobility protocol can be loaded and installed at each node in RAMON. The Mobility Management protocol used in this paper is Mobile-IP [Perk02]. Although, Mobile-IP is widely supported as well as many routing daemons, protocols such as Cellular-IP and Hawaii, among many others can be also be emulated in RAMON [Camb00, Ramj99].

For the experiments presented in this paper, Mobile-IP was the mobility protocol of use. The home and foreign agents are mapped to the mapped in the architecture presented above as part of Node 1, Node 2, and Node 3. Each node also requires of an Access Point, an attenuator, and antenna.

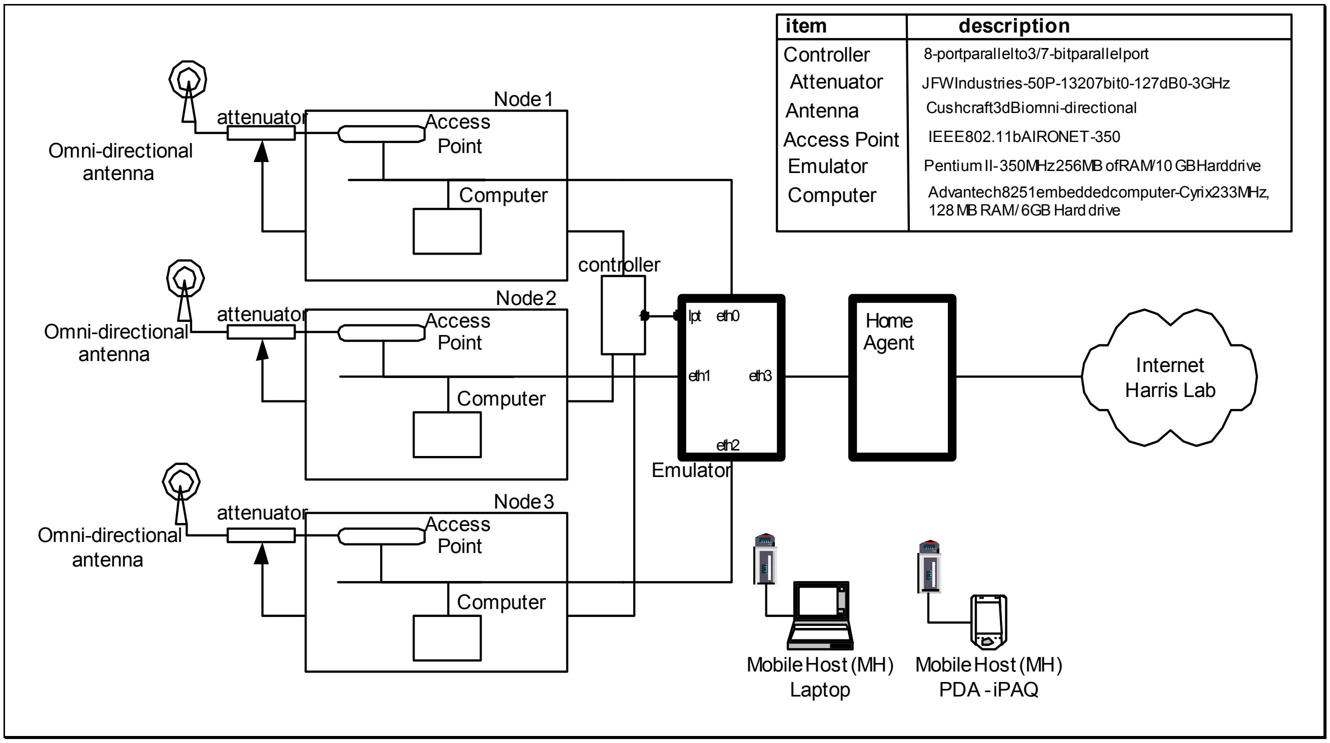


Figure 1. Rapid-Mobility Network Emulator (RAMON)

Each Access Point (AP) is a Wi-Fi 802.11b [ieee99] complaint entry point which in this case correspond to a CISCO 350. The AP was configured with a power output of 100mW and at the channels 1, 6, and 11, respectively. The Mobile Node (MN), in this case a IBM Thinkpad Pentium II 233 MHZ and 128MB of RAM, could be also any other computing terminal compatible with 802.11b. RAMON also has direct access to the internet thru the Harris Computing Lab at the University of Florida. . The wired-network emulator included in RAMON corresponds to the NIST net implementation. The NIST net emulator provides a more robust conceptualization and this development is compatible with low-cost platforms.

The attenuators shown in Figure 1 are used to manipulate and control the signal strength coming out of the access points. This manipulation on the value of signal strength is used to emulate the motion towards and away from a base-station. The attenuator chosen for RAMON have been especially built by JFW Industries (model 50P-1230 [jfw02]). They provide a digitally (software) controlled parallel interface which allows attenuation level stepping from 1 thru 128 dB. A summary of the software and hardware components used in RAMON is included in Table 1 below.

From simulation to emulation in RAMON

As mentioned earlier, network simulation conducted with the *ns* simulator requires a scripting language where the topology and the network architecture are defined. To support a new network technology (say supporting the new 802.11a or 802.11g), each component used on ns, from traffic generators, TCP implementation, and application level interfaces should be implemented as an object file in the *ns* libraries.

The main advantage of using *ns* is the ability to codify the simulation scenario, as well as data collection, using two languages: tcl and C++. Once the implementation of the object is completed in C++ it can be manipulated and used from the scripts made in tcl.

The network simulator *ns,* reads in the input script and creates instances of the objects defined and then starts the simulation. The user is in charge of analyzing the output and the generated trace file, which contains valuable packet information. Several hours of simulation time are needed to simulate several minutes of real-time scenarios (orders of magnitude longer than emulation).

Table 1. List of software and hardware tools used in RAMON

	Item	Description
Software	Operating System	Linux Kernel.2.4.18 modules IP/IP and support for virtual interfaces
	Statistics	Tcpdump[tcpd02]. Tcptrace,[tcpt02] and ethereal [ethe02] are used for collecting statistics
	Emulation	NIST Network Emulator
	Mobility Protocols	Mobile IP – dynamics HUT [Fom99]]
Hardware	Emulator	Pentium II 350 MHz – 256 MB RAM/10 G
	Attenuator	JFW Industries – 50P -1230
	Network node	Embedded computer – Advantech 8251
	Controller	TTL/custom design
	Mobile Host	Laptop IBM Thinkpad/Pentium II 233 MHz-128 MB RAM/4GB Hard drive
	Access Points	CISCO AIRONET 350 [Cis01]
	Antennas	Omnidirectional 3dBi Cushcraft

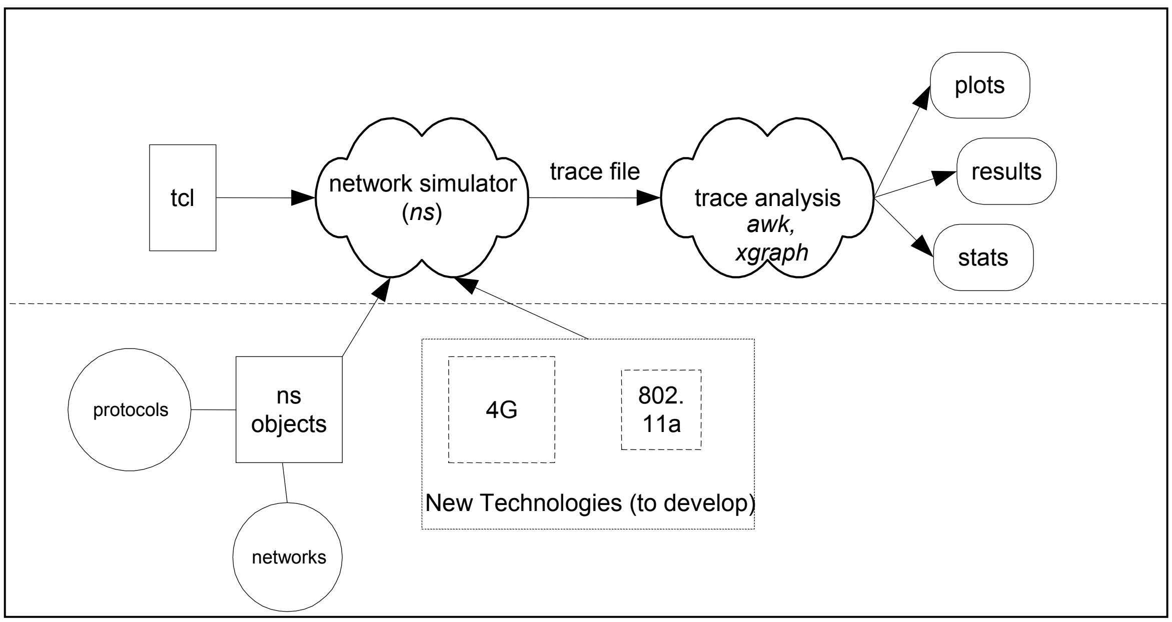


Figure 2. Network simulator (*ns*)

As shown in Figure 2, new technologies would require the simulation community to build and test, new objects implementations into *ns*. The development of a new object model for a network protocol such as IEEE 802.11a may take weeks, if not months, particularly under a non-centralized development process of new object classes and models undertaken by the research community. In RAMON, researchers can quickly define an emulation scenario that integrates the latest technology (actual network hardware), test new protocols and obtain performance results. In fact, the integration of the hardware piece into the test bed architecture, is reduced to acquisition and integration, which is much simpler process than the creation of source code compliant to the simulator environment (otcl and tcl/c++ objects). For instance, the experiments presented in this paper using Wi-Fi complaint equipment, could be reproduced using IEEE 802.11a in a matter of days, and not months as would be required in the case of extending a simulator.

Attenuation Control and Emulation of Speed

In order to emulate speed, two factors should affect the mobile node: the received signal strength and the signal to noise ratio. These factors can be varied from the access point and received at the client adaptor (network card) level. Mobility is then emulated by increasing the signal strength of one AP and decreasing the other two, or the combination of any two or more APs (based on the paths of mobility and the scenario). The association of the 802.11 client to the mobile network is defined by the internal properties of the wireless card.

For instance, Eq. 1 represents the path loss equation and the signal received by a network node at a distance *d* from the AP.

$$S_r(dBW) = S_t(dBW) + G_t(dB_i) + G_r(dB_i) - K_o - n\log_{10}(d) \quad (1)$$

The values of G_i indicate the gains at the both ends of the antenna, using the isotropic in dB_i. In other words, the signal strength received at the mobile node is the summation of all the gains (S_t, G_i) minus the propagation loss due to fading of the signal. This propagation loss depends on the many characteristics of the terrain and was empirically defined by [Phal95] using different values of K_o and *n,* depending upon different terrain conditions at different frequency values.

Propagation Model

The experimental values and equations used for the propagation in RAMON correspond to the modeling for indoor and micro-cellular environments [Pahl95], which is depicted by Eq 2. The empirical model indicates that the attenuation is negligible at closer distance from the antenna, and quickly logarithmically decays at certain distances using different values of *n* and K_o. In this case 10, and 20 are used in Eq. 2.

$$A(d) = \begin{cases} 0, & d \le R/100 \quad d >= 1.2R \\ 10 + n\log(d), & R/100 < d \le 0.9R \\ 20 + 10(n+1.3)\log(d), & d > 0.9R \end{cases} \quad (2)$$

In Eq2, *d* is the distance between the AP and the mobile node and *R* is the cell ratio (which has a value of 500 m). Also we used a simple square attenuation model, which is used to simplify and determine the handoff rate.

$$A(d) = \begin{cases} 0 & 0 \le d \le 0.9R \\ 128 & d > 0.9R \end{cases} \quad (3)$$

Although, the models depicted several values of attenuation to use in the attenuator, experimental measurements indicated that the valid range of attenuation was from 0 to 60 dB, approximately. Anything bellow this value was affected by the AP signal leakage, which is difficult to completely circumvent.

Figure 3 shows the value measured at the mobile node using a WaveLAN 802.11b card and the Linux operating system at an emulated speed of 20 m/s. The attenuation value corresponds to two values of *n* ranging from 2.5 to 3.5. All the experiments were conducted with the mobile node physically located 10 m away from RAMON.

Experimental Results

Our research examines the ability of mobile networking protocols to cope with speed under various wireless networks. A mobility scenario of a vehicle passing by a straight segment of a road equipped with 802.11b APs is shown in Figure 4. This scenario assumes that the majority of the communication takes place between the mobile node and the correspondent node in the internet. The experiment consisted of an FTP transfer of a 28MByte file located at several hops from RAMON but which was nevertheless emulated as a 20 ms delay between the gateway (Home Agent) and the correspondent host.

Figures 5 through 7 correspond to different attenuation models at a constant speed of 20 m/sec. Figure 5 depicts the speed of 20 m/s. The throughput is found to follow the shape of the attenuation function received at the network card level. The sequence-time plot also indicates that handoff occurs between 1 to 5 seconds. On the average, the peak throughput decreases as the distance from the home-agent increases while the delay between the end-points increases.

Figures 6 and 7 represent similar experiments. On the average, the smaller the value of *n,* the lower the average throughput. In this specific case (Figure 6), throughput is measured at 134Kbytes/sec down from 141Kbytes/sec after more than 53342 packets transferred and more than 60Mbytes of information exchanged (three times the original file of 28MBytes). Figure 7 depicted a much higher performance value for throughput and smaller handoff time for any speed lower than 20 m/sec.

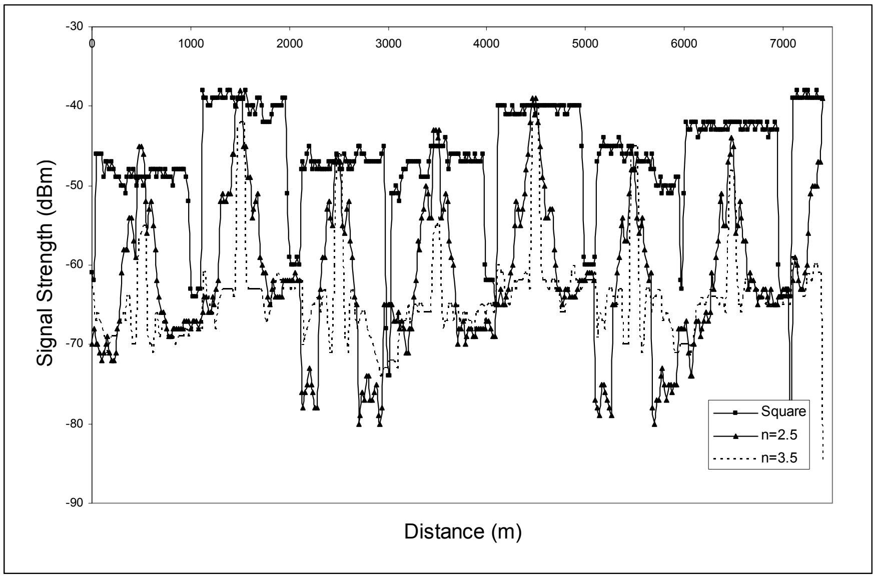


Figure 3. Experimental values of signal strength measured at the mobile node using three different attenuation patterns (speed = 20 m/s).

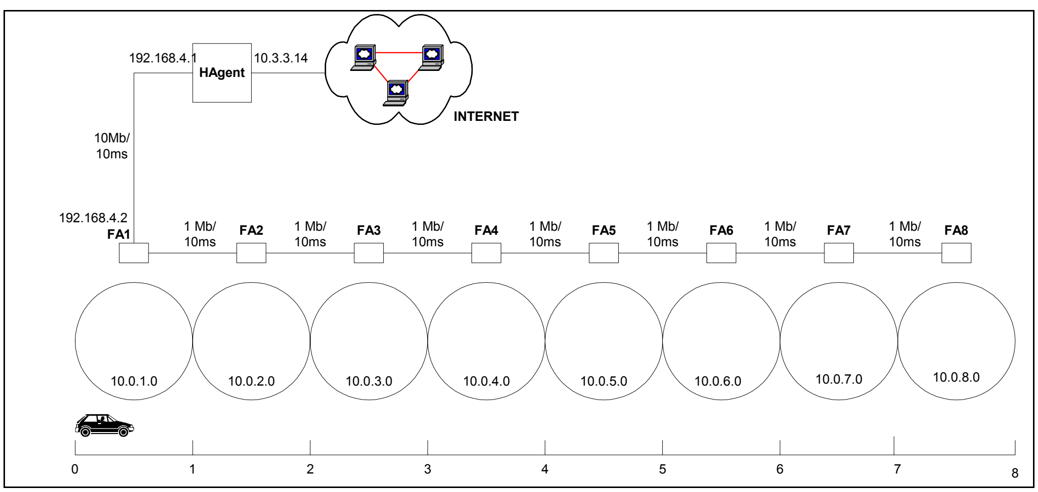
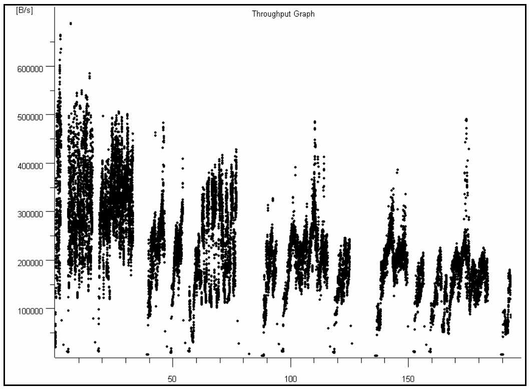
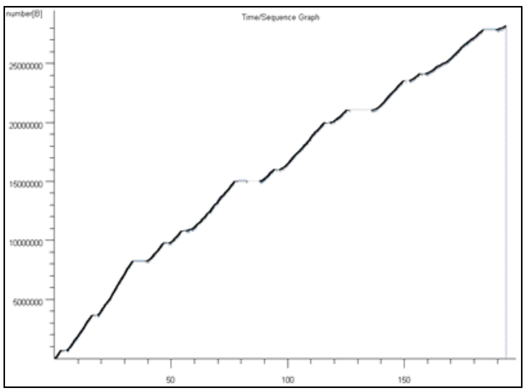


Figure 4. A Simple mobility scenario emulated in RAMON



(a)



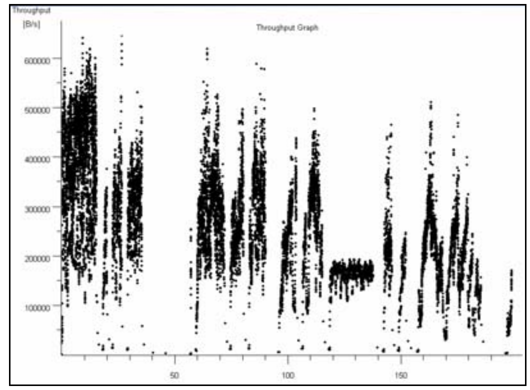
(b)

Figure 5. Throughput and time-sequence plot at 20 m/sec (*n=2.5)*

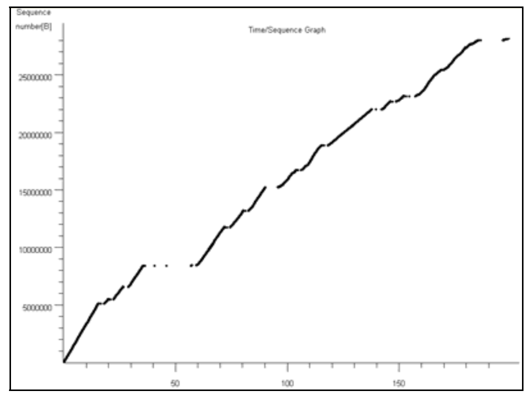
This assertion is true as speed was increased and average values of throughput and handoff delay were measured (Figure 8).

We have used RAMON to verify previous simulation-only results (using *ns*) obtained by other researchers, that studied Mobile-IP performance under different speeds. As depicted in Figure 9, the performance of mobile-IP is over-estimated by using a simplified squared propagation model, at speeds smaller than 20 m/sec. As speed increases the card depends only on the variations of signal strength detected to initiate handoff

The behavior observed using the squared attenuation pattern is linear and at 80 m/s only reaches 60 Kbytes/sec. This final experiment at 80 m/sec required the FTP session to be initiated before the emulation took place. This situation was not required at any of the speeds lower than 80 m/sec. For the experiments where the FTP session was initiated at the time the emulation started, the throughput value vas not greater than 12 Kbytes/sec. This fact can be observed in Figure 9, where at speed of 80 m/sec, the majority of data is transferred during the first 20 seconds of the emulation.



(a)

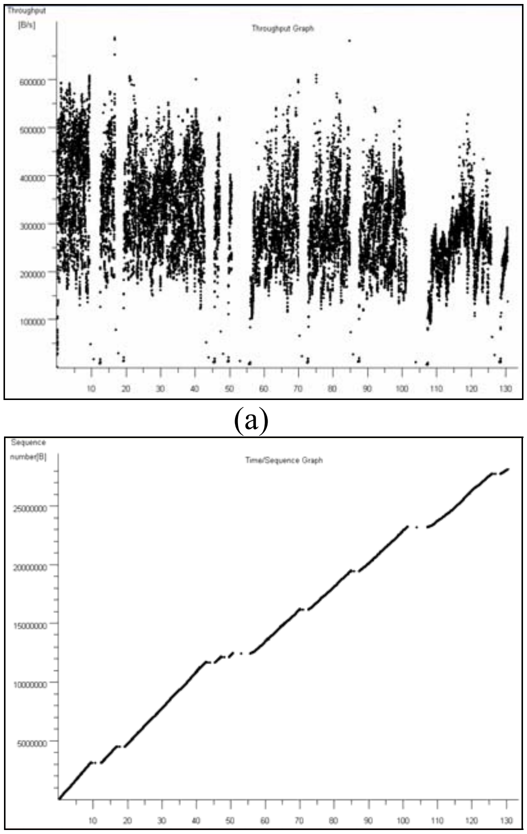


(b)

Figure 6. Throughput and time-sequence plot at 20 m/sec (*n*=3.5)

Figure 9a shows the time-sequence plot when using *n=2.5* and the results indicate that at higher distances from the base station, an increase in the delay of a few hundred of milliseconds is enough to drop the bandwidth to almost zero after 30 seconds of emulation

Other test bed platforms and experimental results have related the handoff rate as physical variable that is equivalent to speed, which is correct for a simple attenuation model (Eq.3). Campbell, et al. [Camb01] presents the throughput as a function of the handoff rate between two access points only, without considering signal strength effect or any of the variable conditions included in RAMON, (e.g., increased delay on crossing different access points, different attenuation models, realistic Mobile-IP implementation, among others). The results shown in this paper indicate that simply forcing handover between two access points at different rates is not sufficient to demonstrate the effects of speed on mobile protocols.



(a)

(b)

Figure 7. Throughput and time-sequence plot at 20 m/sec (*square*)

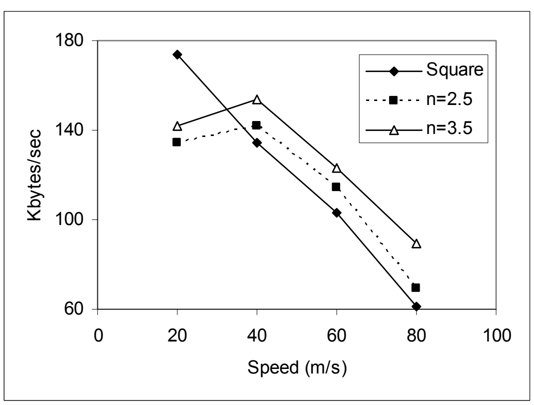
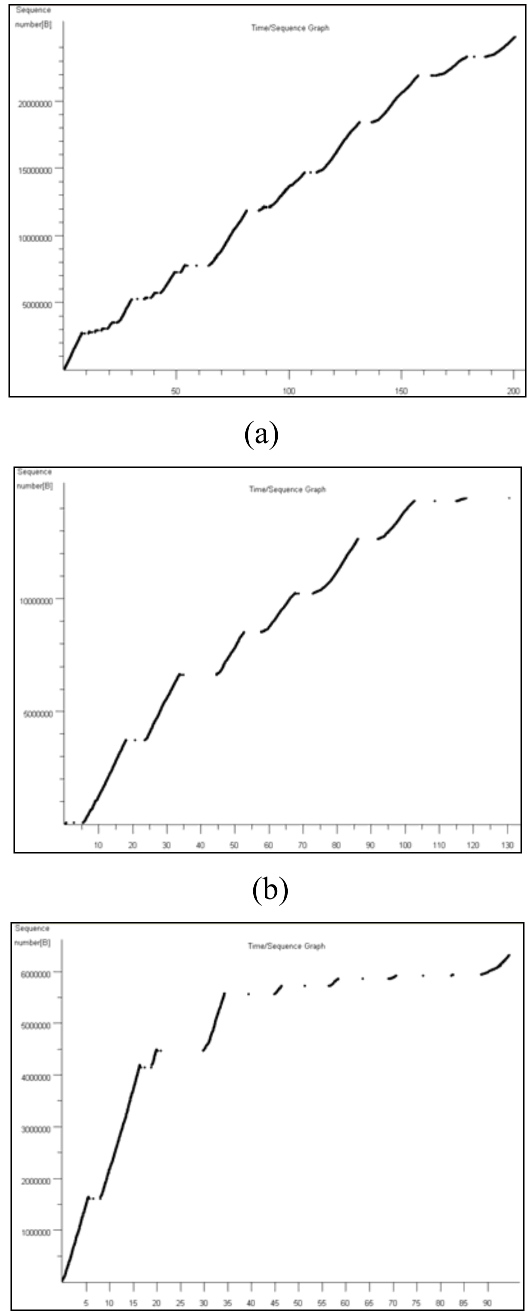


Figure 8. Average throughput and speed using different attenuation patterns.



(a)

(b)

(c)

Figure 9. Time-sequence plot for speeds (n=2.5) of (a) 40 m/s, (b) 60 m/s, (c) 80 m/s

Figure 8 depicts the difference on average throughput and speed using different attenuation models. The figure shows a great level of degradation on the average value of throughput as speed increased of at least 50% at 80 m/sec when compared to the average throughput at 20 m/sec. This expected performance loss is greater than the expected by Campbell [Camb01] of only 25% at 20 handoff/min or an equivalent speed value of 300 m/sec. (assuming a cell diameter of 1000 m) Lastly, we can assure that the effectiveness of a handoff protocol needs to be thoroughly tested using emulated conditions that resemble realistic scenarios. Therefore, in order to cope with the variability of signal strength, network latency, and speed, an emulation environment as RAMON is very much needed for the testing of mobile and wireless networks.

Conclusions

A novel approach for wireless and mobile network emulation is presented in this paper. The RAMON emulator can effectively replicate realistic conditions of mobility providing interesting insights and observations previously unknown and non-observed in pure simulation experiments such as ns [Hern01]. Using RAMON, we have shown that handoff and throughput change significantly with the attenuation model used in the study. Therefore, a careful selection and capture of such models are necessary for obtaining accurate data about the performance of a given wireless network.

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References

[All97] M. Allman, A. Caldwell, S Ostermann. "ONE: The Ohio Network Emulator", TR-19972, School of Electrical Engineering and Computer Science, Ohio University, August 1997.

[Bolot93] C Bolot, "*End-to-End Packet Delay and Loss Behavior in the Internet*," ACM Computer Communication Review, Vol. 23, No. 4, October 1993, pp. 289-298.

[Camb00] A. T. Campbell, Gomez, J., Kim, S., Turanyi, Z., Wan, C-Y. and A, Valko "Design, Implementation and Evaluation of Cellular IP", *IEEE Personal Communications,* Special Issue on IP-based Mobile Telecommunications Networks, Vol. 7, No. 4, pp. 42-49, August 2000.

[Camb01] A. T Campbell, J Gomez, S. Kim and C. Wan. "Comparison of IP Micro-mobility Protocols", IEEE Wireless Communications, February 2002, pp. 72-82.

[Cis01] http://www.cisco.com/univercd/cc/td/doc/pcat/ao350ap.htm

[ethe02] http://www.ethereal.com/

[Fall00] K. Fall, K. Varadhan, editors. NS notes and documentation. The VINT project, LBL, February 2000. http://www.isi.edu/nsnam/ns/

[Hern01] E. Hernandez and A. Helal, "Examining Mobile-IP Performance in Rapidly Mobile Environments: The Case of a Commuter Train," Accepted to LCN 2001 in Tampa, FL, Nov 14-16, 2001

[ieee99] IEEE-board, "Part11: Wireless LAN Medium Access Control (MAC) and Physical Layer Specification (PHY), Piscataway, New York, 1999.

[jfw02] http://www.jfwindustries.com/

[Perk02] C. E. Perkins, "IP support for mobility RFC-3002", IETF-RFC, January 2002.

[Ramj99] Ramachandran Ramjee, Thomas La Porta, Sandy Thuel, Kannan Varadhan, and Shie-Yuan Wang. "HAWAII: A Domain-based Approach for Supporting Mobility in Wide-area Wireless Networks ",International Conference on Network Protocols, ICNP'99

[Fons99] Forsberg, D., Malinen, J.T., Malinen, J.K., Weckström, T., Tiusanen, M., "Distributing Mobility Agents Hierarchically under Frequent Location Updates," Sixth IEEE International Workshop on Mobile Multimedia Communications (MOMUC'99), San Diego 1999.

[Pahl95] K. Pahlavan, A. Levesque "Wireless Information Networks", John Wiley & Son's, New York, 1995.

[Pasw02] K. Pawlikowski, H. Jeong, J Lee. "On Credibility of Simulation Studies of Telecommunication Networks", IEEE Communications Magazine, January 2002, pp 132-139.

[tcpd02] http://www.tcpdump.org

[tcptr02] http://www.tcptrace.org/