An adaptive networking protocol for rapidly mobile environments

Interview Talk

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Motivation

Mobile-IP is the most widely used mobility solution in IPv4 and IPv6 networks. However, the performance for vehicles moving at high-speeds is questionable. Predictable trajectory and mobility, network originated handoff, and distributed registration can improve the performance of Mobile-IP without the use of costly micro-mobility protocols.

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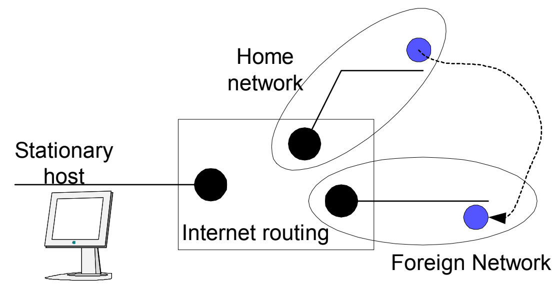
- Performance of Micro- and Macro-Mobility protocols
- RAMON: A proposal for network emulation.
- Predictable mobility in wireless networks
- Extensions for a predictable Mobile-IP

Introduction – Concepts in Mobile Networks

- 1. Forwarding Agent when a MH is foreign network



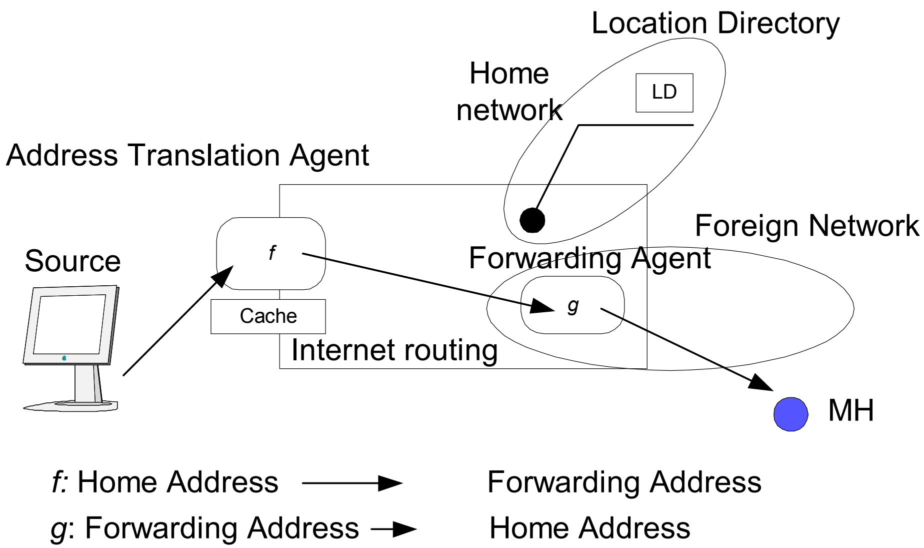
- 2. Location Directory (LD), location information

$$g(\textit{fowarding address}) \rightarrow \text{home address}$$

- 3. Address Translation Agent (ATA)

$$f(\text{home address}) \rightarrow \text{forwarding address}$$

Introduction – Packet Forwarding Model

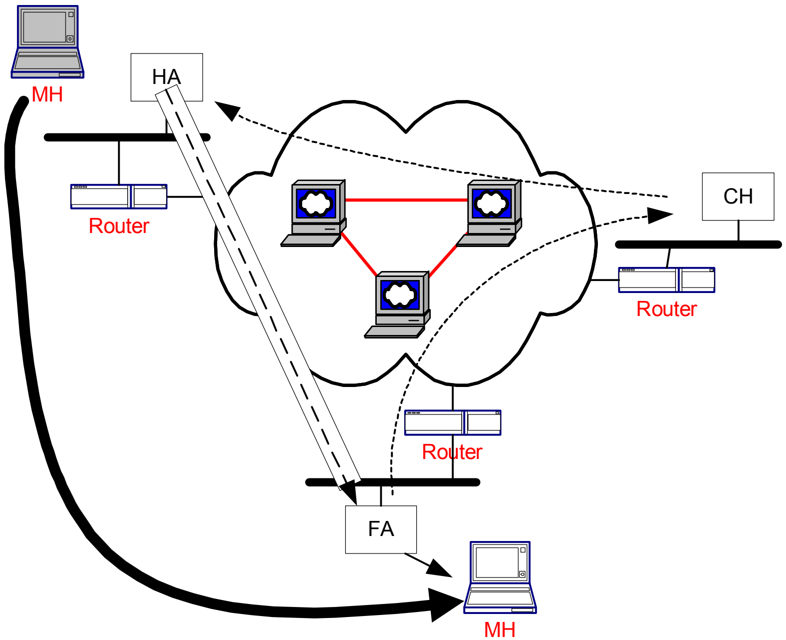


Network-layer mobility is solved by registering in a centralized database of location, LD, which also solves problems of authentication, accounting, and authorization of mobile users in the network. However, network delays, time for authentication, and handoff render the packet-forwarding model unusable for fast moving hosts

Related Research

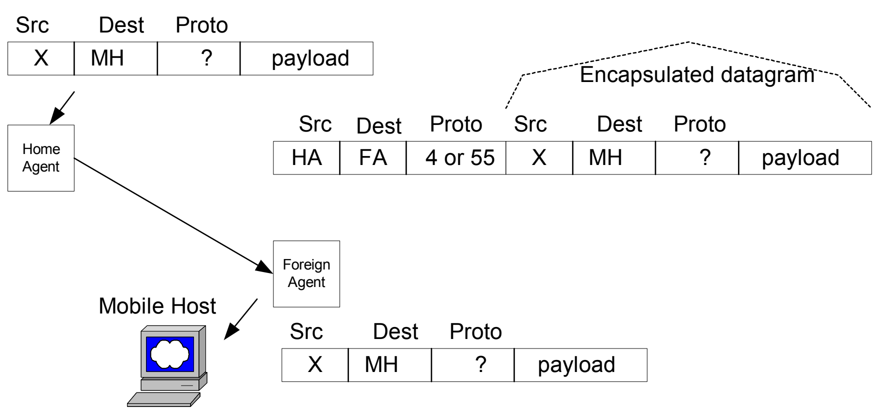
- Solutions to the problem of mobility
  - Macro-Mobility protocols
    - Mobile-IP
    - Hierarchical Mobile-IP (Hierarchical Foreign Agents)
  - Micro-Mobility protocols
    - Cellular-IP
    - HAWAII

Mobile-IP



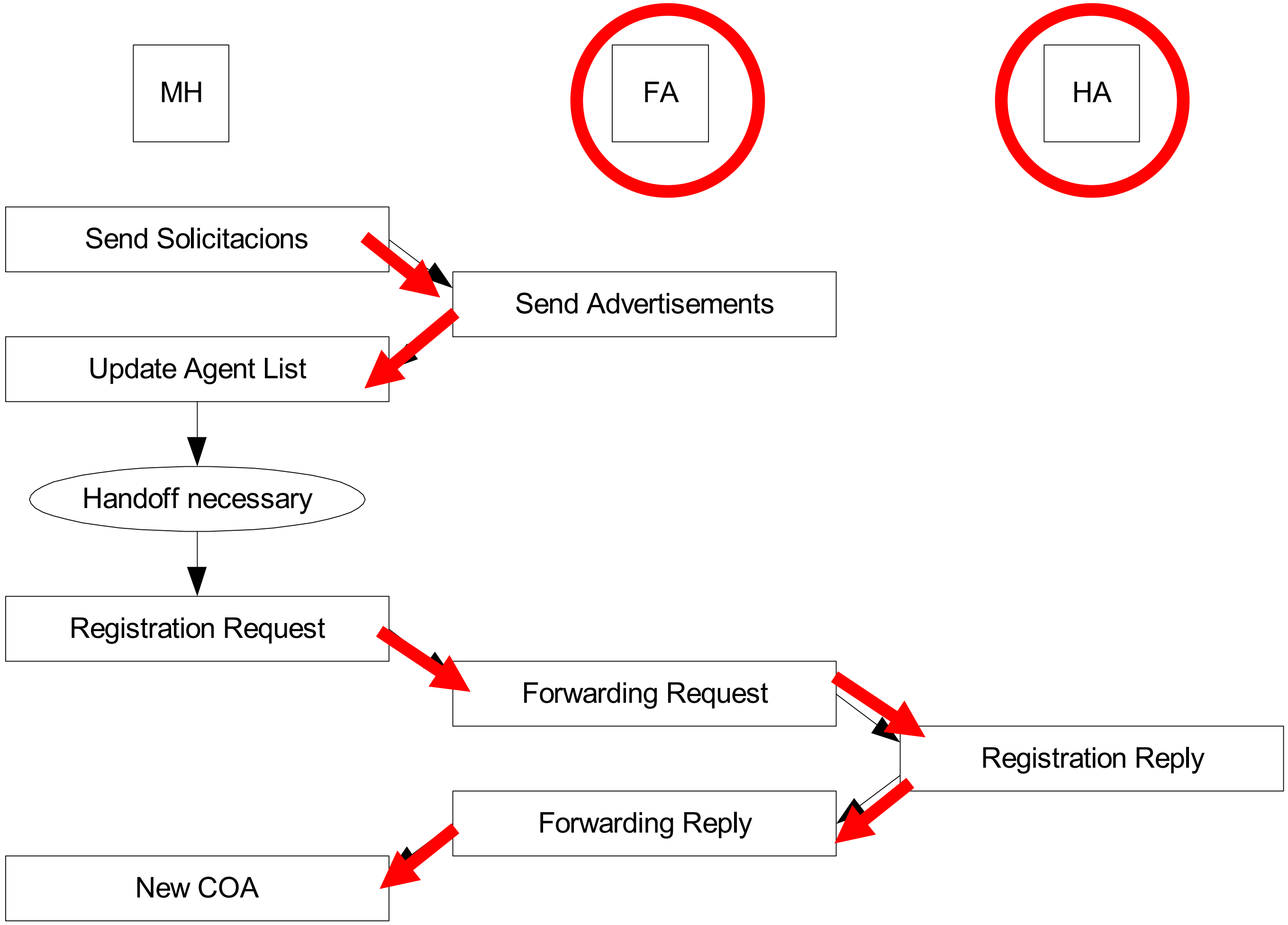
Triangular routing in Mobile-IP

- Mobile-IP follows the LD/FA model
- Encapsulation is required when packets are forwarded
- Mobile node acquires care-of-address thru DHCP.



- **Registration overhead of 1 sec.**

Handoff in Mobile-IP

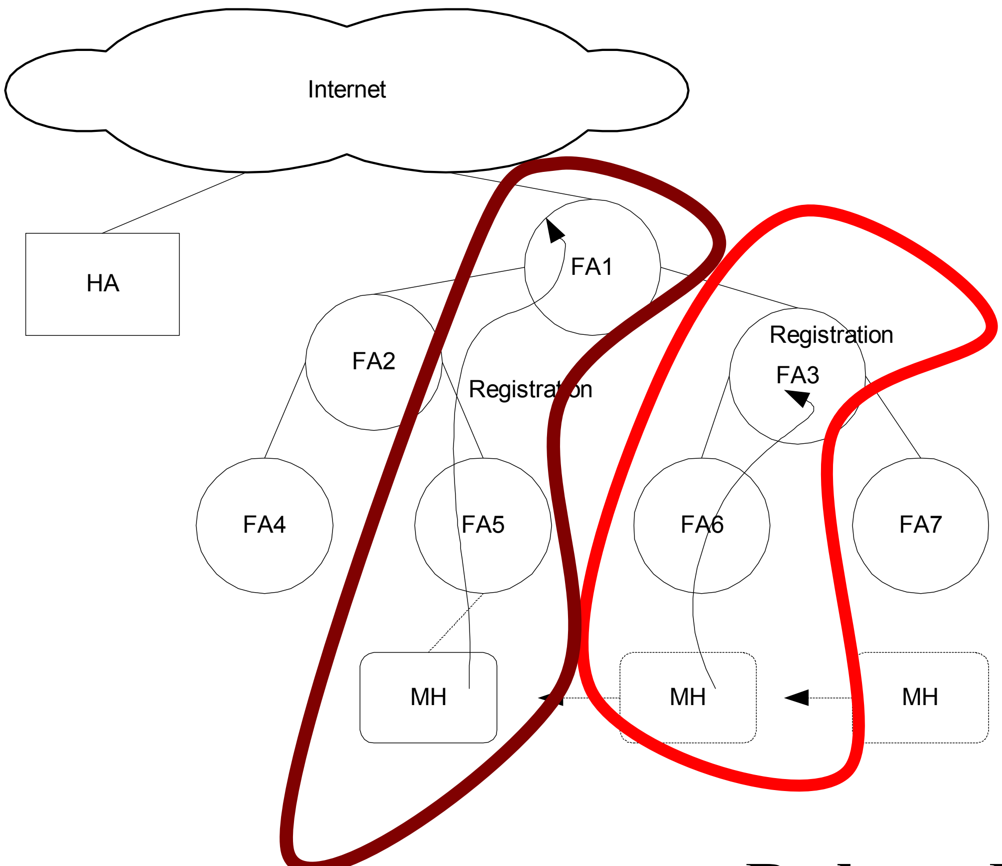


- **Handoff overhead >= Registration Overhead**
- **Handoff Impact = confuses TCP**

Reducing Registration Overhead

Hierarchical Foreign Agents

Early reaction of the research community



An FA includes in its Agent Advertisement message a vector of care-of-addresses, which are the IP address of all the ancestors in the tree as well as its own. By the time the MH arrives to a new cell, it makes an advance registration to the HA, the FA, and the ancestors of the FA.

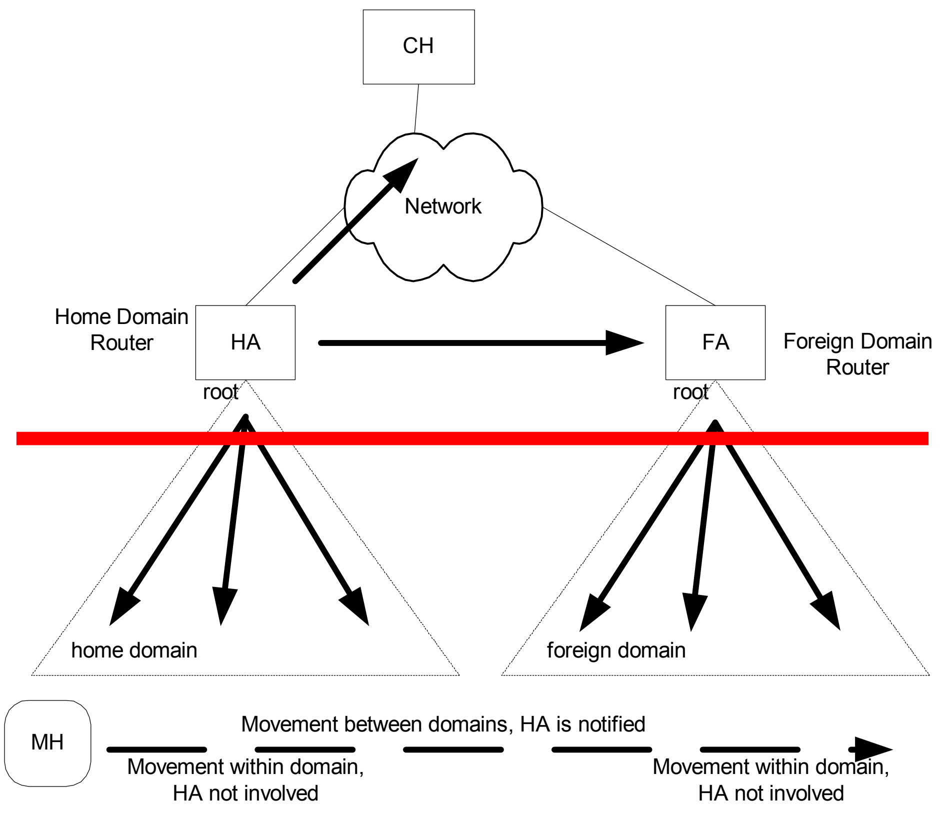
- **Reduces Registration Overhead**
- **Requires many wired-nodes/costly**

During handoff of HFA

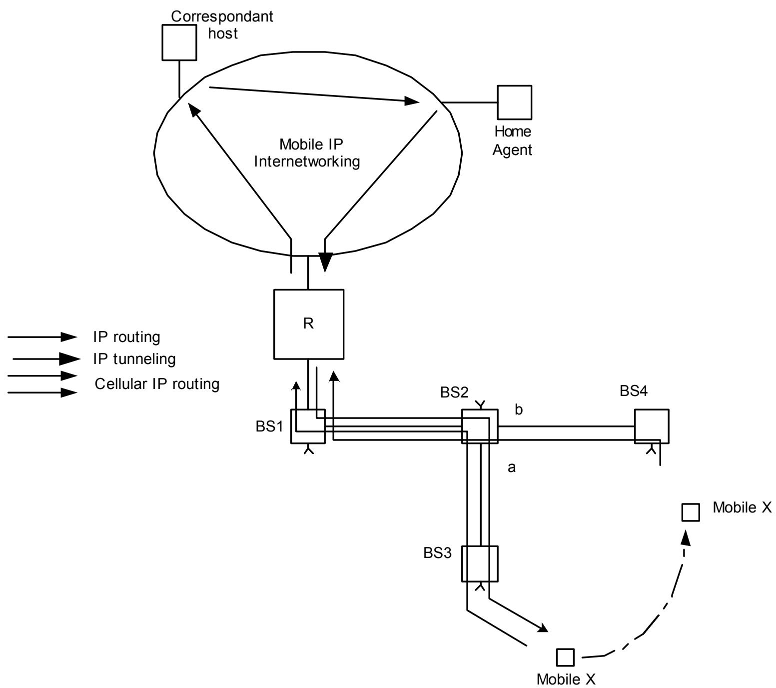
During Handoff, the MH compares the new vector of care-of-addresses with the old one. Again, it chooses the lowest level address of the FA that appears in both-vectors and sends a *Regional Registration Request,* which is processed by the FA. There is no need to notify any higher-level FA about this handoff since those FA already point to the proper location to where to tunnel the packets for the MH

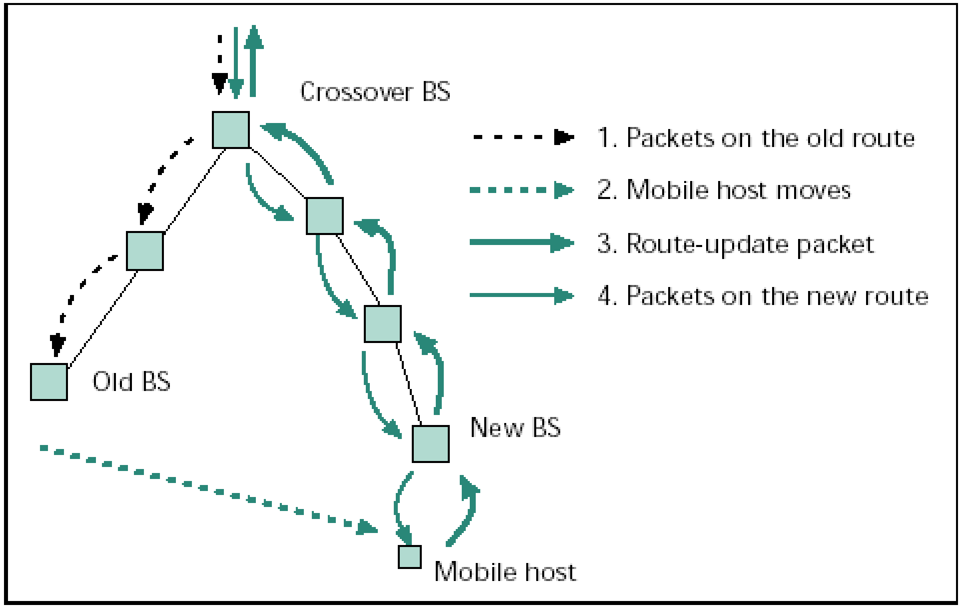
Micro-mobility Protocols

- 2-tier solution
- Micro-mobility model used by Cellular-IP and HAWAII [Camb00, Ramj00]
- Intra-domain handoff is handled by a signaling protocol while the inter-domain handoff is taken care by the Mobile-IP protocol



Cellular-IP

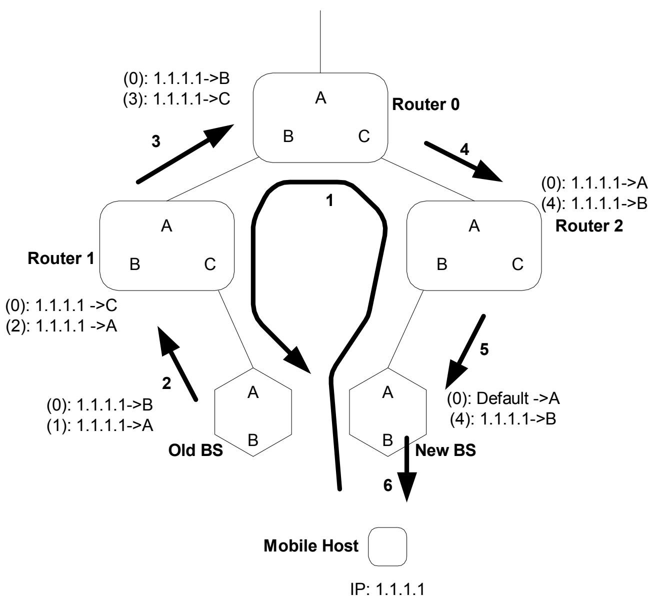




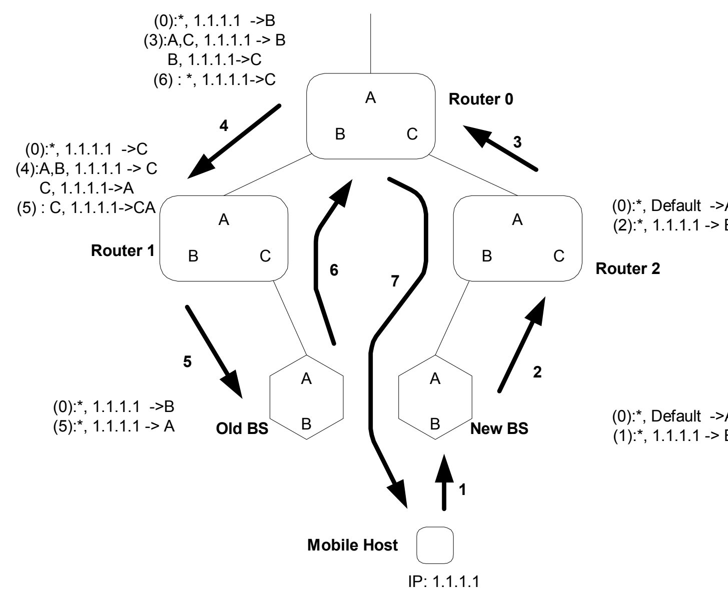
routing **handoff**

Layer-2/3 routing and handoff management, use of Signal strength and telephony-like signaling for paging and handoff management.

HAWAII: *Handoff-Aware Wireless Access Internet Infrastructure*



(a) MSF (Multiple Stream Forwarding)

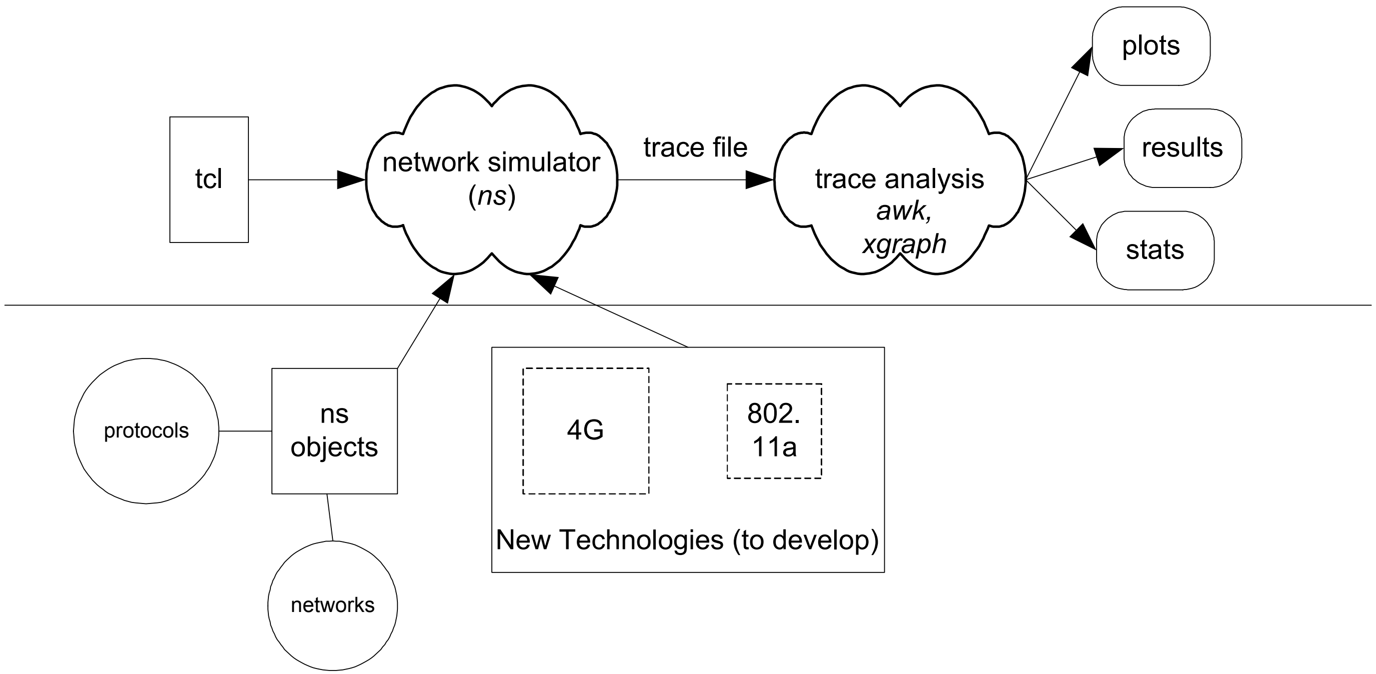


(b) SSF (Single Steam Forwarding)

A closer look to Micro-mobility

- Signaling protocols based on telephony standards.
- Avoid Mobile-IP for handoff
- Costly implementation for a wide-spread area, e.g. train track, tied to speed. Requires the modification of intermediate routers and network infrastructure.
- The packet loss can be described by $r \times T_{hoff}$, where r is the rate and T_{hoff} represents the amount of time to reach the cross-over router from the MH.
- Our research re-examined the performance of Macro- and Micro-mobility protocols in a simulation environment.

Network Simulator (*ns*)

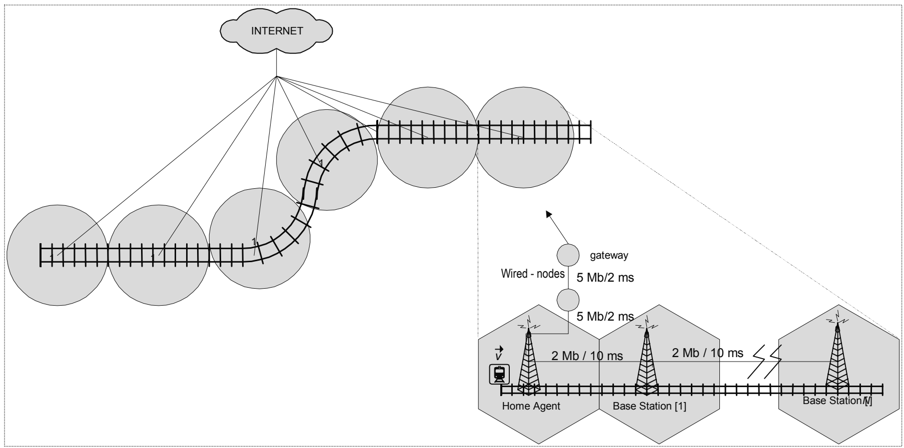


- The *ns* network simulator – Berkeley [Fall00]
- tcl/c++ object oriented, 20 Mbytes of code, wired and wireless network protocols

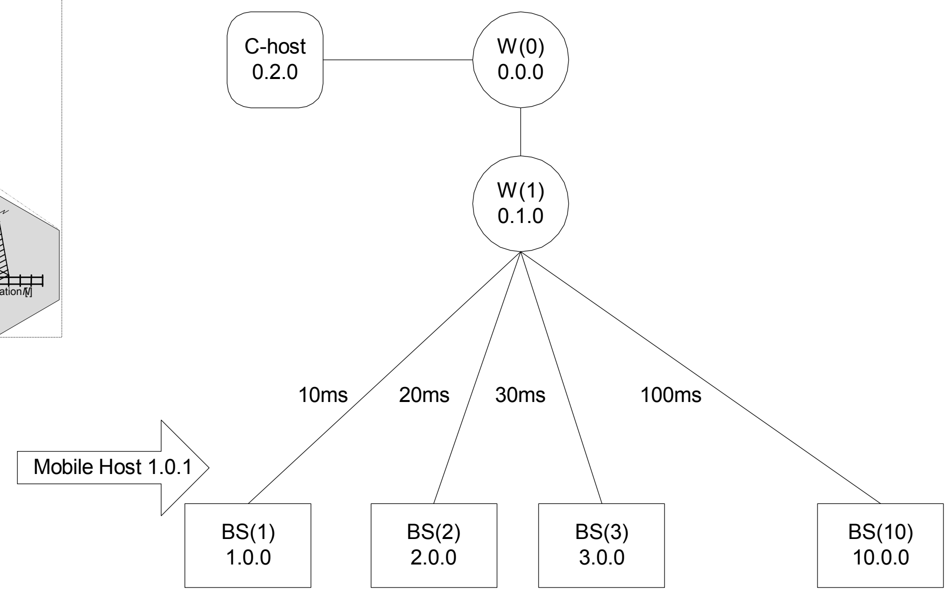
PERFORMANCE OF MACRO- AND MICRO-MOBILITY PROTOCOLS IN A RAPID MOBILE ENVIRONMENT

- Two simulation scenarios were used:
  - Mobile-IP original Berkeley/CMU implementation
  - Columbia University micro-mobility suite
- Results for Macro-mobility protocols were published in LCN 2001.
  - E. Hernandez and A. Helal, "*Examining Mobile-IP Performance in Rapidly Mobile Environments: The Case of a Commuter Train*," LCN 2001, Tampa, FL, Nov 14-16, 2001
  - E. Hernandez and A. Helal "*RAMON: a network emulation testbed*", submitted to Wireless Systems and and Mobile Computing Journal, Wiley & Son's.

ns simulation scenarios

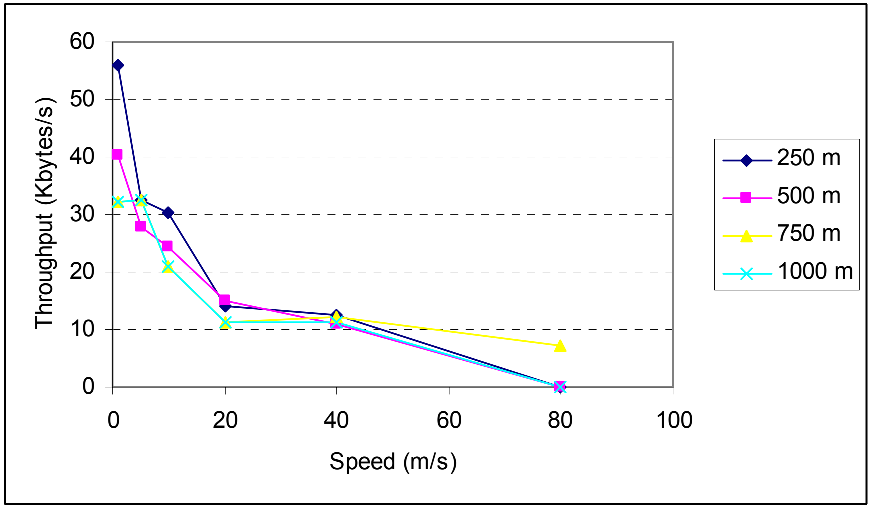


(a) Real track

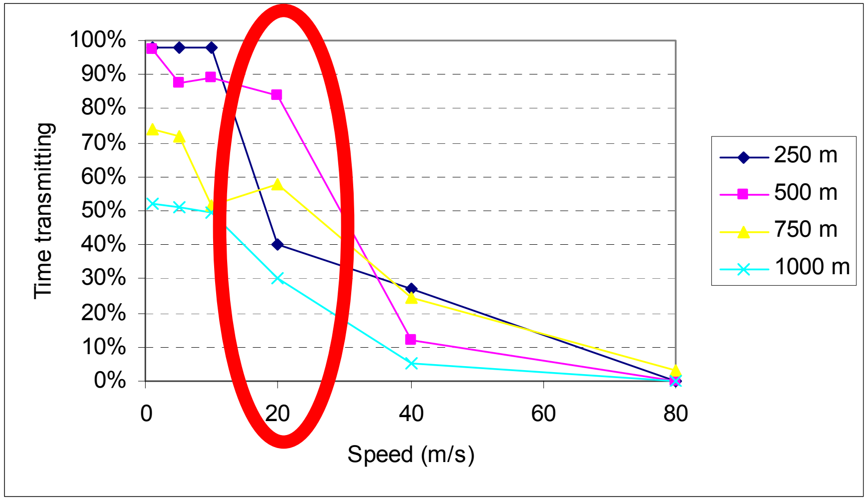


(b) *ns* scenario

Performance of Mobile-IP for TCP transmissions (FTP)



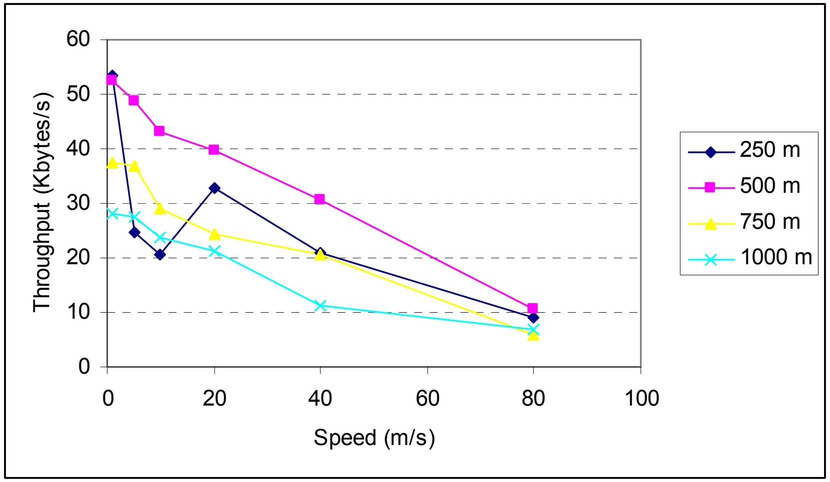
(a) Average throughput

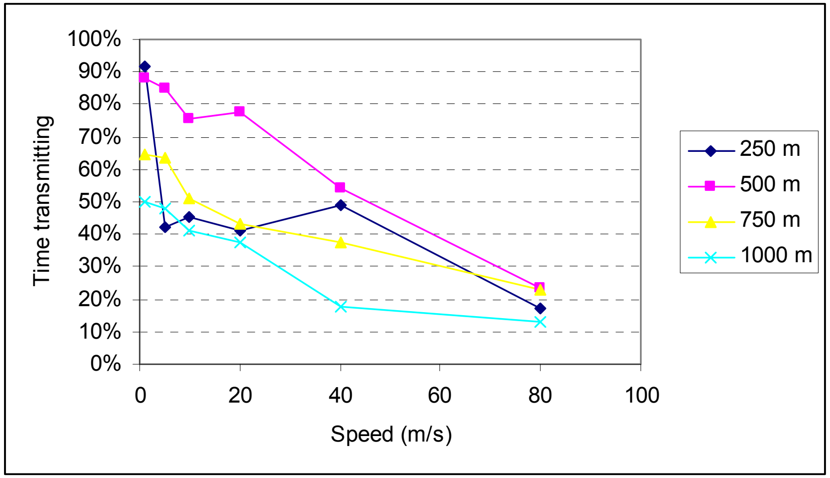


(b) Percentage of usable time (not in handoff)

***ns*-2 simulation. [Hern01]**

Performance of Mobile-IP for UDP transmissions

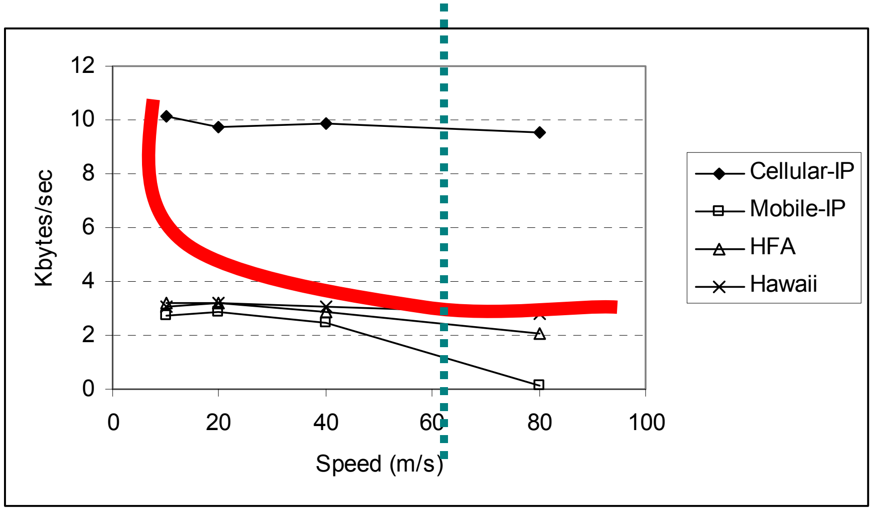




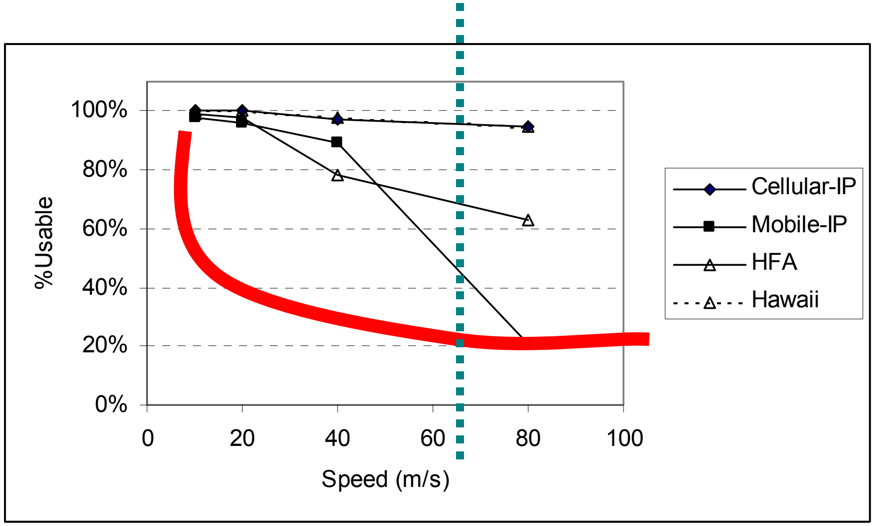
(a) Average throughput	(b) Percentage of usable time (not in handoff)

***ns*-2 simulation. [Hern01]**

Performance of TCP/FTP transmissions macro/micro-mobility



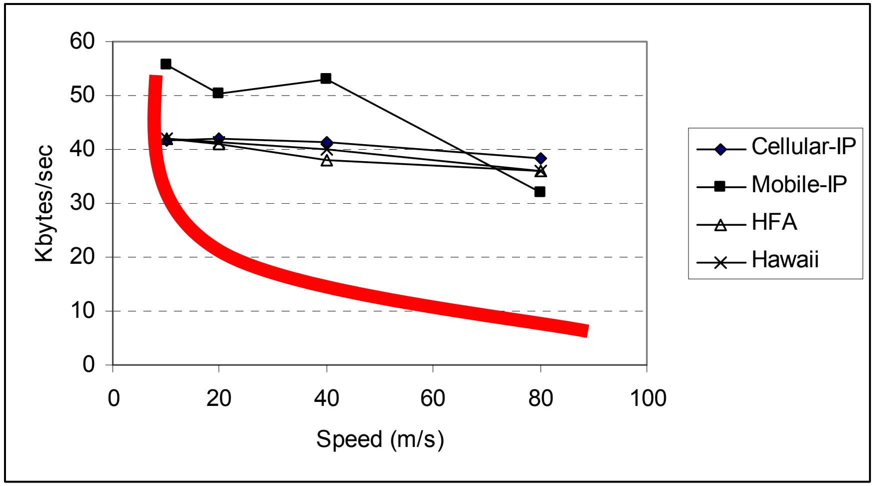
(a) Average Throughput



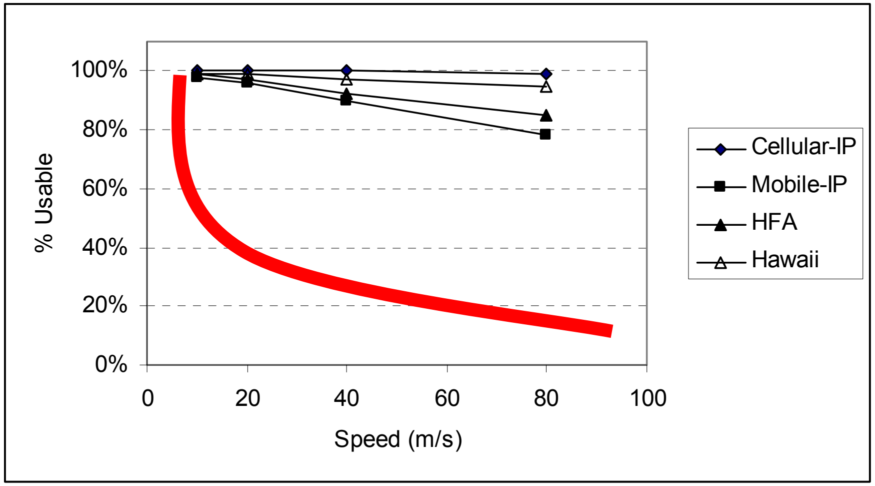
(b) Percentage of usable time

***ns-2* Columbia micro-mobility suite**

Performance of UDP transmissions with macro/micro mobility



(a) Average Throughput



(b) Percentage of usable time

ns-2 **Columbia micro-mobility suite**

Problems with the simulations

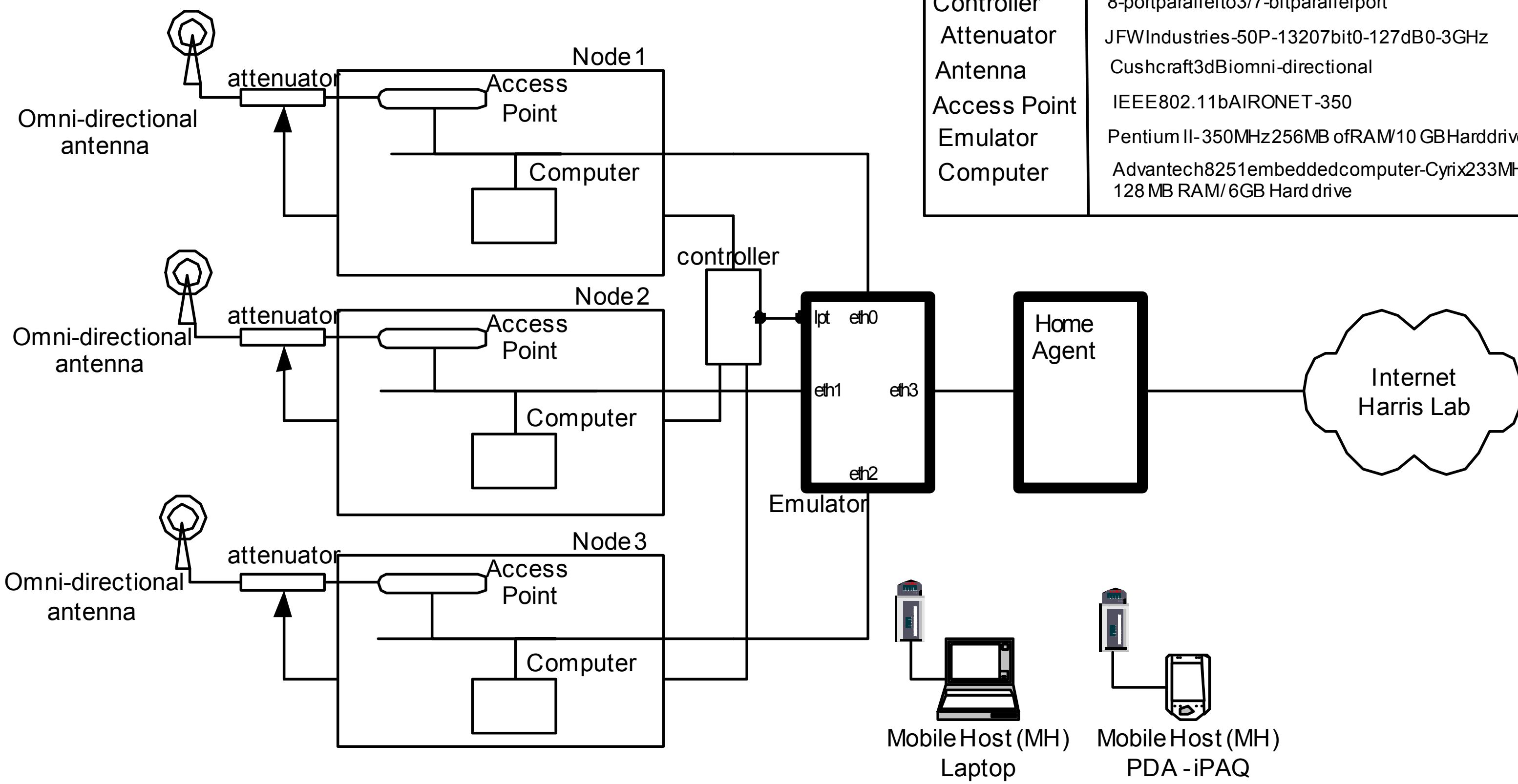
- Columbia uses the NOAH (non-adhoc agent) developed by Widmer [Wid00] as an extension for *ns*
- The NOAH agent has a simplified version of propagation model.
- The NOAH agent has a "improved" handoff mechanism and assumes GPS information
  - NOAH->getX() and NOAH->getY( ) methods
  - Mobile-IP with NOAH outperforms its predecessor.
- It's hard coded the bandwidth at 2Mb/s and difficult to change in the simulator.
- Simulator code is more than 20 Mbytes, why not implement it directly on a testbed?

RAMON : A network emulation approach

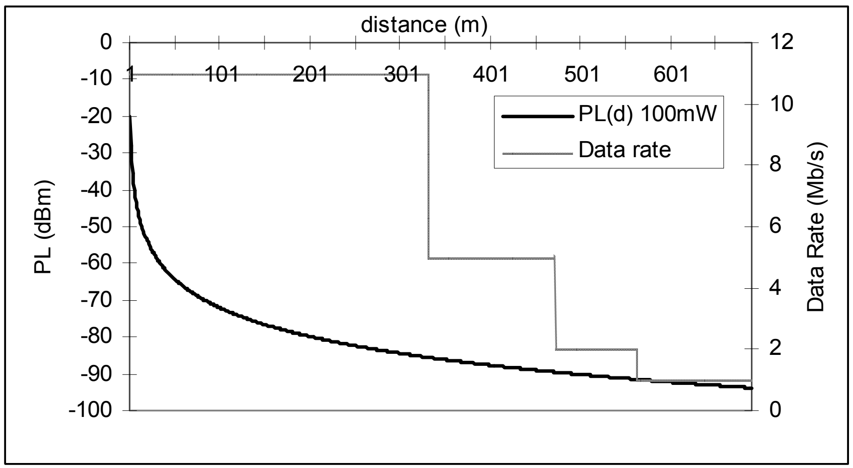
- Criticism of network simulation approaches [Paw02]
- Attenuators used to emulate velocity and handoff
- Real implementation and code-extensions made to **real mobility agents**
- Network emulation language to facilitate, academic and network-engineering work.
- *ns* scripts can be parsed and emulated with minor modifications.
- Applications can be tested in rapid mobility conditions

RAMON: The architecture

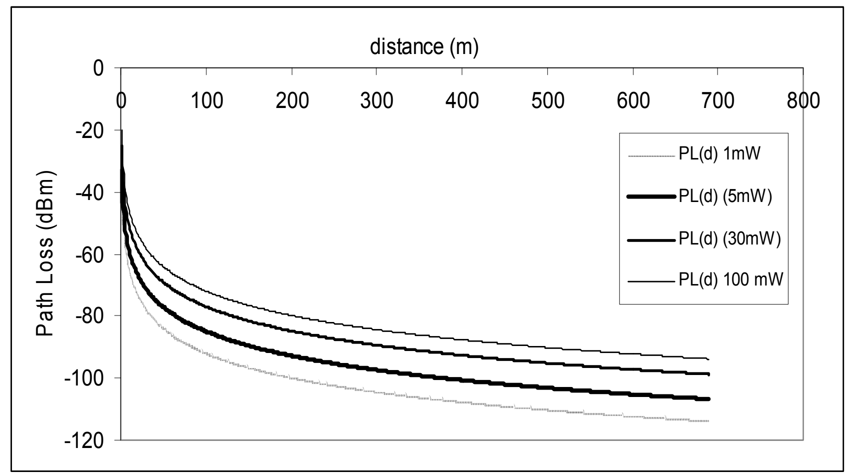
item	description
Controller	8-port parallel to 3/7-bit parallel port
Attenuator	JFW Industries-50P-1320 7bit 0-127dB 0-3GHz
Antenna	Cushcraft 3dBi omni-directional
Access Point	IEEE802.11b AIRONET-350
Emulator	Pentium II-350MHz 256MB of RAM/10 GB Harddrive
Computer	Advantech 8251 embedded computer-Cyrix 233MHz, 128 MB RAM/ 6GB Hard drive



Path loss attenuation and data rates with 802.11b access points



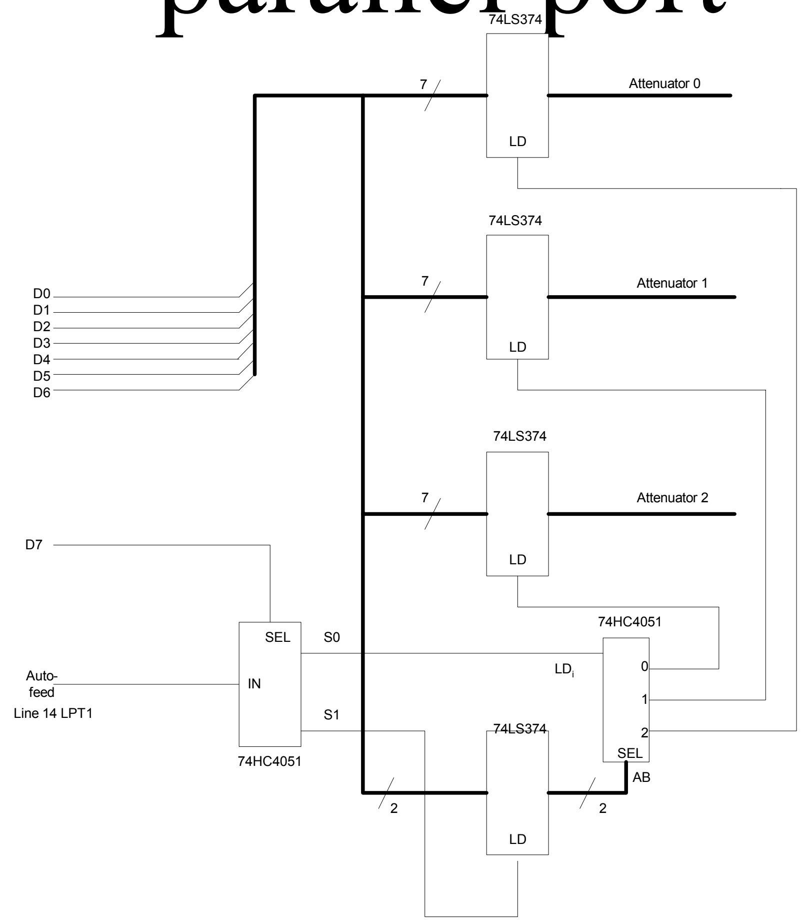
(a) Path loss and data rate for Cisco AP-350



(b) Path loss equations at different transmission power levels (n=2.5)

- **It's necessary two provide actual bandwidth to accurately estimate and reflect the effects of speed and handoff on network cards**

Attenuation Control with the parallel port



Pseudo Code

WriteLPT1(0xxx xxABb); // Select Attenuator <AB> address

WriteLPT1(1xxx xxxxb); // Write data to the attenuator

Emulation of speed

Path Loss Equation: $PL_{recv} = P_{tx} - P(d_o) - 10n\log(\frac{d}{d_o})$

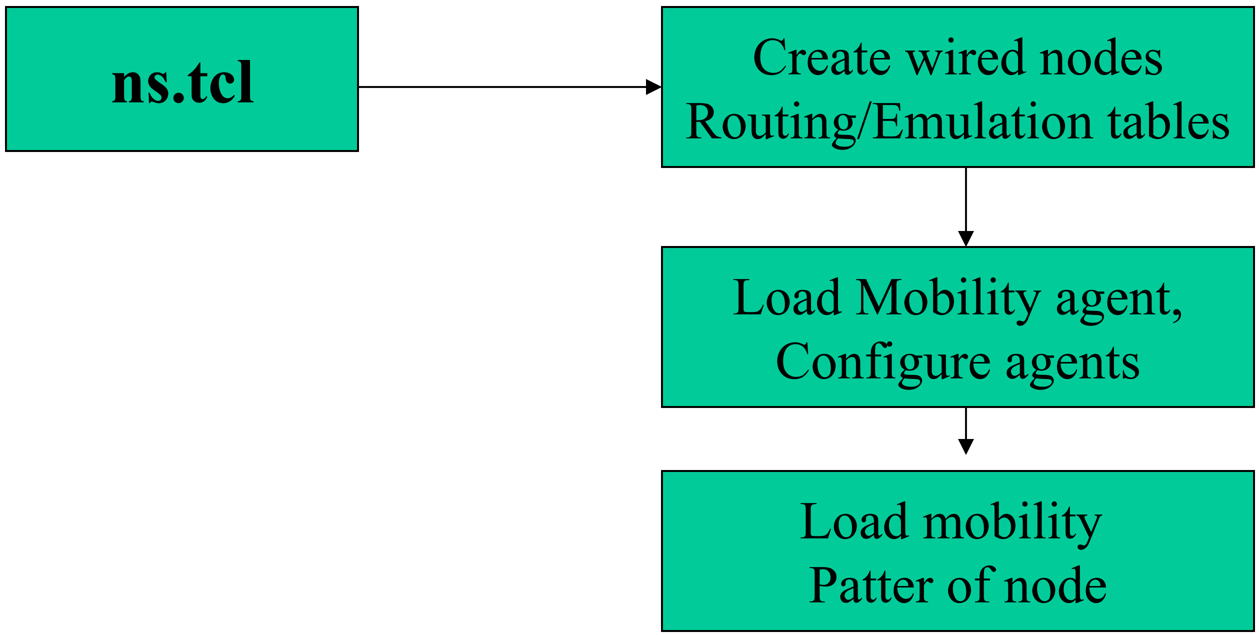
Scenario	Attenuator 0	Attenuator 1	Attenuator 2
No connectivity	-127 dB	-127 dB	-127dB
One cell	0 dB <set < -80 dB	-127 dB	-127dB
Two overlapped cells	0 dB < set < -80 dB	0 dB < set < -80 dB	-127 dB
Three overlapped cells	0 dB < set < -80 dB	0 dB < set < -80 dB	0 dB < set < -80 dB

RAMON emulation language

ns script	Emulation script	Description
`$BS X_` `$BS Y_`	`$BS` *`name`* `X=` `$BS` *`name`* `Y=`	Sets the coordinates of the Base-station
`set BS [$ns node IP]`	`$BS` *`name`* `IP=`	Sets an IP Address for the base-station
`set power 0.289`	`$BS` *`name`* `power=xxx`	The power level in mW in the access-point
`Set HA… /FA…`	`$HA` *`name`* `IP` `$FA` *`name`* `IP`	Sets the HA/FA at an IP address
`set mobile-ip 1`	`$protocol=”MIP“`	The protocol being used
`set wiredNode [$ns node $IP]`	`$WiredNode name` IP_1 IP_2 IP_3	Creates a Wired Node with three interfaces.
`$ns duplex-link $node1 $node2 $bw $latency DropTail`	`$Link` IP_1 IP_2 `bw latency`	Creates a Link between two interfaces using certain bandwidth and latency values
`$ns at $time [$MH etdest x y speed]`	`$MH time x y speed`	Sets the destination position and speed of mobile host. Acceleration = 0.
`$ns at $time start`	`-`	Starts after it’s called
`$ns at $time end`	`$end time`	End of the emulation
`$set opt(prop) Propagation/TwoRayGround`	`$Propagation=”TwoRayGround” |”PathLoss”|any other.`	Sets the propagation model being used.
`N/A`	`$granularity X`	Updates attenuation and speed every X ms

Convert an *ns* script into emulation code

Platform commands




```
$route – add …
$cnistnet –a ….
$fa @ IP…
$ifconfig –eth0:1..
$start attenuators
```

$load pattern

Go emulation!

Goal : Process a modified version of an *ns* script and generate the emulation environment

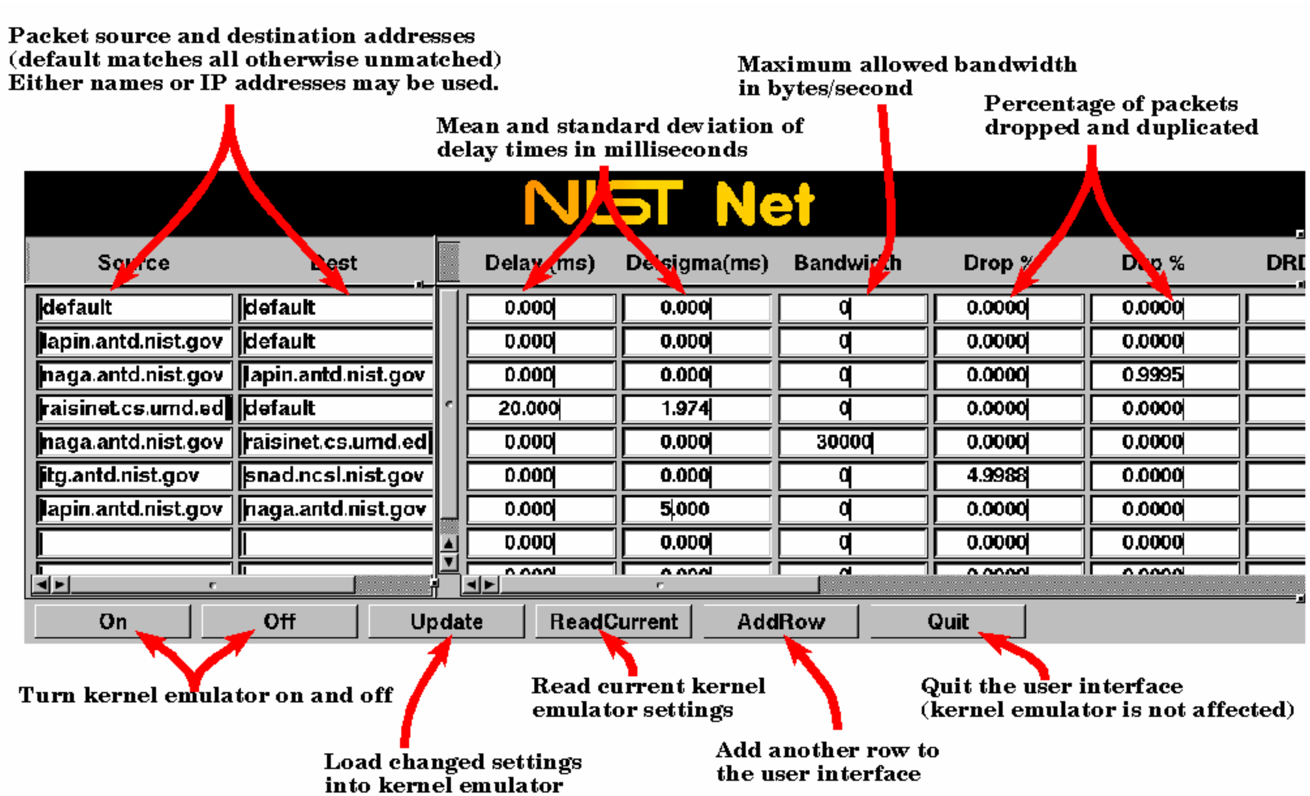
Sample Emulation Script

```
$WiredNode node1  192.168.1.1 192.168.2.1 192.168.3.1
$WiredNode node2  192.168.2.2 192.168.4.1 192.168.5.1
$Link 192.168.2.2 192.168.2.1 10Mb 20ms
$Link 192.168.1.1 128.227.127.11  10Mb 1ms
….
$BS node7 X=250  Y=250  power=20dBm  IP=192.168.7.1
$BS node8 X=750  Y=250  power=20dBm  IP=192.168.8.1
$BS node9 X=1250 Y=250  power=20dBm  IP=192.168.9.1
$BS node10 X=1750 Y=250 power=20dBm  IP=192.168.10.1
$BS node11 X=2250 Y=250 power=20dBm  IP=192.168.11.1
…
$MH 0  1000 250 20m/s
$start 10s
$end-time 1500s
$Propagation=”PathLoss”
$Protocol “MIP”
```

Emulation Code

- Emulation(*MH, granularity*)
- *initializeResources( )*
- *DetermineRoutes(route[][], time_end[], trajectory(MH));*
- **while** *timer() > end_simulation*
- **do**
- **if** *timer>=timer_end[k]*
- **then** *k++*
- *createRoute(route[k][1..3], time_end[k]);*
- *expireRoute(route[k-1][1..3])*
- *emulateMovement(granularity, MH)*
- **return**

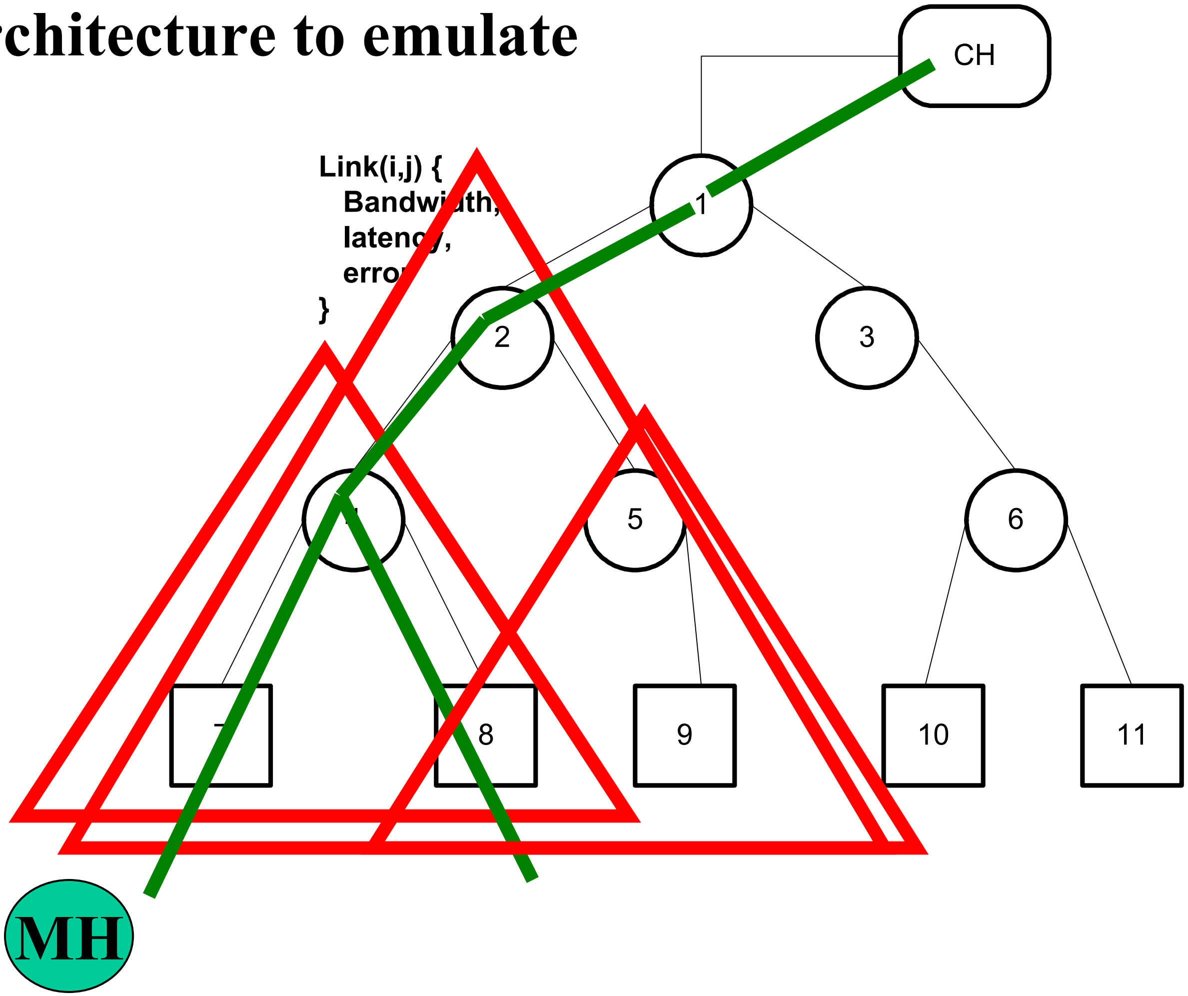
NistNET emulator for wired networks



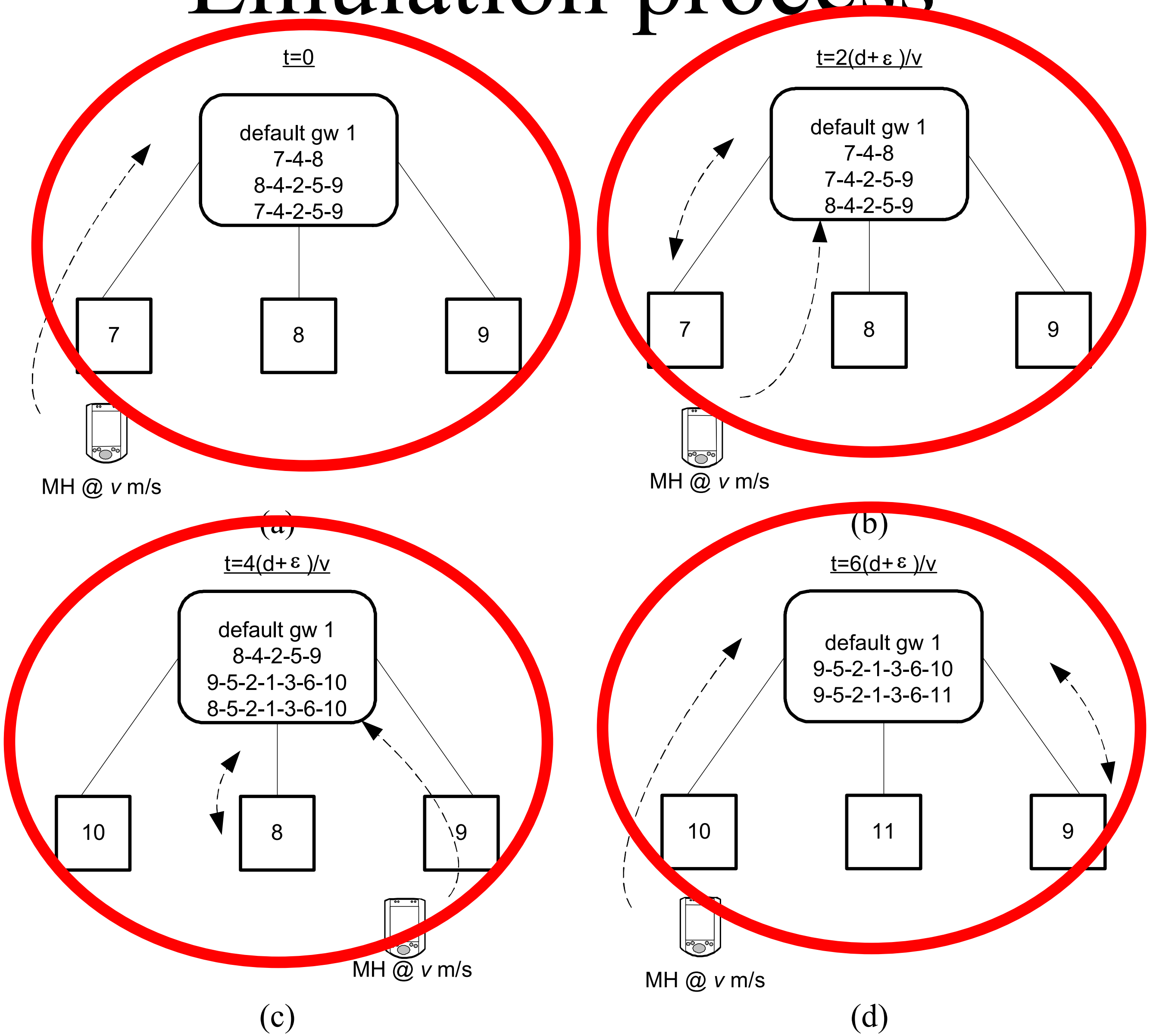
- Wired network emulation required for academic and network engineering of rapidly mobile networks with may service providers and heterogeneous networks.

Example

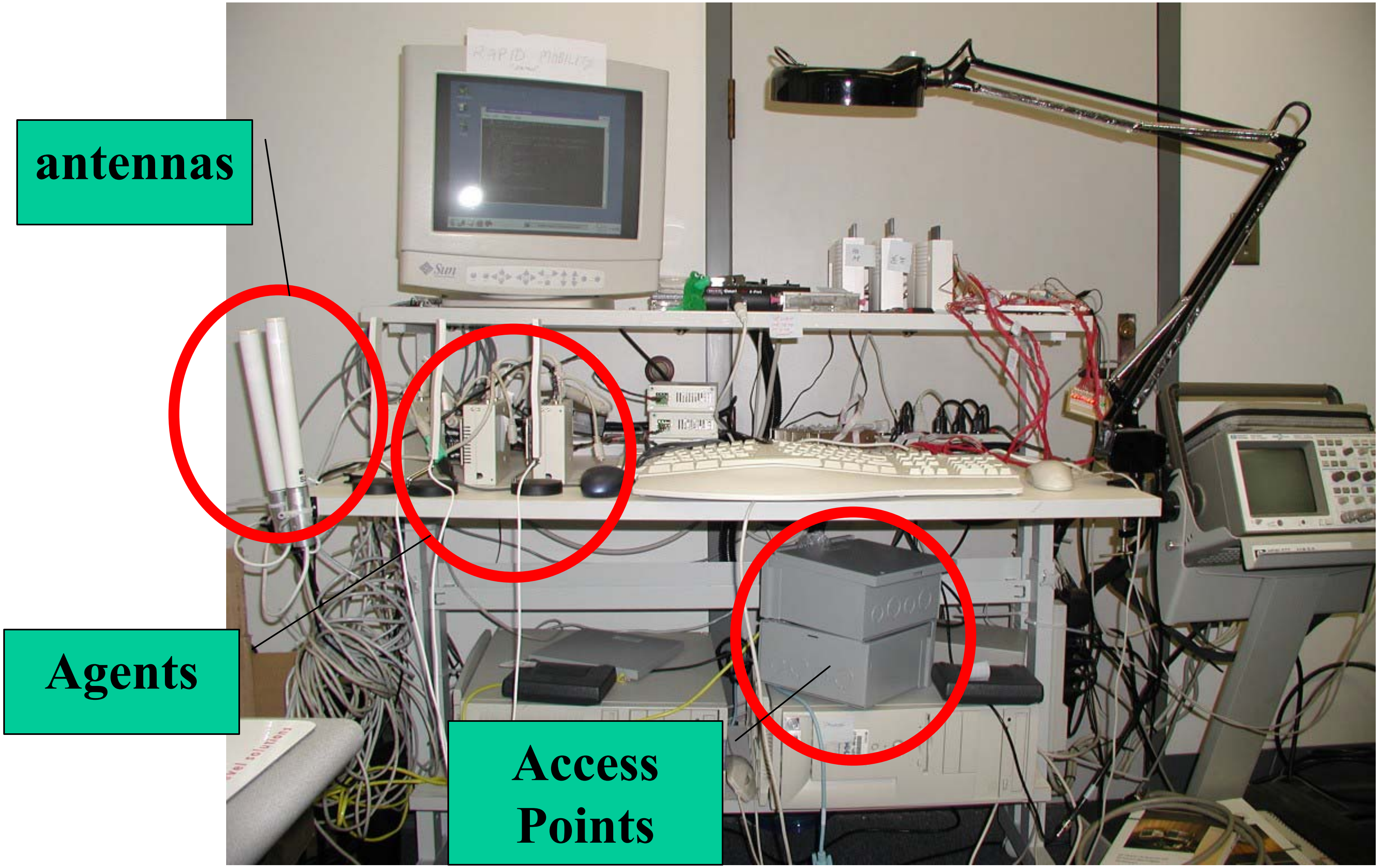
Architecture to emulate



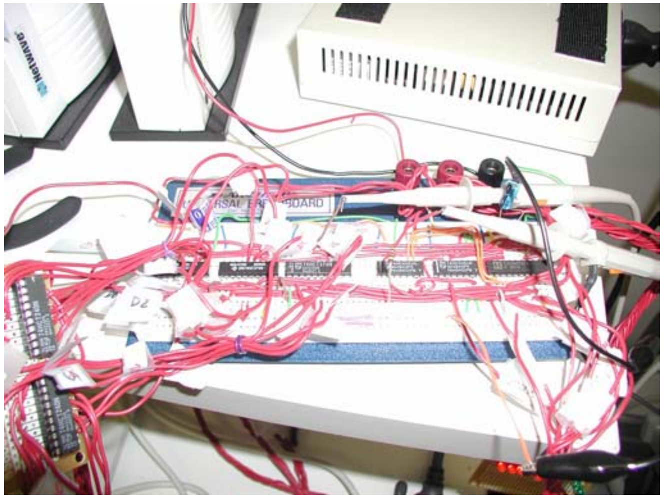
Emulation process



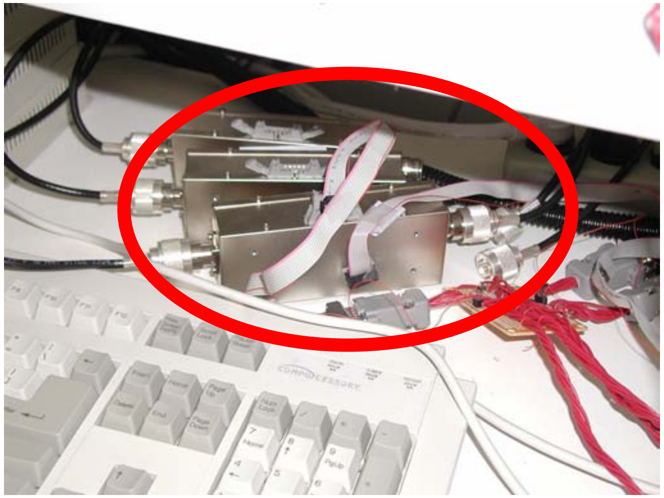
Implementation of RAMON



Programmable Attenuators

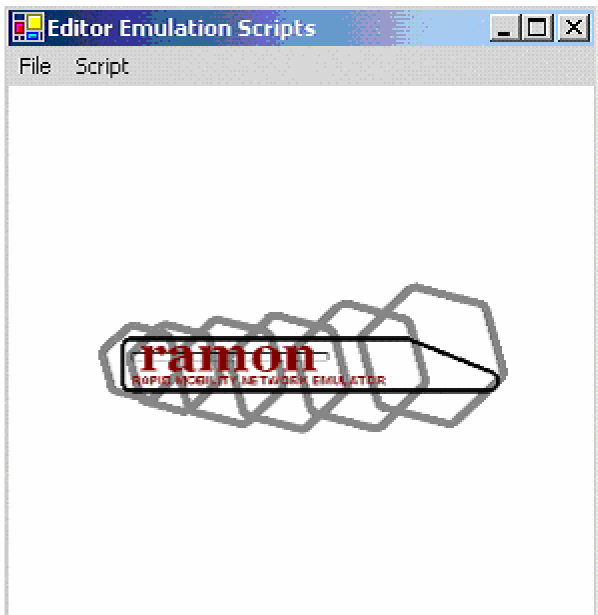


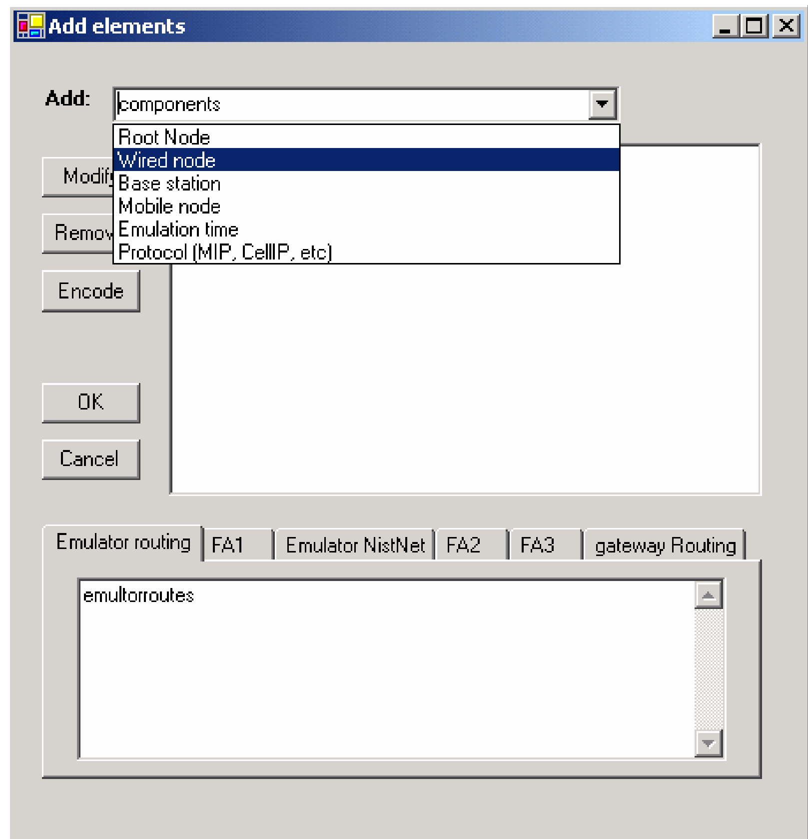
Controller for attenuator



Attenuators

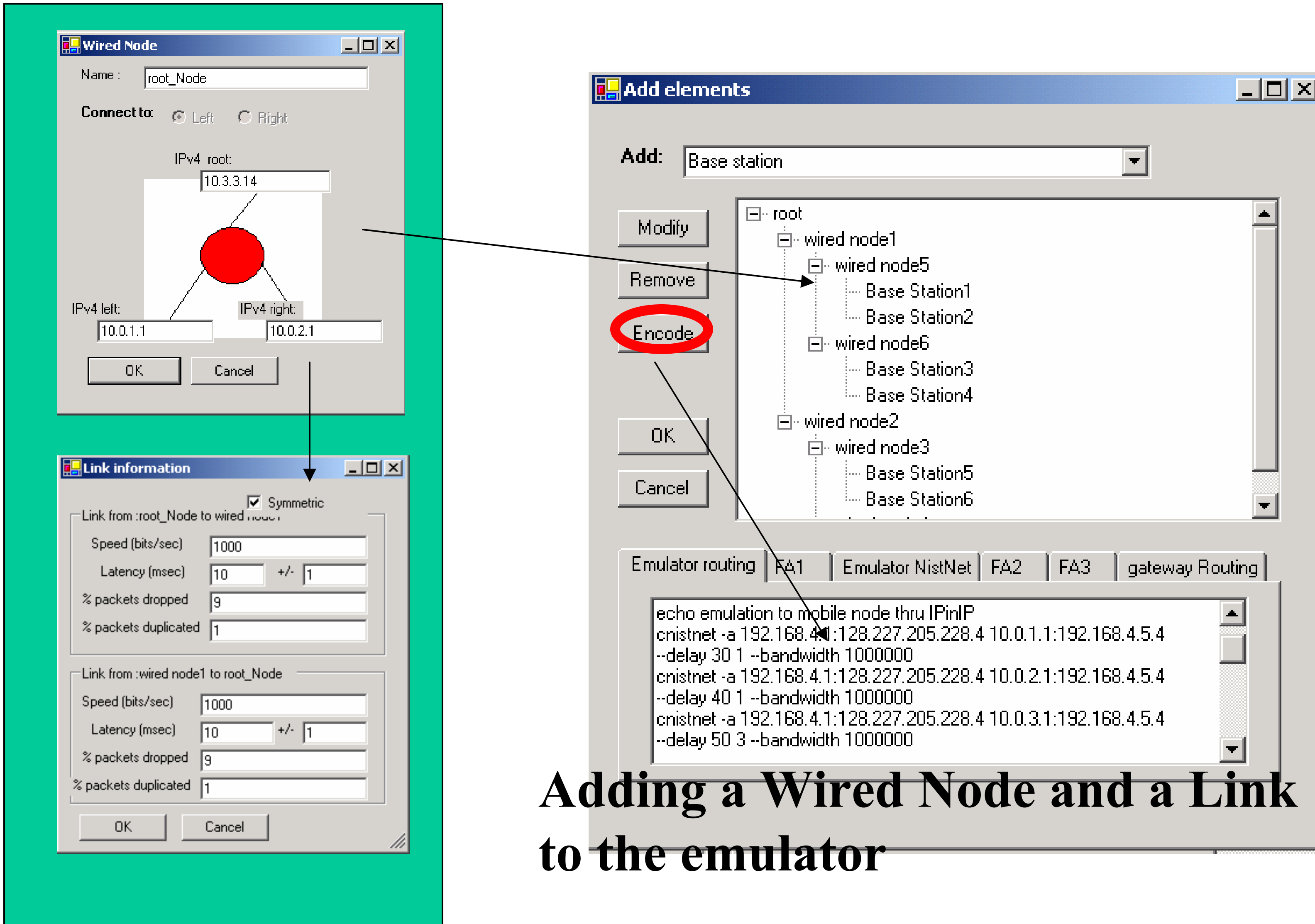
Graphical User Interface for RAMON





- **Application in C# and .NET WinForms**
- **Easy to deploy as a web-service in the future.**
- **Remote experimentation can be available**

GUI for RAMON



Adding a Wired Node and a Link to the emulator

Performance of Mobile-IP in RAMON

$$A(d) = \begin{cases} 0, & d \le R/100 \quad d >= 1.2R \\ 10 + n\log(d), & R/100 < d \le 0.9R \\ 20 + 10(n+1.3)\log(d), & d > 0.9R \end{cases} \qquad \textbf{(1)}$$

$$A(d) = \begin{cases} 0 & 0 \le d \le 0.9R \\ 128 & d > 0.9R \end{cases} \qquad \textbf{(2)}$$

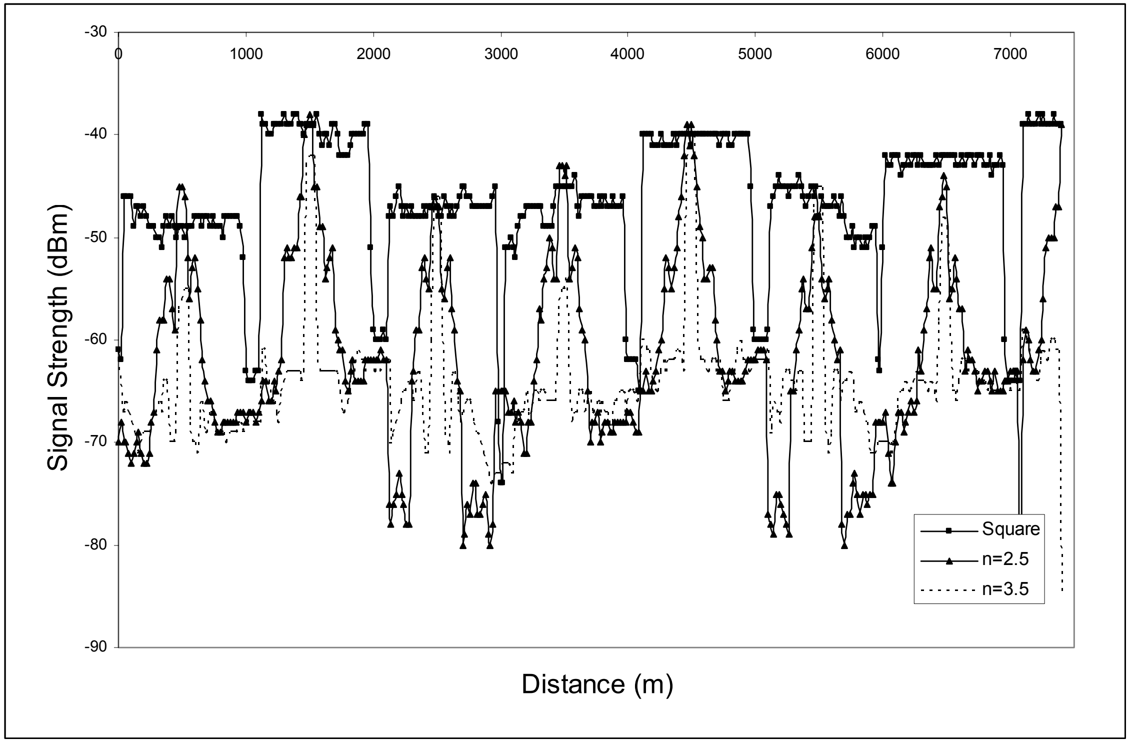
- Attenuation equations (1) gradual path loss equation and (2) square function

Testbed conditions

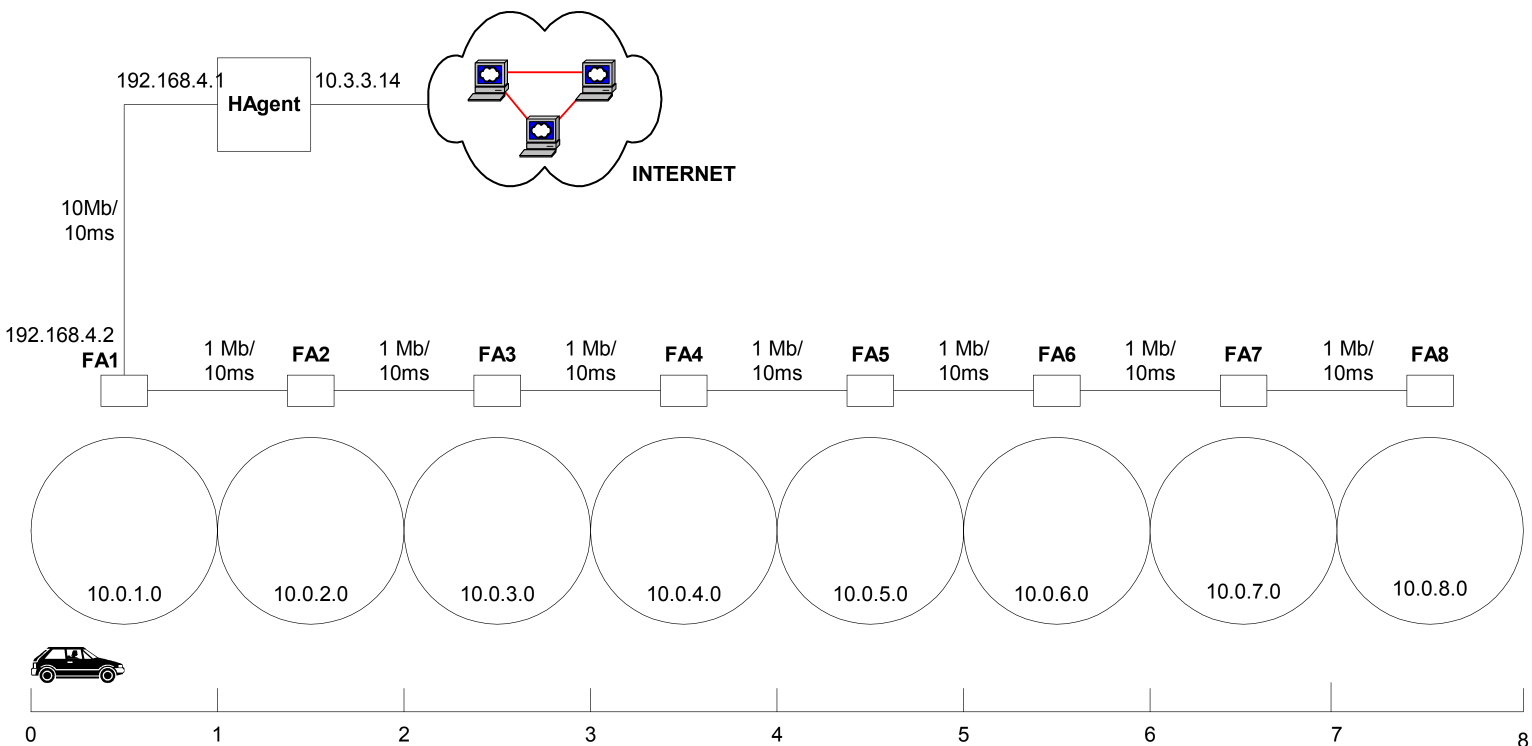
- RAMON testbed
- Emulation scripts created with the tool and verified by hand.
- Dynamics Mobile-IP implementation, agent advertisement = 1 sec, hierarchical Mobile-IP, LFA and HFA required.
- Attenuators required of a special script to be turned off and eliminate the effect of the leaked signal.
- MAC handoff and roaming is within same domain.
- Handoff is not forced to the network card at the mobile node.

Experimental Results

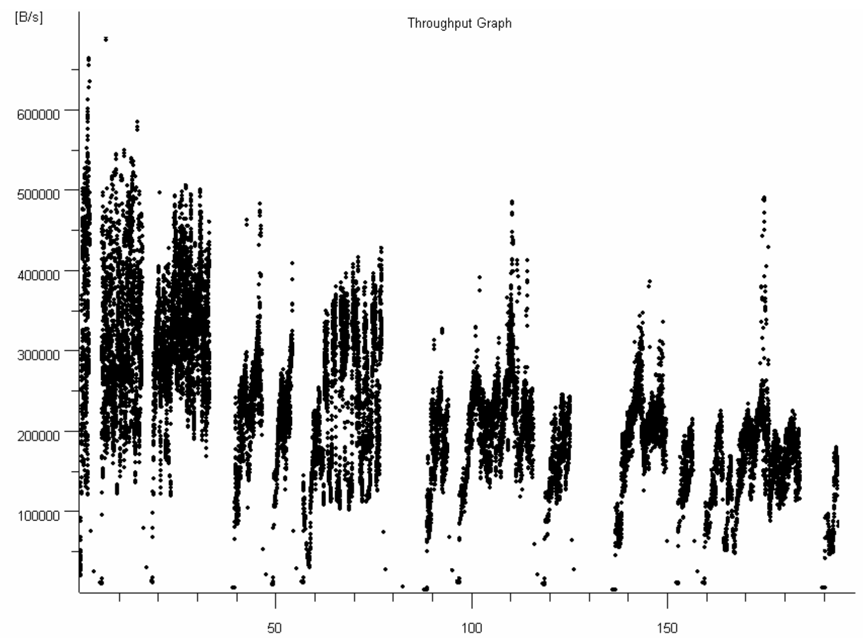
- Signal strength measured with different values of *n*

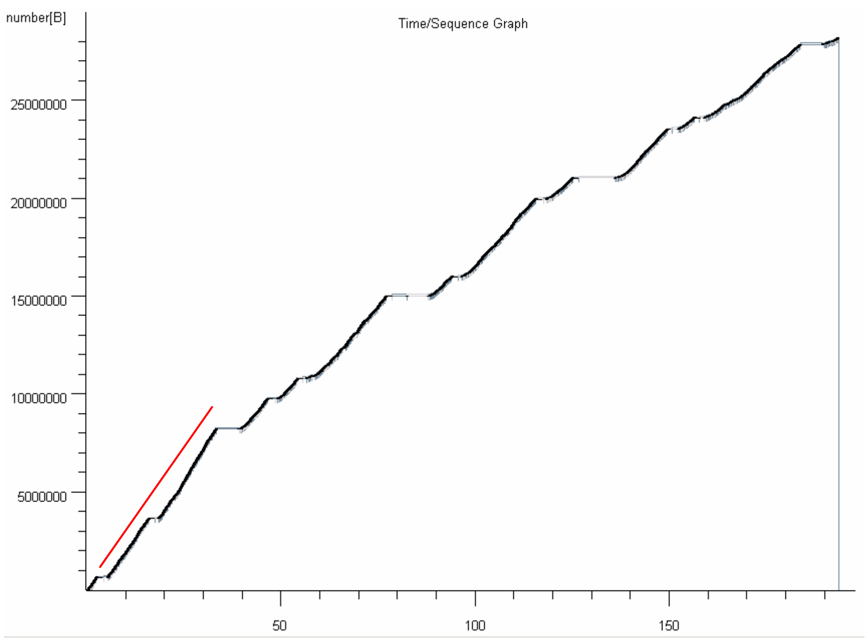


Emulation scenario

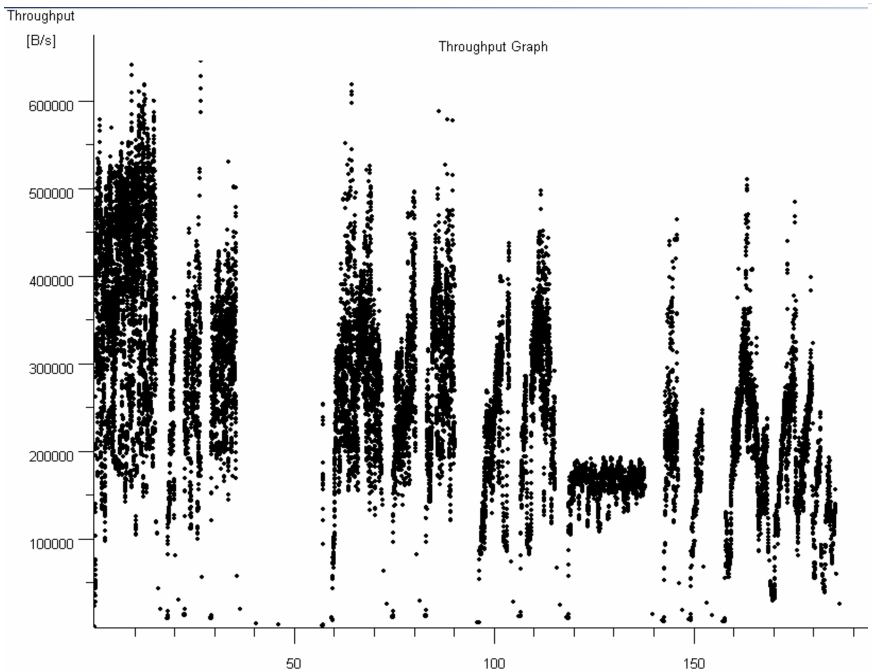


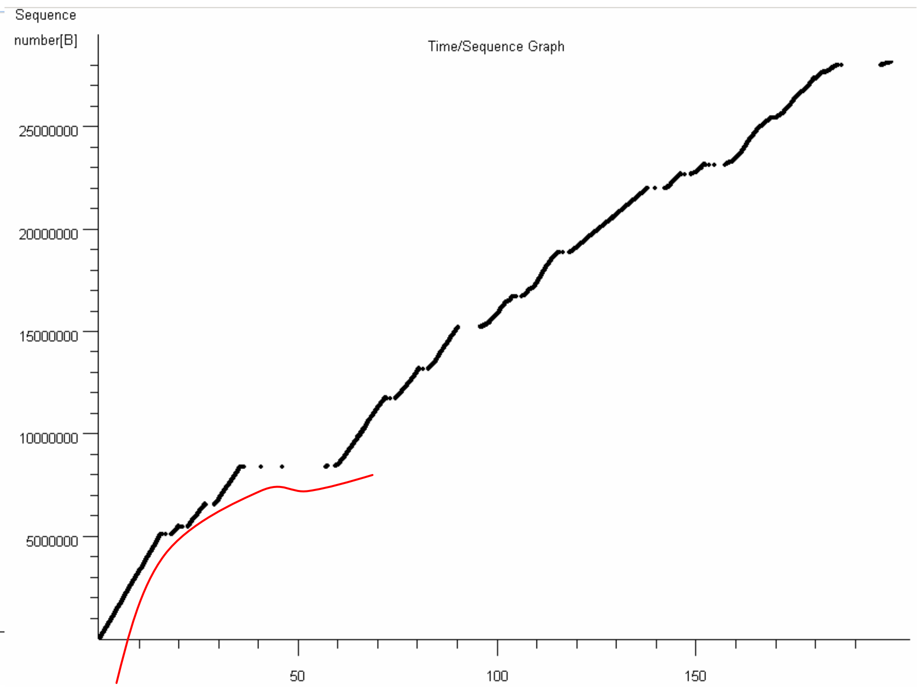
Throughput and TCP sequence numbers plot at 20 m/s (squared attenuation function)





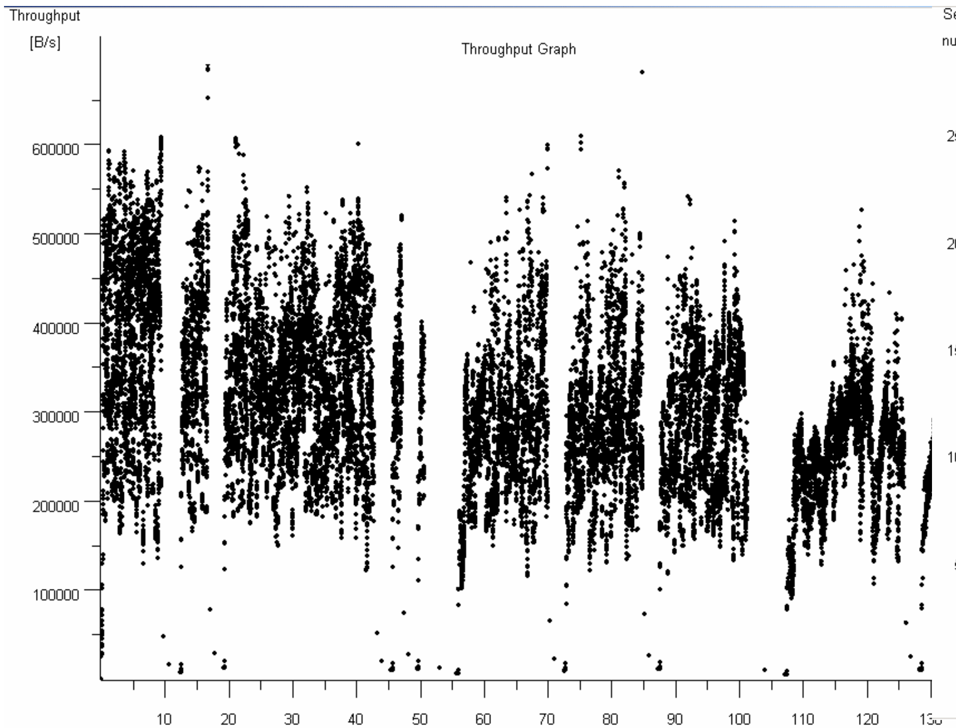
Throughput and TCP sequence numbers (n=2.5) at 20m/s

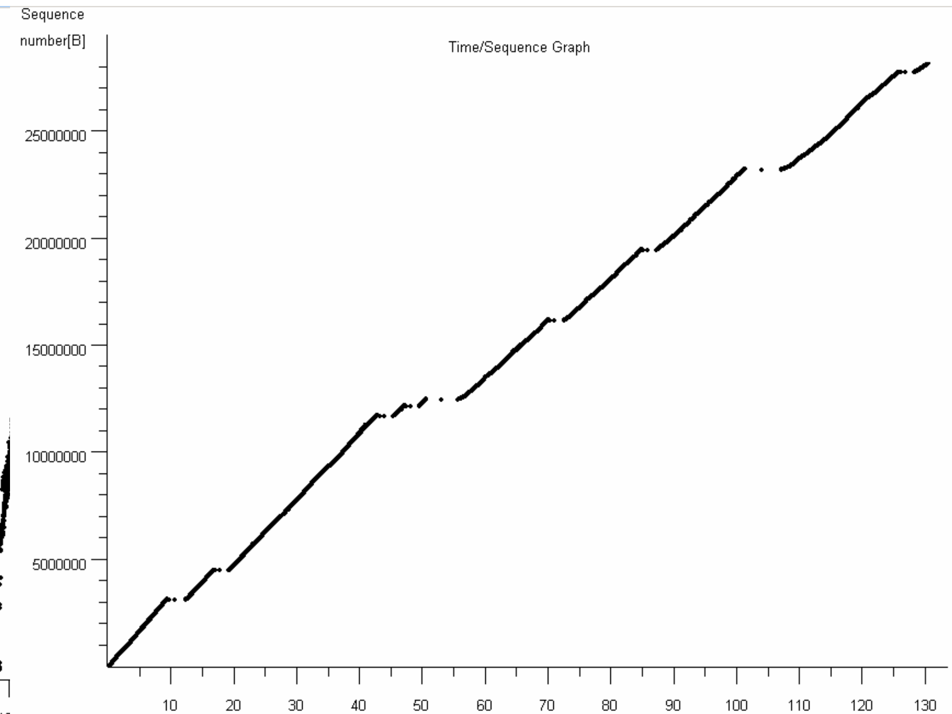




- **TCP-sequence number-time plot is affected by the attenuation model**

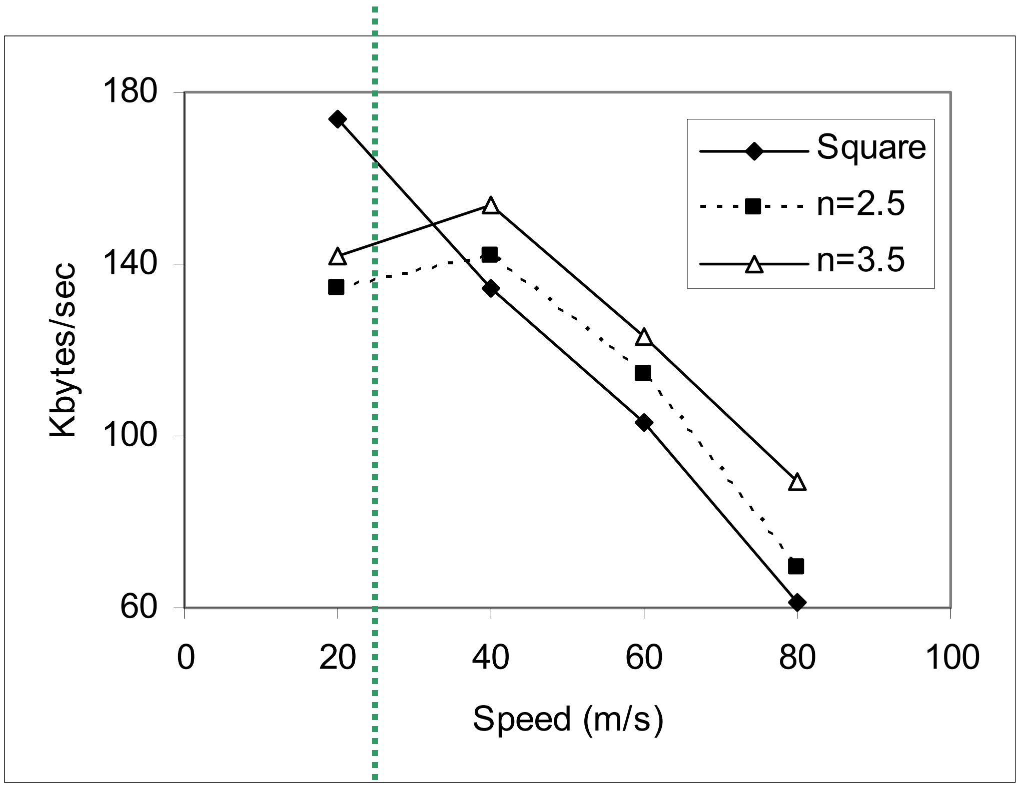
Throughput and TCP sequence numbers (*n*=3.5) at 20 m/s





- **A sharper attenuation pattern results on a semi-linear shape.**

Average throughput at different speeds and attenuation patterns.

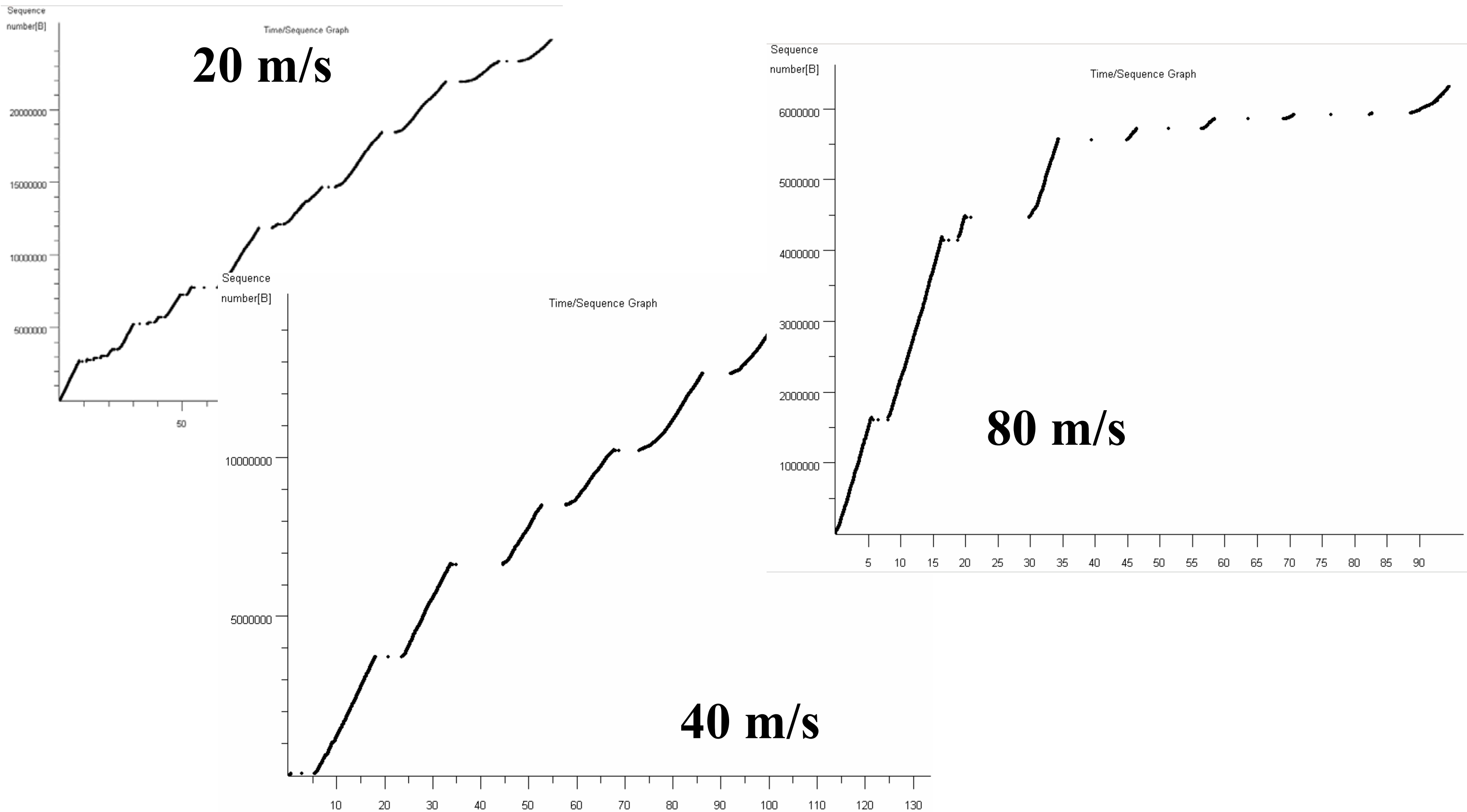


- **In average the attenuation model selected will**

Affect the average throughput observed at different speeds.

- **Throughput is a function of the signal strength received**

TCP sequence numbers – time plot at different speeds.



(c)

Observations

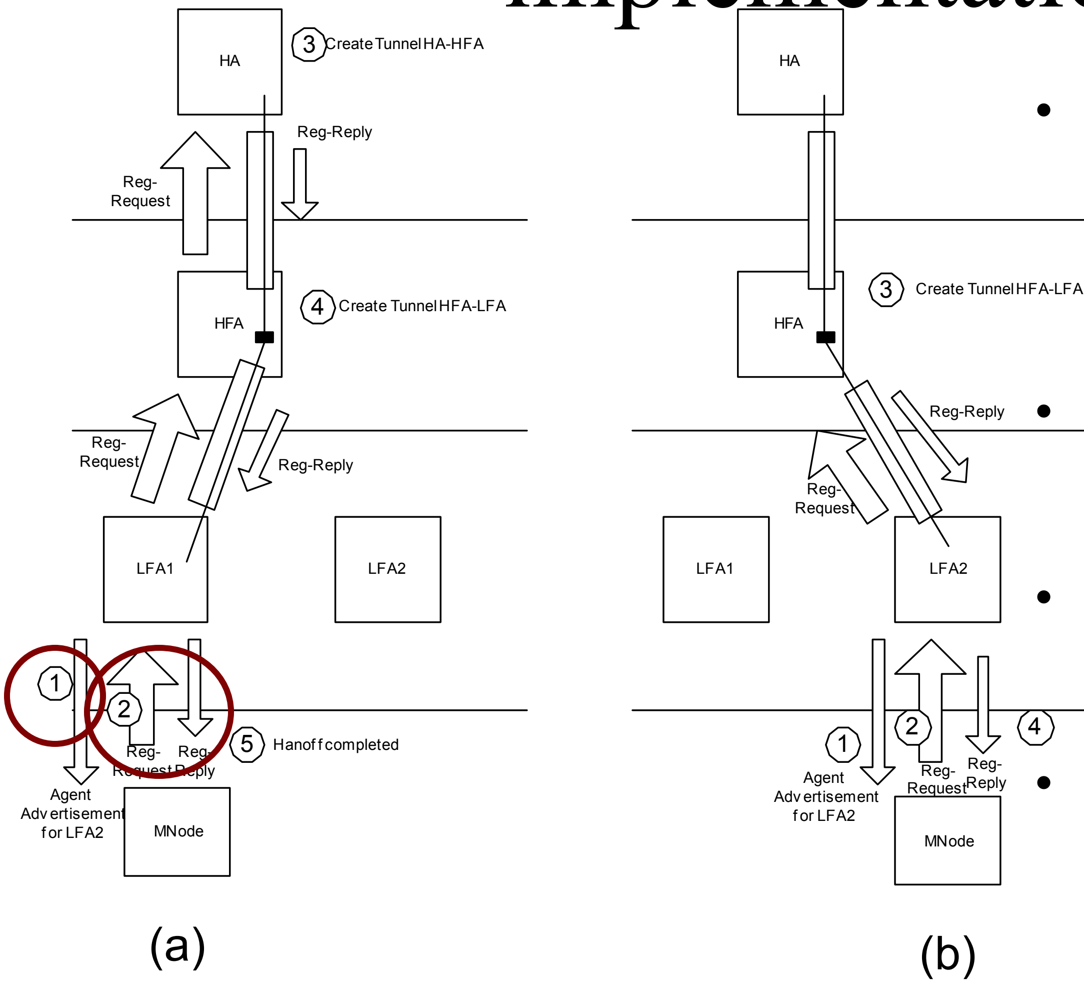
- The results indicate that simply forcing handover between two access points at different rates is not sufficient to demonstrate the effects of speed on mobile protocols. Several authors have used this mechanism in many publications to test handoff performance. Handoff rate as equivalent of speed.
- 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)
- RAMON can replicate realistic conditions of mobility

Predictive Mobility and Extensions to Mobile-IP

- Performance bottleneck of Mobile-IP: *The mobile unit, requires of registration in order to maintain the home network aware of its mobility, the Home Location Register (HLR) and the home agent structure used in mobile-IP [Perk96a]*
- Several experiments were conducted in RAMON and using an agent advertisement time of 1 sec, with no agent solicitation messages, handoff required approximately 2 to 10 seconds depending upon the speed of the mobile host, higher the speed higher the handoff.

$$T_{dwell} + T_{handoff} + \varepsilon >> T_{forward} + T_{registration} + \delta$$

Reactive Mobile-IP (current implementation)

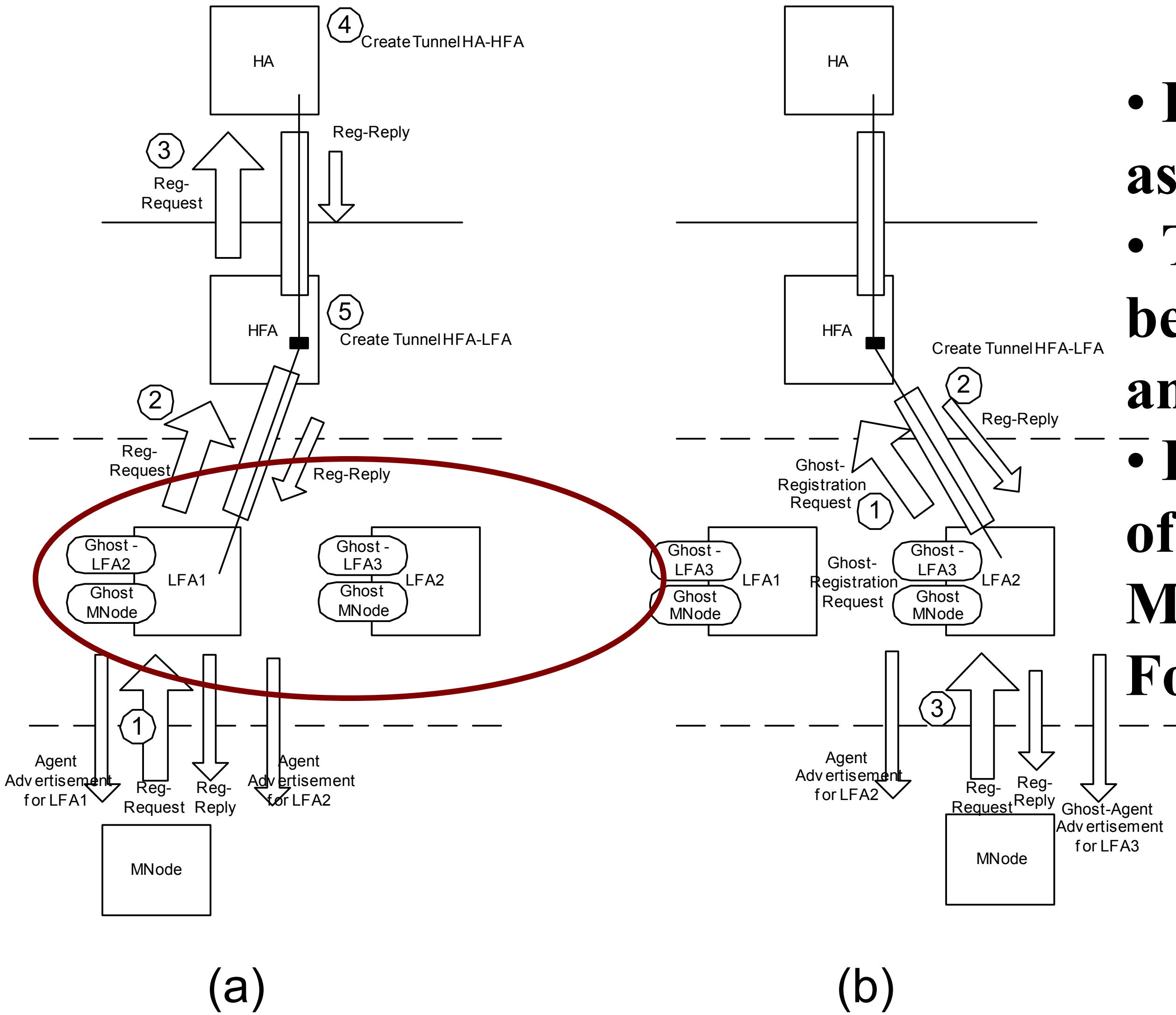


- Even the optimized, hierarchical M-IP (i.e. Lifix) relays on reactive mechanism and the agent advertisements to achieve mobility.
- Fast Handover is only equivalent to O(log(*N*)) time on registration.
- Nothing is said about a more preemptive or predictive alternative for MIP
- GPS or Any Location Management Information is assumed to be available

The “ghost” entities

- ***Ghost Mobile-Node (g-MN):*** As the mobile node moves along the different cells and follows a determined trajectory. A “virtual” repeater capable of registering and allocating resources in a predictive matter could potentially speed-up handoff and augment the performance of Mobile-IP and be able to cope with speed. The g-MN is cable of replicating the registration request, handling the creation of the tunnel, and replicating Authentication and Authorization information from the MN and act on behalf of the MN before is in the range of the new FA.
- ***Ghost Foreign Agent (g-FA):*** Similarly to the process and delegation of authority done with the MN, a g-FA could be created in the neighborhood of the FA. The g-FA will then advertise the FA presence of a different FA.

Ghost Mobile-IP



- **Entities created as the MH moves**
- **They act on behalf of the MH and FA.**
- **Increase the "range" of the signal of the Mobile Host and Foreign Agent**

Ghost Mobile-IP

- Anticipate movement and allocate resources before are required.
- One of the bottlenecks in the current M-IP implementation is the creation of the tunnel (ip-ip), takes a couple of seconds after registration is received by the HA or HFA.
- Kalman Filters can easily track and determine the position of a moving vehicle and be used to anticipate and preemptively allocate resources.

Ghost Mobile Node

- The g-MN creates a replica of the Registration UDP packet that the MN would have sent to the FA or to the HFA, depending on what it would have expected.
- Potential problems with nonce numbers and time-stamping (protection against reply-attacks). MD5 authentication and a shared key is required instead.
- Packet is created as a RAW socket, experimentally we observed the current registration packet and maintained the same values of "Lifetime", Flags, and other Extensions used with Dynamics Mobile-IP implementation.

```
 0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |     Type      |S|B|D|M|G|V|rsv|          Lifetime             |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                          Home Address                         |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                           Home Agent                          |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                        Care-of Address                        |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                                                               |
 +                         Identification                        +
 |                                                               |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 | Extensions ...
 +-+-+-+-+-+-+-+-
```

Ghost Mobile Node

```
g-MN (Home Address, HomeAgentAddress)
while (true) do
        FA ←FindClosestFA(MN)
        if distance(FA, MN) > threshold then
                HFA ←FindHighestFA(FA, HomeAgentAddress)
                Register(FA, Home Address, HFA)
        end
```

distance(FA, MN) is the Predictive distance, otherwise it is not predictive but reactive.

```
0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     Type      |S|B|D|M|G|V|rsv|          Lifetime             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                          Home Address                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                           Home Agent                          |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                        Care-of Address                        |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
   +                         Identification                        +
   |                                                               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | Extensions ...
    +-+-+-+-+-+-+-+-
```

Ghost Foreign Agent

- Extends the range of the FA to allow other FAs in the vicinity to advertise on his behalf.
- ICMP Advertisement packets most be sent to the MH before it arrives to the FA so that the MH can add that FA to the list of potential FA to handoff. Very similar to the Shadow Cluster [Levi95] but in Mobile-IP not in Wireless ATM networks.

Ghost Foreign Agent

g-FA(*ForeignAgent*)

For each *FA* **in** *Topology*

if (distance(*FA*, *ForeignAgent*)>*threshold)* and (*FA*!=*ForeignAgent*)

SendGhostAgentAdv(*ForeignAgent, FA*)

end

Distance is always the same, predicted or current. FA speed = 0;

ICMP packet:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |    Length     |        Sequence Number        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Registration Lifetime      |R|B|H|F|M|G|V|    reserved     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  zero or more Care-of Addresses               |
|                              ...                              |
```

Location tracking with Kalman Filter

- Kalman filters have been used in numerous applications ranging from location tracking and control of physical variables; wireless protocols are not the exception. D. Dailey, et. al.. [Dail00] solves the problem of tracking a vehicle and the time to arrival to a certain destination using the Kalman filter. The prediction done by the predictor is used to inform bus riders and anyone with a smart phone the waiting time of a bus route in Seattle, WA.
- The Kalman filter [Welc02] addresses the problem of trying to estimate the state: $x \in \mathbf{R}$ of a discrete-time controlled process that is governed by a linear stochastic difference equation.

Equations

State vector : $x_k = Ax_{k-1} + Bu_k + w_{k-1}$

Measurement vector: $z_k = Hx_k + v_k$

In our case the state vector indicates, speed in <x,y> and the <x,y> Coordinates of the MH. The Measurement vector are the values of <x,y> measured from a GPS system or a location tracking device.

System equations:

$$\begin{pmatrix} x \\ y \\ v_x \\ v_y \end{pmatrix} = \begin{pmatrix} 1 & 0 & t & 0 \\ 0 & 1 & 0 & t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x \\ y \\ v_x \\ v_y \end{pmatrix} + \begin{pmatrix} w_x \\ w_y \\ w_x^s \\ w_y^s \end{pmatrix}$$

Equations

Matrices representing our system:

:

$$A = \begin{pmatrix} 1 & 0 & t & 0 \\ 0 & 1 & 0 & t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad H = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{pmatrix} \quad v_k = \begin{pmatrix} v_s \\ v_y \end{pmatrix} \quad w_k = \begin{pmatrix} w_x \\ w_y \\ w_x^s \\ w_y^s \end{pmatrix}$$

Kalman Filter Time-Update equations:

$$x_k = Ax_{k-1} + Bu_k + w_{k-1}$$

$$P_k = AP_{k-1}A^T + Q \qquad Q = \mathrm{E}\{w_k w_k^T\}.$$

Equations

Measurement-update equations

$$K_k = P_k^{-} H^T (H P_k^{-} H^T + R)^{-1}$$

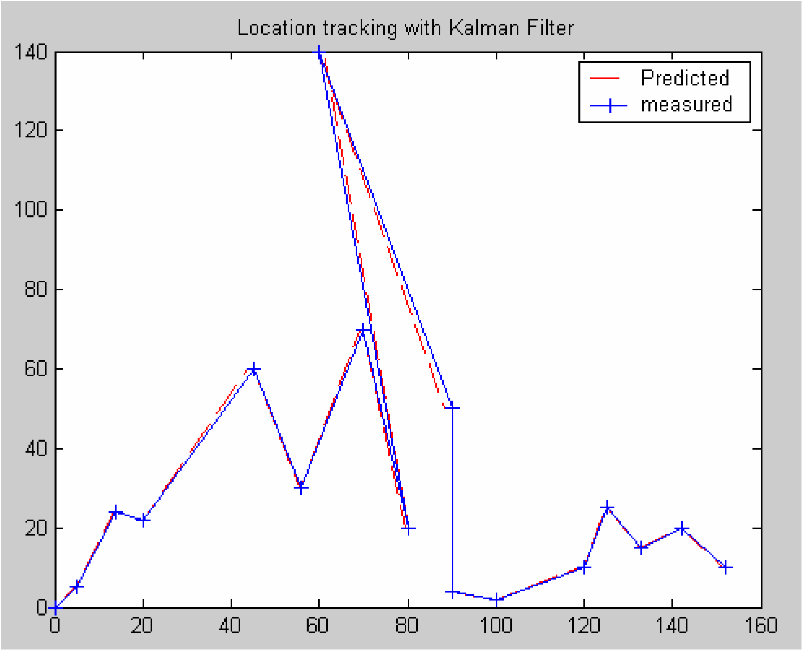
$$x_k = x_k^{-} + K_k (z_k - H x_k^{-})$$

$$P_k = (I - K_k H) P_k^{-}$$

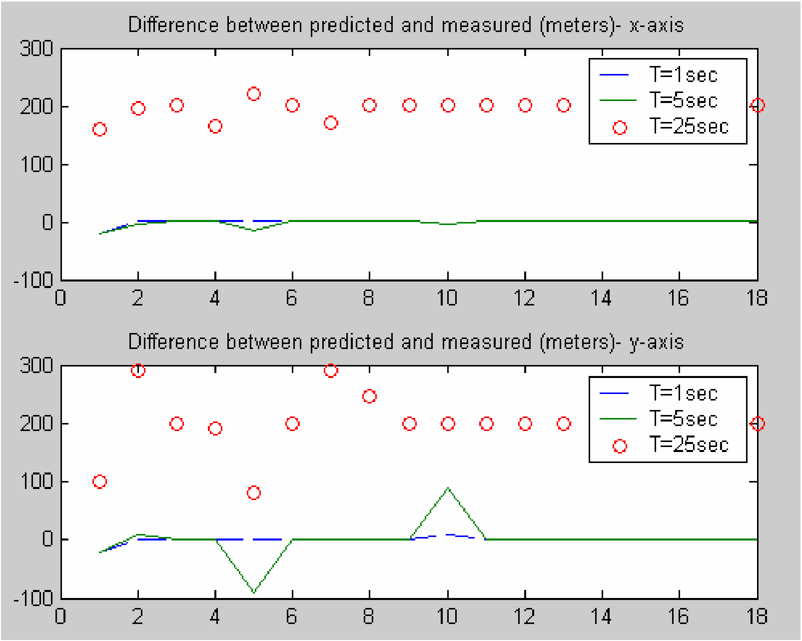
Empirical parameters used :

$$Q = 0.001 * \begin{pmatrix} 15 & 0 & 0 & 0 \\ 0 & 15 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad R = 0.000001 * \begin{pmatrix} 100 & 0 \\ 0 & 0.001 \end{pmatrix}$$

Filter Performance (MATLAB)

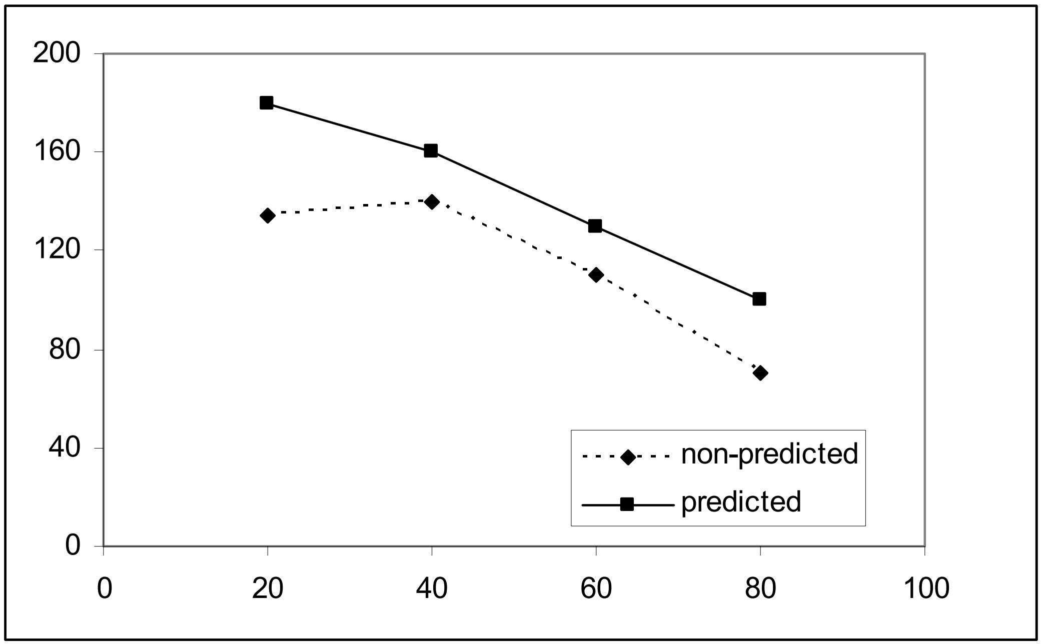


Tracking



Error and sampling rate

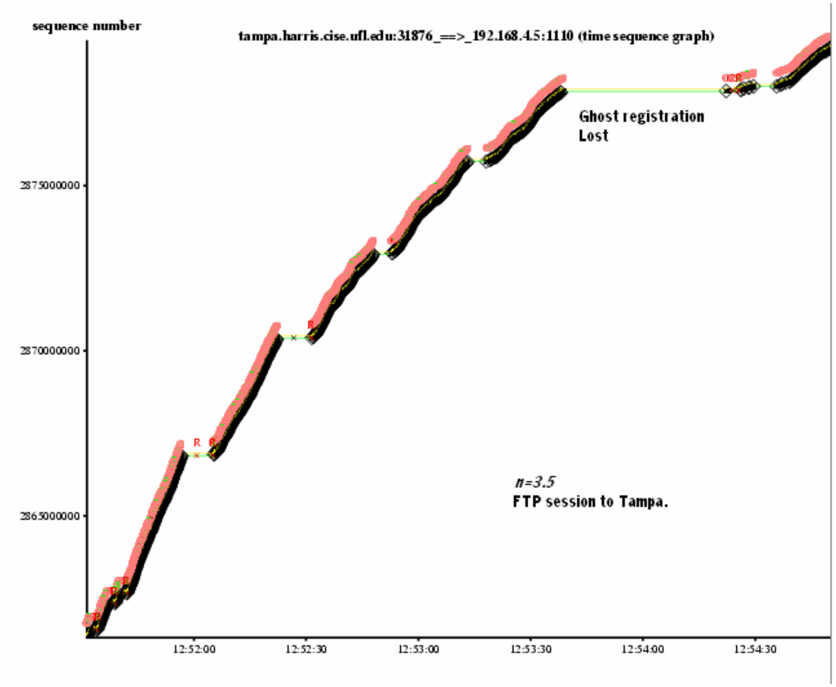
Performance of M-IP and g-MN/FA



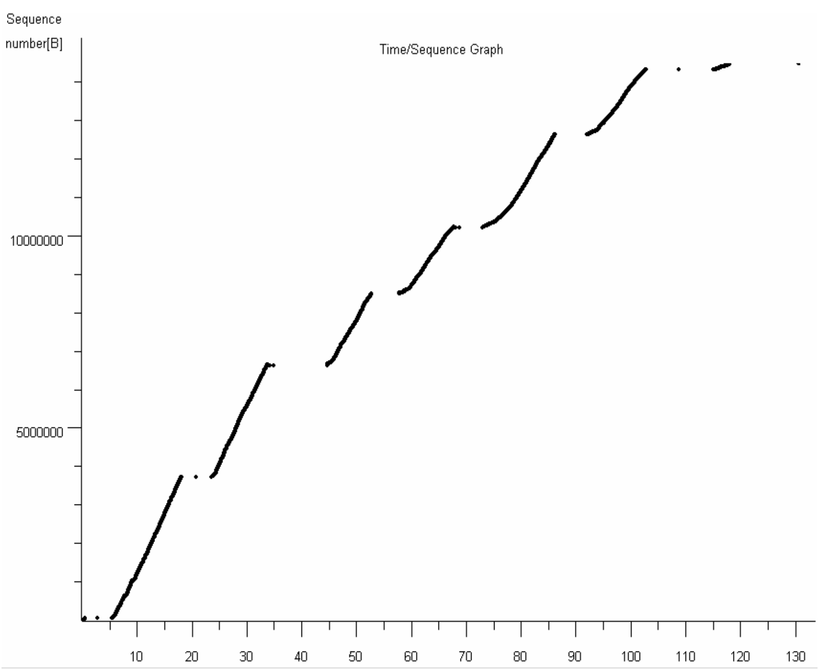
•**The experiments corresponds to *n*=2.5 because was in between squared and *n*=3.5.**

• **Average throughput much higher.**

TCP sequence-time plots at 40m/s

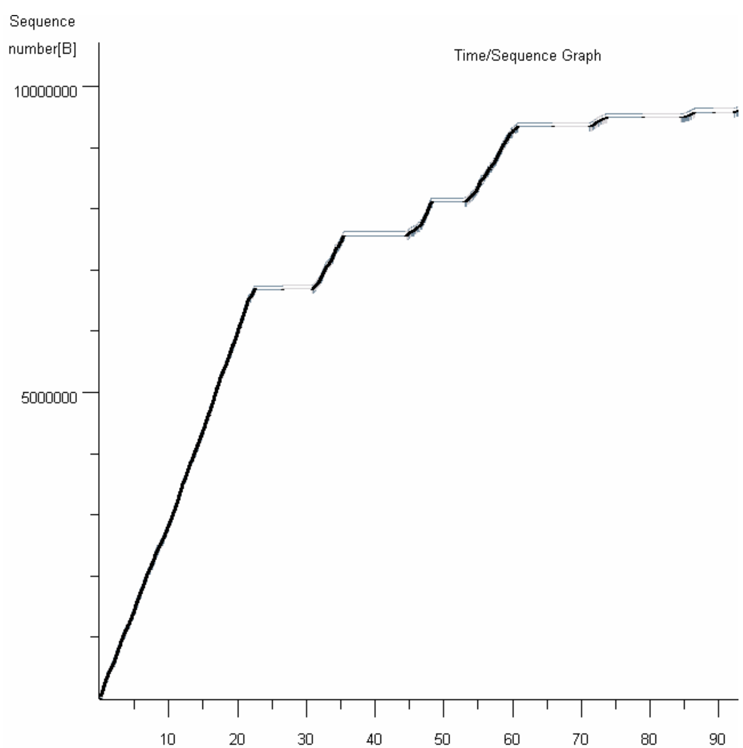


Ghost-MobileIP

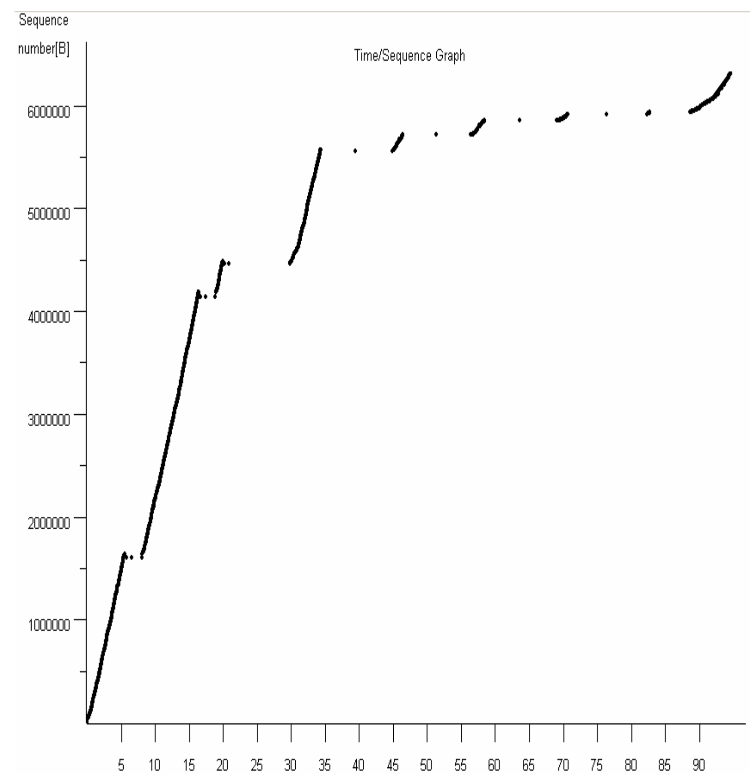


Dynamics MIP

Time-sequence plots at 80 m/s



Ghost MobileIP



Dynamics MIP

Observations

- For 40 m/s and n=2.5 we observed that TCP registered almost 20 million packets transferred, while in the non-predictive case about 14 million packets arrived from the FTP server.
- More than 10 million packets arrived to the mobile node using the predictive algorithm, while about 6 million made during the non-predictive case. This shows an improvement of approximately 1.5.
- Experiments were repeated at least 10 times for the average plot and the time-sequence plot represent the worst case observed.
- Our current approach copes with speed but it doesn't on the RTT of the packet which in our scenario increases per hop

Summary and Future Work

- Mobile-IP requires of registration, tunneling, and triangular routing in order to provide a seamless roaming among foreign networks. The drawbacks of these mechanisms are found in the large overhead required by the infrastructure, which affects the communication process at speeds greater than 20 m/s (72 Km/hr).
- Thru simulation experiments we found that the design of the wireless infrastructure requires a-priori knowledge of the protocols employed as well as speed characteristics of the mobile hosts. Cells can be interleaved at different distances and configurations depending on the speed and mobility behavior of the mobile units. We observed that providing full wireless

Summary and Future Work

- Mobile networking protocols, such as Mobile-IP, are not designed to handle high-speed gracefully. Such protocols produce considerable overhead and high forwarding delay. We found out that protocols based on registration and non-aware packet re-routing are not appropriate for speeds higher than 20 m/s.
- Additionally, we analyzed the micro-mobility protocols, HAWAII and Cellular-IP, both showed significant improvement in the simulator. However, the comparisons made with Mobile-IP under similar assumptions and simulation variables showed a discrepancy with previous results and observations done with the more restrictive handoff mechanisms as well as attenuation models.

Summary and Future Work

- Since experimentation based-upon simulation software largely depends on the assumptions and problem constraints, we decided to create an emulation platform tailored to mimic a more realistic environment of rapidly moving nodes. The emulator, called RAMON, effectively replicates realistic conditions of mobility providing interesting insights and observations previously unknown and non-observed in simulation-based experiments [Hern01].
- We created a GUI to ease the creation of emulation scenarios and potentially manage experimentation remotely.

Summary and Future Work

- 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.
- RAMON indicated that highest performance bottleneck is found in the creation of the tunnel and the reactive mechanism of MIP.

Summary and Future Work

- In a rapid mobility, non-assisted and reactive handoff time is closed in magnitude to the dwell time in the cell. In order to minimize this factor the mobile protocol should be able to be preemptive and predict potential locations where the rapid mobile units are about to cross and handoff will occur faster while maintaining connectivity even at high speed.
- We showed that a Kalman Filter can track the location tracking of a mobile network and improve handoff and henceforth the throughput.
- The proposed extensions for mobile-IP called ghost-entities can interact on behalf of the mobile node and foreign agent. These predicted interaction, aided with the Kalman Filter improved the performance of Mobile-IP at high-speed, from a maximum throughput of 60 Kbytes/sec to 90Kbytes/sec which represents almost 1.5 times increase

Future Work

- Stochastic techniques can be combined or compared with the Extended version of the Kalman Filter, as wells as other well known mechanisms such as Neural Networks and Machine learning.
- RAMON currently supports binary-tree scenarios only, skew or totally balanced topologies. The emulator requires to be extended to allow the emulation of any topology and the GUI should guide the user in the creation of those emulation scenarios. In addition, the incorporation of IEEE 802.11a and many 3G networks.
- RAMON presented several signal leakage problems which might require of special covers or cables in order to reduce signal loss.
- Synchronization issues most be solved when running the emulation.
- RAMON also needs better improvements in the graphical interface and solve all the process synchronization issues during the emulation process which are currently unresolved. Integration of the analysis and experimentation tools should be part of the future implementations of the emulation platform as well as visualization of the resulting throughput, latency, and sequence-time plots.

Future Work

- Other protocols could benefit from the g-MN such as the Interlayer Layer Collaboration Protocol (ILC-TCP) [Chin02] which interacts with the lower layers of the stack to “freeze” TCP and acquired awareness of the wireless conditions
- Mobile IPv6 can be incorporated to the current stack and tested in the emulator.

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