CHAPTER 6

EXPERIMENTAL RESULTS

6.1. INTRODUCTION

In this chapter, the experimental results and their significance are discussed. The performances of the proposed schemes and simulations have been used to validate our model. The proposed protocols which significantly improve the service availability and service continuity for disaster responders have been explained.

6.2. EXPERIMENTAL ENVIRONMENT

6.2.1 Simulator

Simulation is “the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system.

Many software tools are available, each one of them, somehow, can help to simulate a scheme putting together IMS and MIPv6 in an appropriated way. Each one of these tools offers its own advantages and disadvantages. Despite of this, there are some parameters that result decisive at the moment of choosing the appropriated simulator. Some of these characteristics are listed below:
- Open code, so it can be modified and adjusted to very particular requirements.
- Already include wireless functionalities or easy to generate.
- Allow to connect the wireless networks in an easy way.
- Functionalities to have different kind of networks and its components (Public Safety LMR, WCDMA cellular network, WLAN, UMTS).
- Good documentation and support in general.
- Preferable if it works as a network simulator and not in general with predictive and/or mathematical models.

Keeping in mind these preliminary requirements, the chosen simulator was the Networks Simulator NS2. NS is a discrete event simulator, targeted at networking research. As advantages, NS provides substantial support for simulation of Transport Protocols, routing, and multicast protocols over wired and wireless networks. Due to the fact that NS is a tool that is still being developed, it provides the advantage that its code and modules can be modified and added by the user (mainly tcl and C++ programming).

6.2.2 Network Simulator 2

Network Simulator (Version 2), widely known as NS2. NS2 is an open source event-driven simulator designed specifically for research in computer communication networks. Since its inception in 1989, NS2 has continuously gained tremendous interest from industry, academia, and government. Having been under constant investigation and enhancement for years, NS2 now contains modules for numerous network components such as routing, transport layer protocol, application, etc. To investigate network performance, researchers can simply use an easy-to-use scripting language to
configure a network, and observe results generated by NS2. Undoubtedly, NS2 has become the most widely used open source network simulator, and one of the most widely used network simulators.

Simulation of wired as well as wireless network functions and protocols (Routing algorithms, TCP, UDP) can be done using NS2. In general, NS2 provides users with a way of specifying such network protocols and simulating their corresponding behaviors. Due to its flexibility and modular nature, NS2 has gained constant popularity in the networking research community since its birth in 1989. The group of researchers and developers in the community are constantly working to keep NS2 strong and versatile.

### 6.2.2.1 NS2 architecture

NS2 provides users with executable command ns which take on input argument, the name of a Tcl simulation scripting file. Users are feeding the name of a Tcl simulation script (which sets up a simulation) as an input argument of an NS2 executable command ns. The simulation trace file is created, and is used to plot graph and/or to create animation. Figure 6.1 shows the basic architecture of NS2.

NS2 consists of two key languages:

- C++
- Object-oriented Tool Command Language (OTcl).
While the C++ defines the internal mechanism (a backend) of the simulation objects, the OTcl sets up simulation by assembling and configuring the objects as well as scheduling discrete events (i.e., a frontend). The C++ and the OTcl are linked together using TclCL. Mapped to a C++ object, variables in the OTcl domains are sometimes referred to as handles. Conceptually, a handle (n as a Node handle) is just a string in the OTcl domain, and does not contain any functionality.

Instead, the functionality (receiving a packet) is defined in the mapped C++ object (class connector). In the OTcl domain, a handle acts as a frontend which interacts with users and other OTcl objects. It defines own procedures and variables to facilitate the interaction. The member procedures and variables in the OTcl domain are called instance procedures (instprocs) and instance variables (instvars), respectively.

NS2 provides a large number of built-in C++ objects. It is advisable to use these C++ objects to set up a simulation using a Tcl simulation script. After simulation, NS2 outputs either text based or animation based simulation results. There are tools used to interpret these results graphically and interactively. The tools are

Figure 6.1 NS2 Basic architecture
• NAM (Network AniMator)
• XGraph

Extract a relevant subset of text based data and transform it to a more conceivable presentation for analyzing a particular behavior of the network.

6.2.2.2 Cygwin

NS2 is a free simulation tool. It runs on various platforms including UNIX (or Linux), Windows, and Mac systems. To run NS2 on Windows based operating systems, a bit of tweaking is required. Basically, the idea is to make Windows based machines emulate the functionality of the Unix-like environment. A popular program that performs this job is Cygwin. For ease of installation, all-in-one package is used. By default, Cygwin does not install all packages necessary to run NS2. It needs to manually install the addition packages shown in Table 6.1.

<table>
<thead>
<tr>
<th>Category</th>
<th>Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developments</td>
<td>gcc,gcc-objc,gcc-g++,make</td>
</tr>
<tr>
<td>Utils</td>
<td>Patch</td>
</tr>
<tr>
<td>X11</td>
<td>xorg-x11-base,xorg-x11-devel</td>
</tr>
</tbody>
</table>

6.2.2.3 NS2 Installation advice

Advice 1 : Install it under Windows, windows is sometimes more familiar and more friendly for working with the files.

Advice 2 : Trying to install the all in one version for windows with Cygwin.

Advice 3 : Installation using all in one version under Cygwin. This allows to have some other programs and functionalities (i.e. emacs) and easy to update and install more programs after the initial
installation. Easy to follow instructions from http://www.isi.edu/nsnam/ns/ns-cygwin.html, the installation is easy but the validation process is too long and not really necessary if all the installation worked properly.

**Advice 4**: Use also the Pre-built binaries suggested in that page there is a problem with the libraries if ns/nam is not ran from the folder of ns2 (i.e. running from the home), the best solution is copy the files in the folder $usr$ lib in the folder main library for ns2 after that ns can be ran from everywhere.

**Advice 5**: If trying to rebuild the examples from tutorial it is important to notice that movement and traffic scenario files might be in a different folder.

Only node movements can currently be seen in nam, Dumping of traffic data and thus visualization of data packet movement in nam for wireless scenarios is still not supported. BS nodes are like gateways between wireless networks (domains). Hierarchical routing is needed for implementation of gateways in a BS. Domains and sub-domains (clusters) must be used to segregate wireless nodes. Packets are routed in a wireless topology using their ad-hoc routing protocols which build forwarding tables by exchanging routing queries among their neighbors.

### 6.2.3 NS2 Simulation Steps

The followings show the three key step guidelines in defining a simulation scenario for measuring the handoff delay and optimal radio resource utilization in a heterogeneous mobile wireless network.
Step 1 : Simulation Design

The first step in simulating a network is to design the simulation. This step, determines the simulation purposes, Interworking public safety LMR/cellular network configuration and assumptions, the performance measures, and the type of expected results.

Step 2 : Configuring and Running Simulation

This step implements the design in the first step. It consists of two phases:

Network configuration phase: In this phase network components (node, IMS architecture) are created and configured according to the simulation design. Also, the events such as handoff from public safety LMR to cellular network are scheduled to start at a certain time.

Simulation Phase: This phase starts the simulation which was configured in the Network Configuration Phase. It maintains the simulation clock and executes events chronologically. This phase usually runs until the simulation clock reached a threshold value specified in the Network Configuration Phase.

Step 3 : Post Simulation Processing

The main tasks in this step include verifying the integrity of the program and evaluating the performance of the simulated network. While the first task is referred to as debugging, the second one is achieved by properly collecting and compiling simulation results.
6.2.4 Simulated Scenario in NS 2.28

After getting the basic theoretical knowledge about, IMS, SIP, Public Safety LMR and 3G cellular networks are gathered and the simulator is chosen; it is important to come back to the problem and get a clear view of it.

The scenario proposed is shown in Figure 6.2. Here, the handoff is done by the mobile node (MN) by changing its access network. Essential components are simulated from the two different access networks. The connection functionality is implemented based upon the access point of view (AP). The IMS/SIP part, at the beginning, functions as register, connection establishment and proxy tasks are simulated. Finally, a correspondent node (CN) main function generates the traffic to the MN. All the components are interconnected with each other by the use of SIP server.

The scenario in NS2 is composed of three domains, the public safety LMR, the cellular network and the Internet. The mobile node, called MN is a wireless node switching from the public safety LMR to the cellular network. The handoff done in two different ways, the first one is by separating enough the two access networks and moving the node with a considerable speed with “break before make” procedure. So the handoff seems as a disconnection. The proposed seamless SIP makes the connection before breaking the existing session connection between MN and CN via public safety LMR network. It follows “make before break” procedure.
RESULTS AND DISCUSSIONS

In this section, the performance of the proposed schemes and simulations has been shown to validate the model.
Figure 6.3 Set up the IP Multimedia Subsystem

The 3GPP (Third Generation Partnership Project) defines the IMS (IP Multimedia Subsystem) as the component that supports the multimedia services. IP Multimedia Subsystem works in conjunction with the Packet Switched Core Network for supporting legacy telephony services as well as new multimedia services. The IMS enables IP based network to support both the IP telephony services as well as the multimedia services.

SIP is the signaling protocol used between the MH or User Equipments (UE) and the IMS as well as with its internal components. As far as the SIP signaling is concerned, the main component of the IMS involved is the Call Session Control Function (CSCF), which is basically a SIP server. The CSCF plays three vital roles, the Proxy CSCF (P-CSCF) role, the Interrogating CSCF (I-CSCF) role and Serving CSCF(S-CSCF) role. Figure 6.3 shows that creation of public safety LMR network and cellular network which are integrated by three CSCF’s of IMS.
Figure 6.4 Create a Single LMR and a Single cellular network cell

Figure 6.5 Communication happened before handoff
Figure 6.4 shows that a single LMR cell and a single cellular cell of interoperable LMR network and cellular network. Disaster responders could accesses both the LMR and cellular networks; where as commercial users can only access the cellular network. A public safety land mobile radio cell contains a number of multimode mobile stations. A cellular network cell contains a number of mobile stations, which is not allowed to access the LMR network.

The communication between the disaster responder (MN) and disaster commander (CN) through the public safety LMR network radio access is shown in Figure 6.5.

![Figure 6.5 Communication Diagram](image)

**Figure 6.5 Communication Diagram**

Figure 6.6 shows that the disaster responder from public safety LMR network moves over to the cellular network coverage to access the cellular network bandwidth, if it is available.

![Figure 6.6 Handoff Diagram](image)

**Figure 6.6 Handoff from LMR network to a cellular network**
The session handoff is happened, when the disaster responder moves from LMR network coverage to cellular network coverage. During this session handoff, the disaster responder accesses the cellular network bandwidth. For this purpose, the bandwidth is reserved in advance. The proposed S-SIP protocol makes the session handoff is seamless because it is based on “Make-before-break” mechanism. The “Make-before-break” mechanism is shown in Figure 6.7.

Figure 6.7 MS access the radio resources from a cellular network

Figure 6.8 MS (Disaster responder) is getting command from the RN(Disaster commander)
The seamless communication is happened between the disaster commander (CN) and disaster responder through the cellular network radio resources after the session handoff from LMR network to a cellular network and it is shown in Figure 6.8. The disaster responders (MN) access the radio resources of cellular network for multimedia services and increased data rates. The handoff delay is reduced, and radio resources are efficiently utilized in this scenario. Due to this, fast disaster response and recovery is obtained.

The handoff delay is compared in the novel schemes with that of existing general SIP-based handoff scheme and it is shown in Figure 6.9. The comparison explained that the handoff delay is very close to zero, which means that most handoffs are seamless. In addition, the interoperable LMR/cellular networks and non-interoperable LMR/cellular networks are compared.

Figure 6.9  Handoff delays based on “break before make” and “make before break”
The proposed interoperable system significantly improves the service availability and service continuity for disaster responders. The proposed schemes are guaranteed the QoS constraints by keeping new service blocking and handoff dropping probabilities below the target values. To guarantee the QoS requirements, some bandwidth should be reserved in the cellular network.

The optimal reserved bandwidth is obtained based on the linear programming solution. A single LMR cell and a single cellular CDMA cell are considered in a LMR/cellular interoperable system. One class of video traffic is considered. The data rate of each video flow is 64 Kbps. The capacity of the LMR is assumed between 144 and 384 Kbps.

Table 6.2 System Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Notation</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target SIR for video traffic</td>
<td>$\omega$</td>
<td>8dB</td>
</tr>
<tr>
<td>Bandwidth in the cellular network</td>
<td>$W$</td>
<td>3.84M</td>
</tr>
<tr>
<td>Orthogonality factor</td>
<td>$\rho$</td>
<td>0.4</td>
</tr>
<tr>
<td>Intercell/intracell ratio</td>
<td>$\gamma$</td>
<td>0.55</td>
</tr>
<tr>
<td>Data rate for video traffic</td>
<td>$R$</td>
<td>64kbps</td>
</tr>
<tr>
<td>Common control channel power</td>
<td>$P_p$</td>
<td>33dBm</td>
</tr>
<tr>
<td>Background noise power</td>
<td>$P_N$</td>
<td>-106dBm</td>
</tr>
<tr>
<td>Maximum base station power</td>
<td>$P_T^{\text{MAX}}$</td>
<td>43dBm</td>
</tr>
<tr>
<td>Capacity in the LMR</td>
<td>$C$</td>
<td>144-384kbps</td>
</tr>
<tr>
<td>Processing delays</td>
<td>$D_{P,\text{MN}}$</td>
<td>20ms</td>
</tr>
<tr>
<td>Processing delays</td>
<td>$D_{P,\text{RN}}$</td>
<td>20ms</td>
</tr>
<tr>
<td>Processing delays</td>
<td>$D_{P,\text{CSCF}}$</td>
<td>20ms</td>
</tr>
<tr>
<td>Processing delays</td>
<td>$D_{P,\text{DHCP}}$</td>
<td>20ms</td>
</tr>
<tr>
<td>Transmission delay over the LMR</td>
<td>$D_{T,L}$</td>
<td>50-100ms</td>
</tr>
<tr>
<td>Transmission delay over the cellular network</td>
<td>$D_{T,C}$</td>
<td>30ms</td>
</tr>
<tr>
<td>Transmission delay over the internet</td>
<td>$D_{T,I}$</td>
<td>50-200ms</td>
</tr>
</tbody>
</table>
The numerical values for the system parameters are given in Table 6.2. The transmission delays over the LMR wireless link and the Internet set as variable values. The new session arrival rate in the system is 
\[ \lambda_n = \lambda_{l,n} + \lambda_{c,n}, \]
Where \( \lambda_{l,n} \) and \( \lambda_{c,n} \) are new session arrival rates in the LMR and the cellular network, respectively. The numerical value states that 
\[ \lambda_{c,t} = 0.005, \lambda_{l,t} = 0.002, \lambda_{l,h} = 0.002 \text{ and } w_{l,n} = w_{c,n} = w_{l,h} = 1. \]

### 6.3.1 Handoff Delay Improvement

Figure 6.9 shows the sequence numbers of packets at the corresponding time on the X axis. The MN leaves the LMR and initiates the handoff at time 3.5s. From the Figure 6.9, it is noticed that, in the traditional SIP-based handoff scheme, the MN cannot have communication with the RN between 3.5s and 4.7s, which is unacceptable for real time multimedia applications. This is caused by the handoff delay in the traditional SIP based handoff scheme, in which the old session in the LMR is broken before the new session is setup in the cellular network.

Comparatively, it is evident that the seamless-handoff scheme supports seamless handoff between these two networks. During the handoff process, the MN attaches to the cellular network, obtains a new domain/IP address and joins the session with the new address before the old session with the LMR is terminated. No packets are lost during this seamless handoff scheme.

A different network configuration has given effect on the handoff delay performance. The transmission delays set over the Internet as 50ms and 150ms. Figure 6.10 shows the handoff delay with different transmission delays over the LMR. Handoff delay in the proposed scheme is very close to
zero, which means that most handoffs are seamless independent of the network configurations.

![Figure 6.10 Handoff delay in different internet delay](image)

**Figure 6.10 Handoff delay in different internet delay**

In contrast, the transmission delay over the Internet has effect on the handoff delay in the traditional SIP based scheme. Larger handoff delay has occurred due to the larger Internet transmission delay.

### 6.3.2 Optimal Radio Resource Utilization

Figure 6.11 shows the radio resource utilization in different schemes. In this figure, the total new session arrival has occurred 40% in the LMR area. It is observed that the radio resource utilization is significantly increased in the proposed interoperable system compared to the existing non-interoperable system. The simulation results roughly agree from the analysis, which is true for all of the following figures shown.
Figure 6.11 Radio resource utilization

Figure 6.12 Service availability and Service continuity
Figure 6.12 shows the service availability and continuity QoS in different schemes. The blocking probability in the proposed scheme is significantly less than that in the existing scheme for new sessions from disaster responders, in which the LMR and the cellular network are not interoperable. The handoff dropping probability in the proposed scheme is significantly less than that in the existing scheme for new sessions from disaster responders. In the existing scheme, when a disaster responder moves out of the LMR with an ongoing session, the ongoing session must be dropped.

In contrast, in the proposed scheme, the ongoing session is handoff to the cellular network. The service availability and service continuity are improved significantly in the proposed scheme compared to the existing scheme. If there are 30% of the total new session arrival has occurred in the
LMR area, we have the similar results, which are shown in Figure 6.13. The following figures shows 40% of the total new session arrivals occur in the LMR area.

6.3.3 Guaranteed Service availability and Service Continuity

The proposed scheme is guaranteed the QoS constraints, which is shown in Figure 6.14. The new session blocking probability QoS constraint is 3% for disaster responders, which means the new session blocking probability for disaster responders cannot exceed 3%.

![Figure 6.14 Service availability and Service continuity with QoS constraints](image)

The handoff dropping probability constraint is 0.5%. In the Figure 6.14, the proposed scheme is always guaranteed the QoS constraints with a variety of traffic loads. This is achieved by reserving the limited bandwidth in the cellular network for disaster responders. The optimal
bandwidth is reserved based on the linear programming solution which is explained in the next subsection.

### 6.3.4 Optimal Reserved Bandwidth

The optimal reserved bandwidth is obtained by solving the linear program. Figure 6.15 shows the optimal bandwidth that needs to be reserved to guarantee the QoS requirements for disaster responders. Service availability and service continuity are the significant QoS requirements in the LMR/cellular interoperable heterogeneous network to the seamless communication for fast disaster response and recovery. The limited bandwidth is reserved exclusively for disaster responders and some bandwidth is reserved partially for them.

![Figure 6.15 Optimal reserved bandwidth](image)

Figure 6.15 Optimal reserved bandwidth
When the new session arrival rate is 0.06, the new session arrivals from the cellular network will be rejected when there are 8 (or 9 and 10) users in the cellular network; whereas, session arrivals from the LMR always accepted whenever some bandwidth is available. When there are 7 users in the cellular networks, the new session arrivals from the cellular network is accepted with a probability of 0.1129. This randomized policy is due to the QoS constraints, which is explained in Linear programming solution.

6.3.5 Heterogeneous Network Performance

Figure 6.16 is shown that the cellular network performance when it is applied the session schedule manager. The needs of the increased performance are throughput, packet delivery ratio and packet delay, which are measured in cellular network after session schedule.

Figure 6.16 Cellular network performance

Figure 6.17 shows that the public safety LMR network performance when applied the session schedule manager. The needs of the increased performance are throughput, packet delivery ratio and packet delay, which are measured in public safety LMR network after session schedule.
Service availability and service continuity are achieved optimally whenever the overall radio resource utilization gets increased. Due to this cause interworking heterogeneous network performance gets increased. Figure 6.18 shows that the overall radio resource utilization and it confirms that the network performance is increased.