



Network modeling and simulation

NIST Advanced Network Technologies Division

- The Advanced Network Technologies Division (ANTD) is part of the National Institute of Standards and Technology's Information Technology Laboratory
- ANTD's mission is to: "Provide the networking industry with the best in test and measurement technology":
 - To improve the quality of networking specifications and standards
 - To improve the quality and expedite the commercial availability of new networking products
- Major Competencies:
 - Modeling and Simulation for Measurement Science
 - Mathematical Analysis IT, Measurement and Testing
 - Standards Development and Deployment

ISSI Simulation Tool for P25

- Objectives:
 - Develop a simulation tool to model (or emulate) the behavior of the ISSI system in order to help users gain insights on how the ISSI interface works.
 - It should provide feedback on various deployment configurations and parameters without the need for procuring and setting up expensive testbeds and demonstrations.

ISSI Simulation Tool for P25

- What To Expect:
 - A tool can help answer a multitude of configuration and parameter issues before/during and after deployment
 - It can be used for network planning purposes
 - Given application requirements produce network satisfying solutions
 - It can help in troubleshooting problems and issues with an experimental set-up
 - Given a physical network produce application expectations
 - A tool with a user friendly interface
 - It can help users play a number of “what if” scenarios, gain insights on what works and what does not without the need for purchasing and deploying costly equipment

Tools for Evaluating the Behavior of Network Protocols

1. Mathematical modeling
 - Based on the availability of vendor fact sheets or theoretical results
 - Provides a back of the envelope approximation
2. Simulation modeling
 - Includes network protocol behavior details
 - Studies a number of “what if” scenarios
 - Varying accuracy range
3. Experimental measurements
 - Vendor implementation specific
 - Difficulty tying results to protocol options and parameters

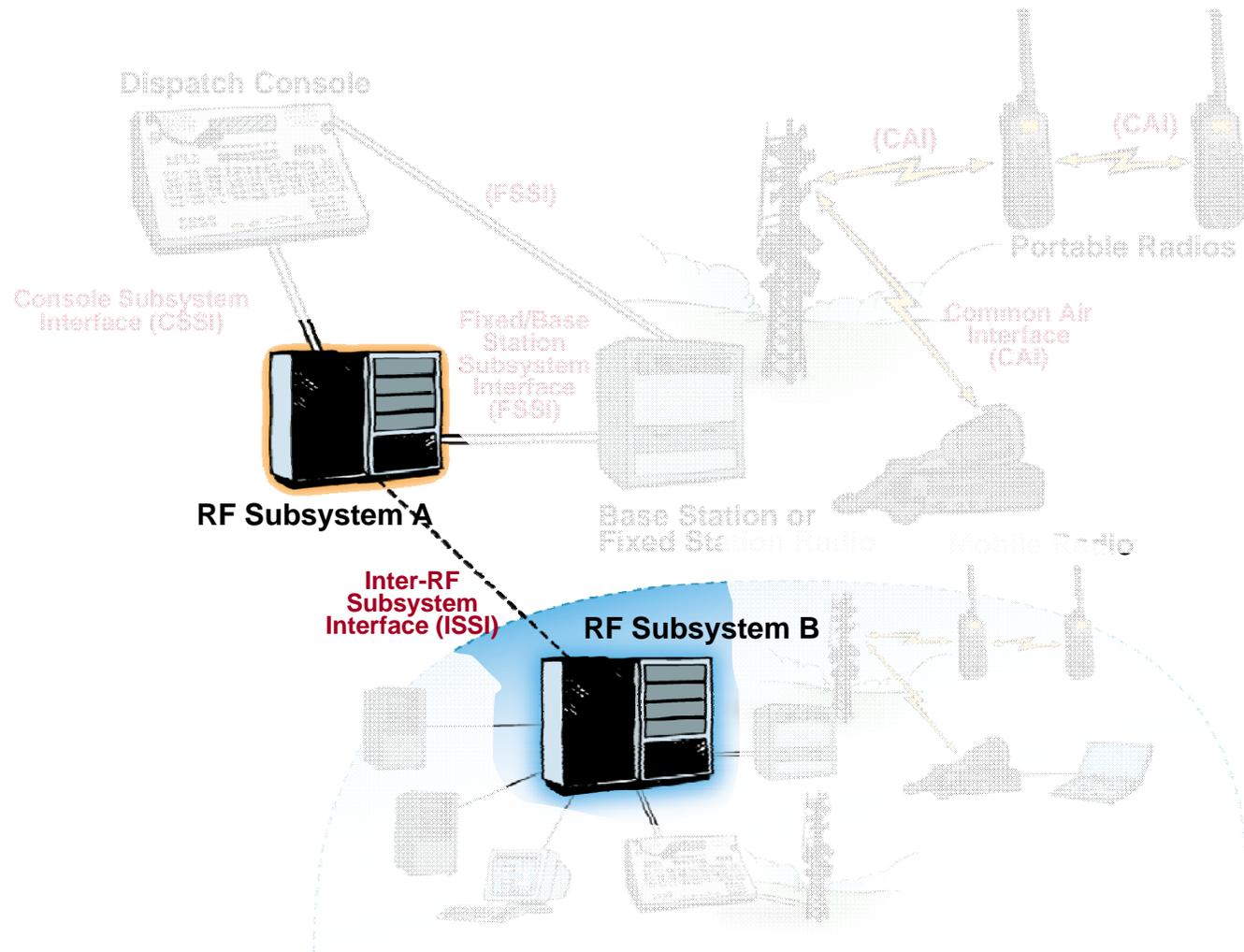


Network Simulation Modeling

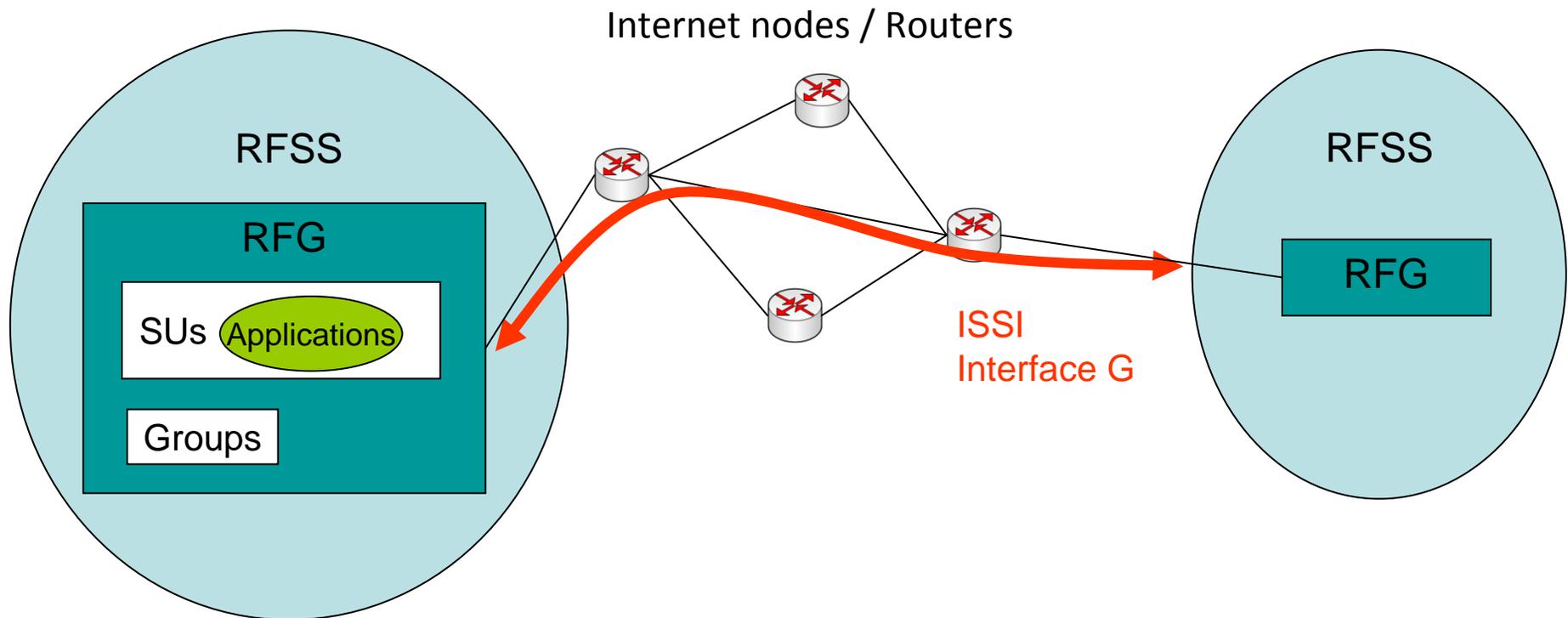
Based on protocol specifications:

- Identify area(s) of special interest
- Model the behavior of the protocol under interest
- Consider the input that would effect the behavior
- Develop performance measures
- Obtain and analyze the results

ISSI: Area of interest within P25



Modeling entities



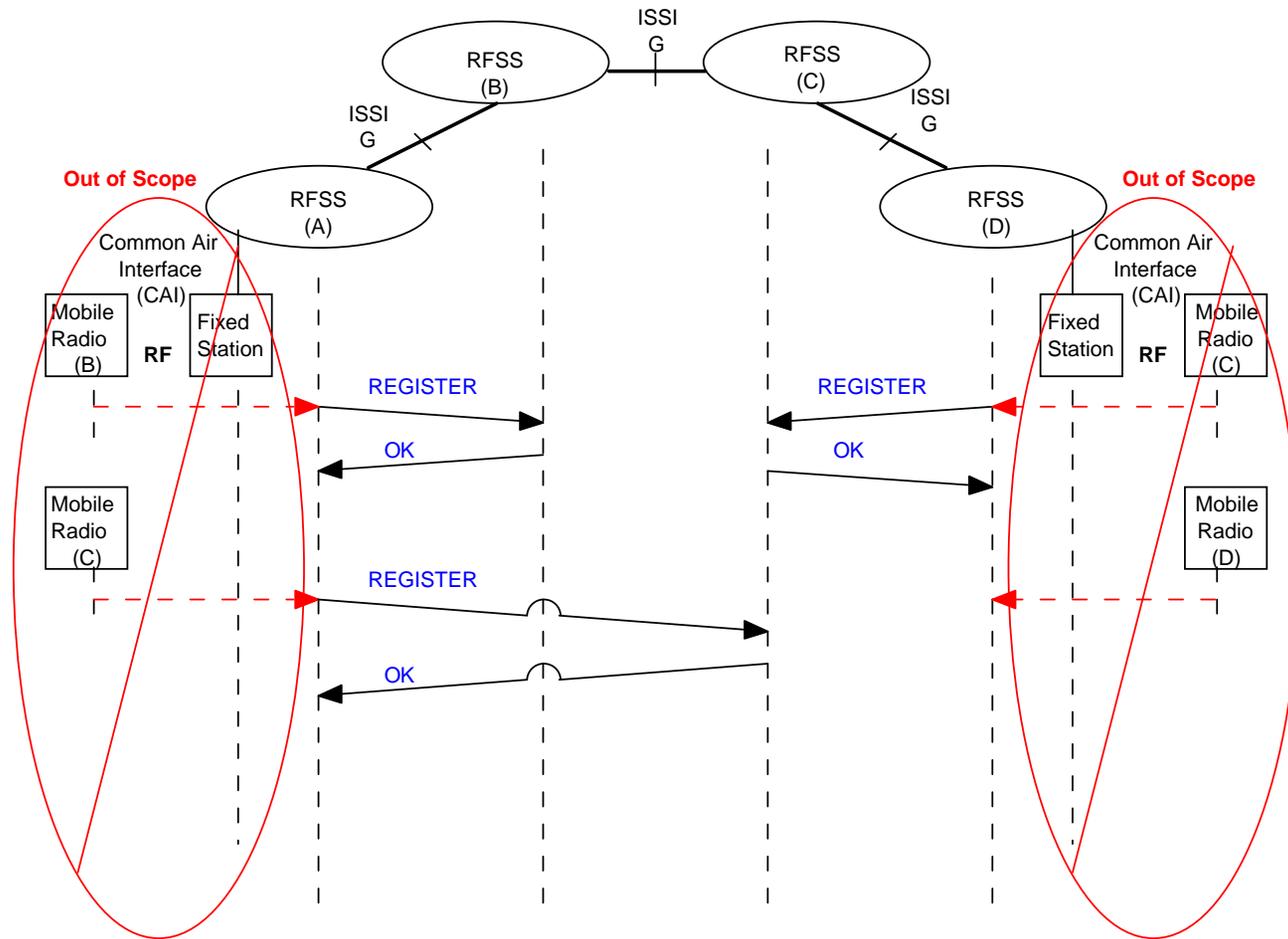
Simplifying assumptions based on areas of interest

- RFSS functionalities are aggregated into a single entity, the RFG.
- SUs are logical entities defined in the RFSS (not real nodes):
 - No packet exchanged between SU and RFSS
 - Movement is instantaneous

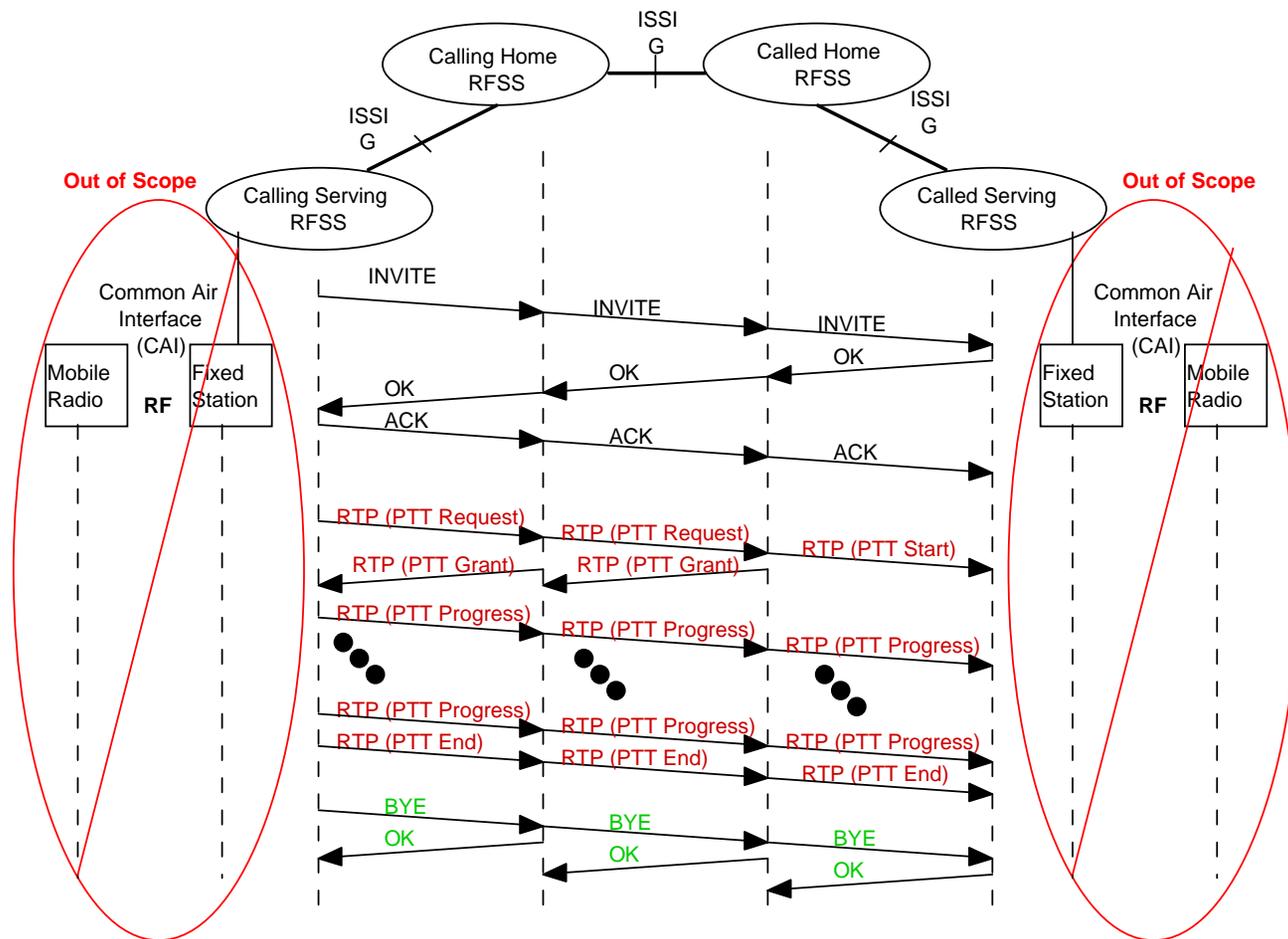
Areas of interest within ISSI

- Mobility:
 - SU registration and roaming
 - Group registration
- SU-to-SU call setup:
 - Availability check
 - Call roaming
 - Two-way call model
 - Real audio feed
- Group call setup:
 - Statistical-based talk spurt generation
- Collocation (serving RFSS = home RFSS)
- Resource management:
 - RTP resources
 - RF resources

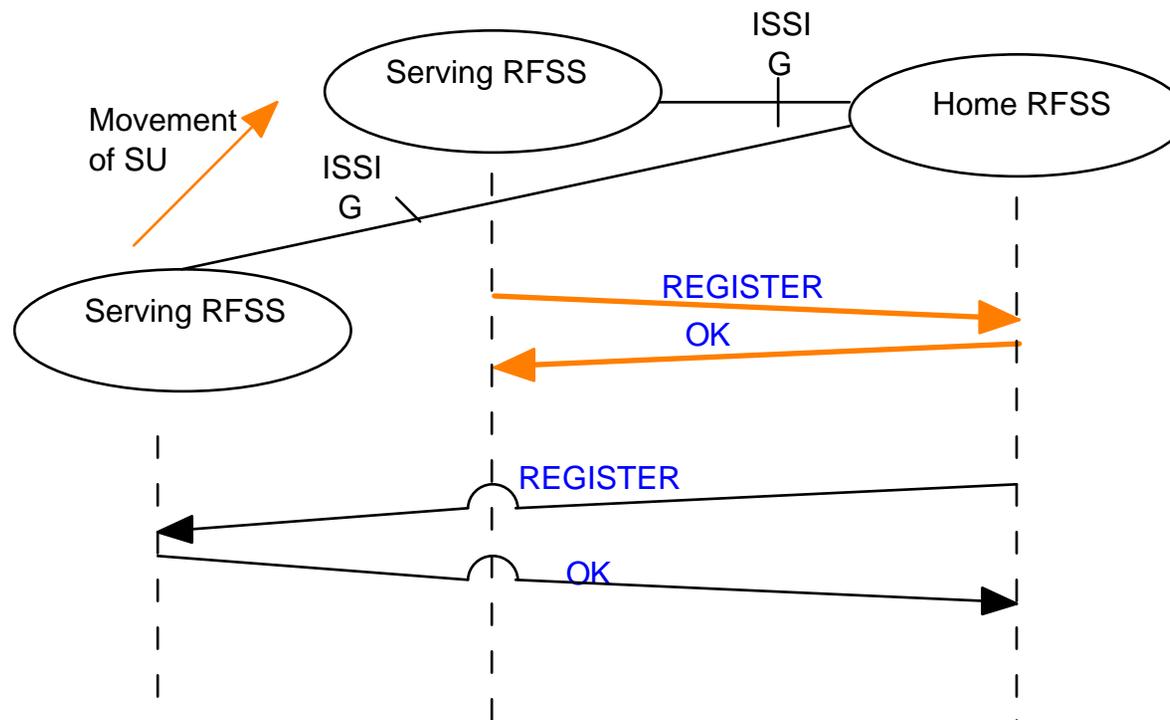
ISSI Communication Flow Diagram: SU registration



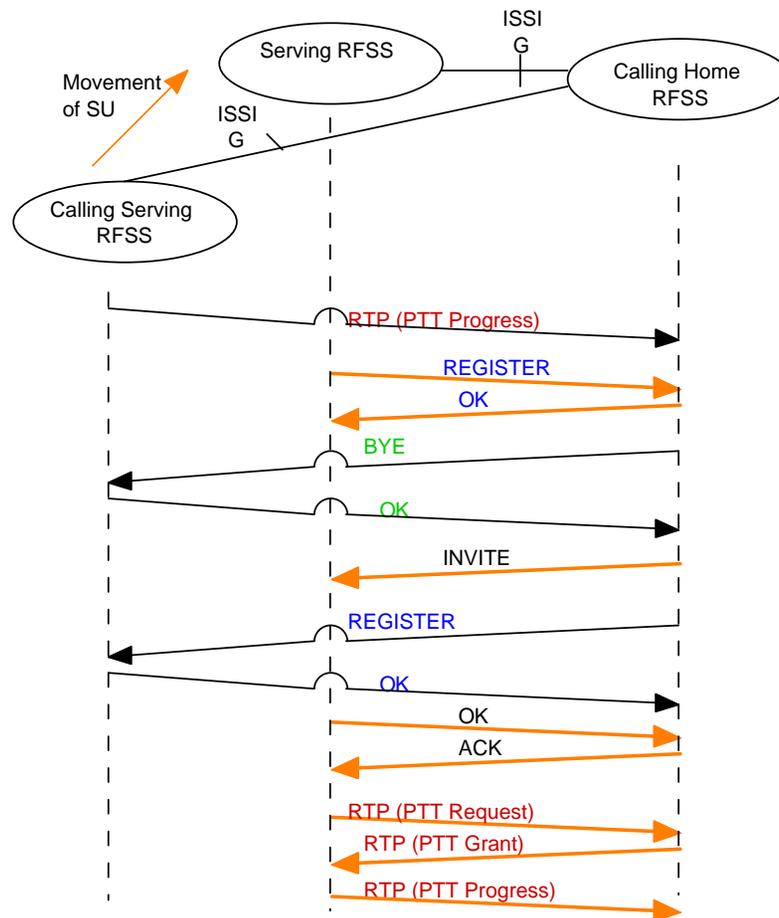
ISSI Communication Flow Diagram: Call set-up



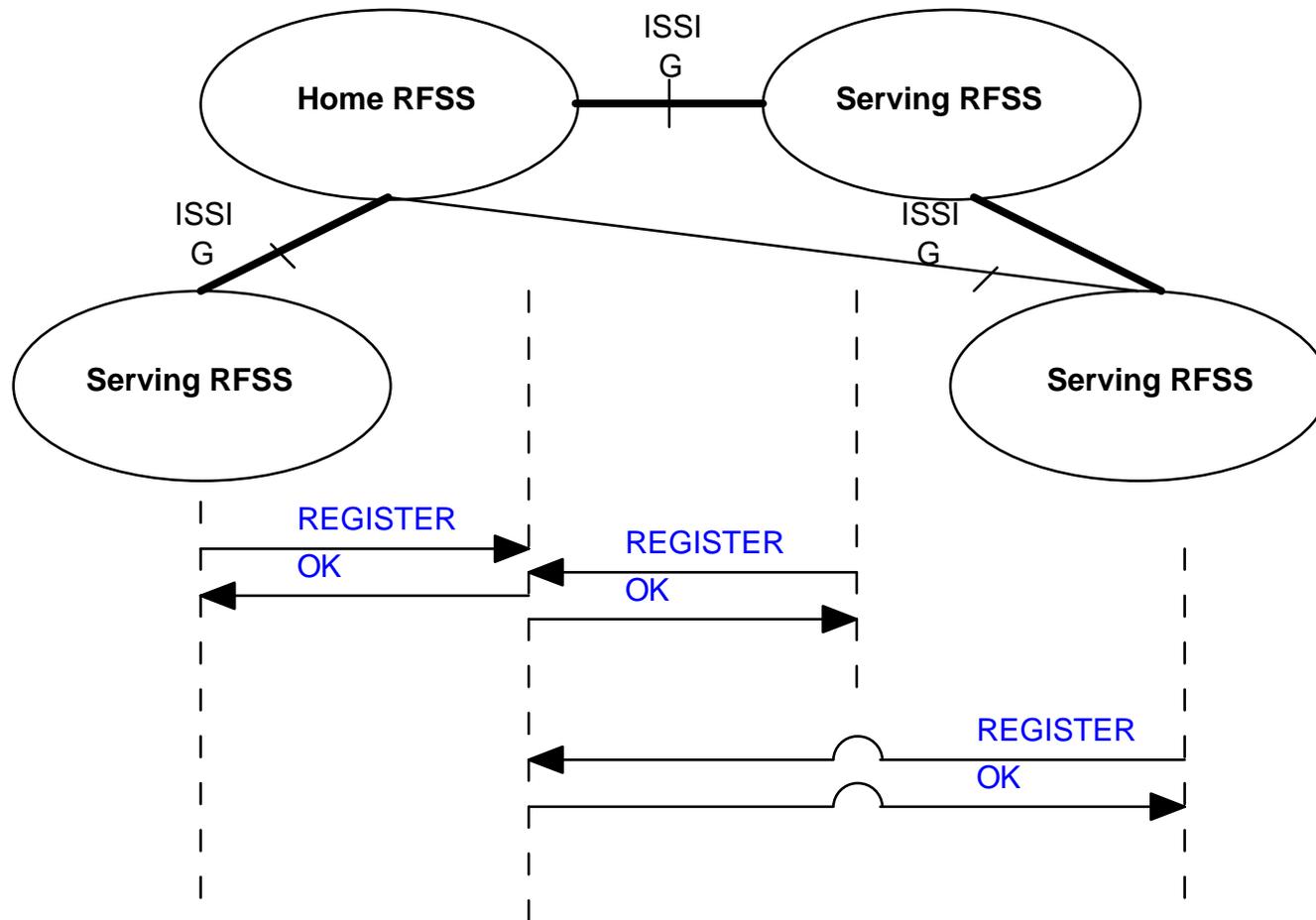
ISSI Roaming Flow Diagram



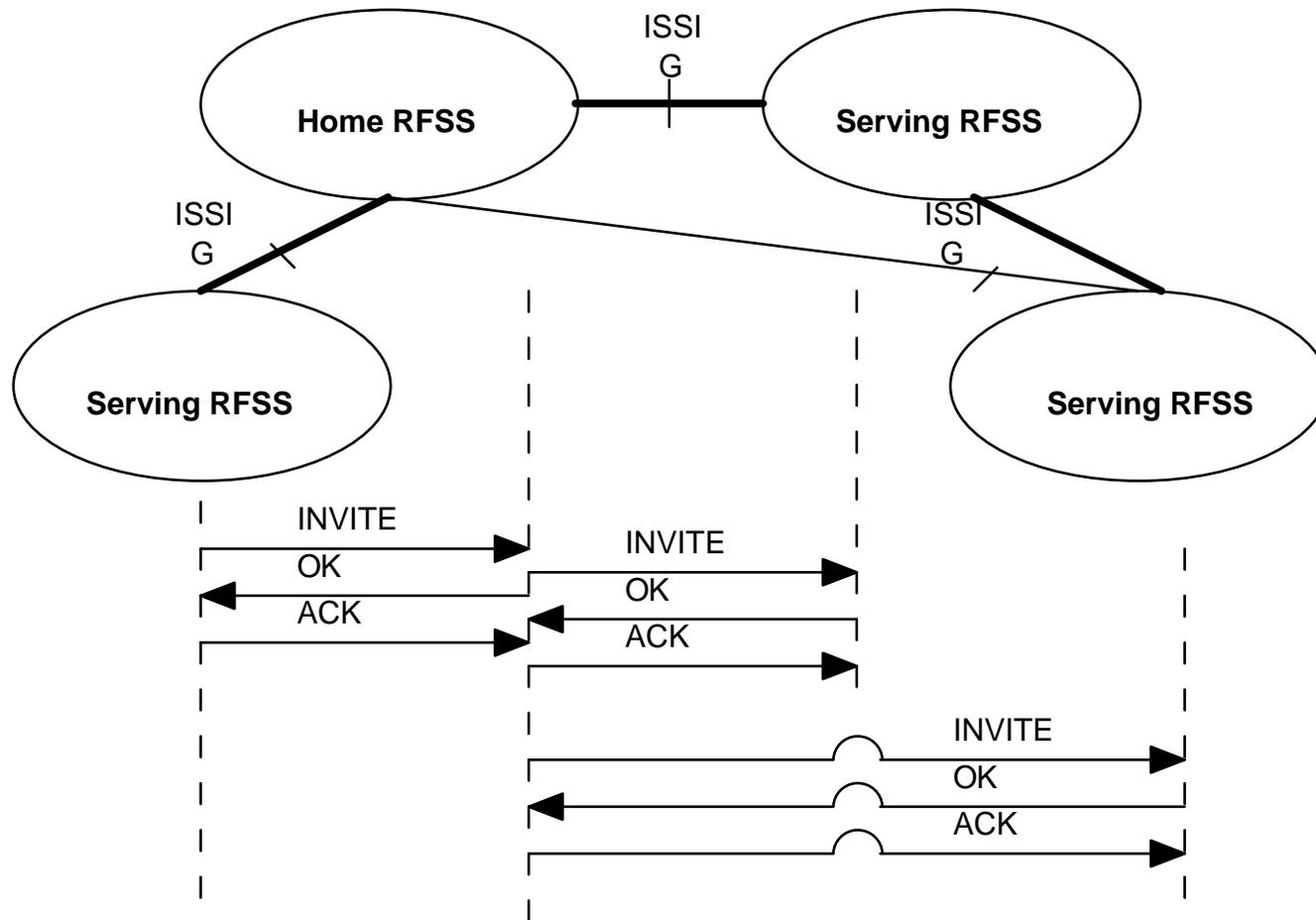
ISSI Roaming Flow Diagram (with an active call)



ISSI Communication Flow Diagram: Group Registration



ISSI Communication Flow Diagram: Group Call Set-up



Measure the Protocol Behavior

- Define performance measures based on evaluation objectives
 - Evaluate the behavior of the ISSI protocol*
 - Give insights on deployment configurations*
- Define usage scenarios including applications and network topologies
 - Consider select network deployment topologies*
 - Identify input parameters*
- Conduct evaluation
 - Vary input parameters
 - **Analyze measurements**
 - Validate results



Iterative process

Example Evaluation Objectives

- Is there enough bandwidth capacity to support all users?
 - Answer based on the observed measurements of the delays/latencies and packet losses.
- What are delays and latencies observed on the different calls?
 - Do the delays and latencies conform to expected performance?
- Are there any calls rejected?
 - If so, need to investigate whether it is due to capacity issues or priority issues.
- Is the application quality acceptable (e.g.. audio)?
 - If not, examine delay and packet loss measurements.

Generic Network Performance Measures

ITU-T Y.1541: Network Performance objectives for IP-based services

- IP Packet Transfer Delay (IPTD): upper bound on the mean end-to-end delay (UNI-to-UNI).
- IP Packet Delay Variation (IPDV): upper bound on the $1-10^{-3}$ quantile on the IPTD minus the minimum IPTD.
- IP Packet Loss Ratio (IPLR): upper bound on the packet loss probability.
- IP Packet Errored Ratio (IPER): upper bound on the number of errored packets per total packets sent.
- IP Packet Reordering Ratio (IPRR): upper bound on the number of packets reordered per total packets sent.

Other useful measures

- Access Delay (seconds): the time it takes to transmit a packet from the time it is passed to the MAC layer until it is successfully received at the destination – generally accounts for queuing and retransmissions delays.
- Throughput (bits/s): the number of bits successfully received divided by the time it took to transmit them over the medium

Simulation Model Network Statistics

Node	<ul style="list-style-type: none"> •Statistics overview (min/max/mean data rate, delay) 	<ul style="list-style-type: none"> •Number of packets sent •Number of packets received •Number of packets dropped •Number of packet forwarded •Forwarding delay •Sending rate •Receiving rate
Link	<ul style="list-style-type: none"> •Statistics overview (min/max/mean data rate, delay) 	<ul style="list-style-type: none"> •Number of packets sent •Number of packets received •Number of packets dropped •Queuing delay •Transmit delay •Sending rate •Receiving rate
Application	<ul style="list-style-type: none"> •Start time, stop time •End points •Statistics overview (min/max/mean data rate, delay) 	<ul style="list-style-type: none"> •Number of packets sent •Number of packets received •Packet delay •Packet jitter •Forwarding delay •Sending rate •Receiving rate

Simulation Model ISSI Statistics

	Simulation wide statistics	Dynamic statistics
RFSS	<ul style="list-style-type: none"> •Number of registration performed (as home or serving) •Number of calls initiated and completed 	<ul style="list-style-type: none"> •Load (SUs registered, active calls)
SU	<ul style="list-style-type: none"> •Mobility information (registration time and status) •Call information (time, duration, status) 	
Group	<ul style="list-style-type: none"> •List of servings registered •Calls made to the group (time, initiator, duration, status) 	<ul style="list-style-type: none"> •Number of servings registered for the group
SU to SU calls	<ul style="list-style-type: none"> •Call information (calling, called, time, duration, status) •Statistics overview (min/max/mean data rate, delay) •List of segments (i.e. connection between 2 RFSSs) establish during the call 	<ul style="list-style-type: none"> •End-to-end, per segment, and per link: <ul style="list-style-type: none"> –Data rate –Delay
Group calls	<ul style="list-style-type: none"> •Call information (calling,time, duration, status) •List of servings 	<ul style="list-style-type: none"> •Per segment and per link: <ul style="list-style-type: none"> –Data rate –Delay

Input Parameters

- Topology
 - Number of nodes
 - Links,
 - Capacity
 - Media type
 - Node connectivity
- Scenario
 - Application
 - Voice traffic
 - Subscriber Unit to Subscriber Unit (SU-to-SU)
 - Subscriber Group (SG) / Group Call / Talk Group
 - Data traffic
 - Movement (roaming) of Subscriber Unit (SU)
- Administrative configurations
 - Number of RF resources (external)
 - Number of Priorities for calls (SIP) and resources (RTP)
 - Preemption availability

Analyze the results

- Post-process data trace
- Compute statistics report based on measurements
- Adequate presentation of the results
 - Visualize measures (graphs, tables)
 - Assess application quality (audio, video)



ISSI Network Simulation Toolkit Overview

ISSI Simulation Toolkit Facts Sheet

- An extension to the NS-2 event-driven simulation platform which is a publicly available network simulation package used for network research in Industry and Academia
- Code is written in C/C++ and runs on multiple platforms including Linux, MAC OS, and Windows
- Configuration input to simulation program (i.e., a scenario script) is written in Tcl
- The Graphical User Interface (GUI) is written in Java and can also run on multiple platforms

Tool Architecture

Client



GUI:

- Java (version 1.6 required)
- Platform independent

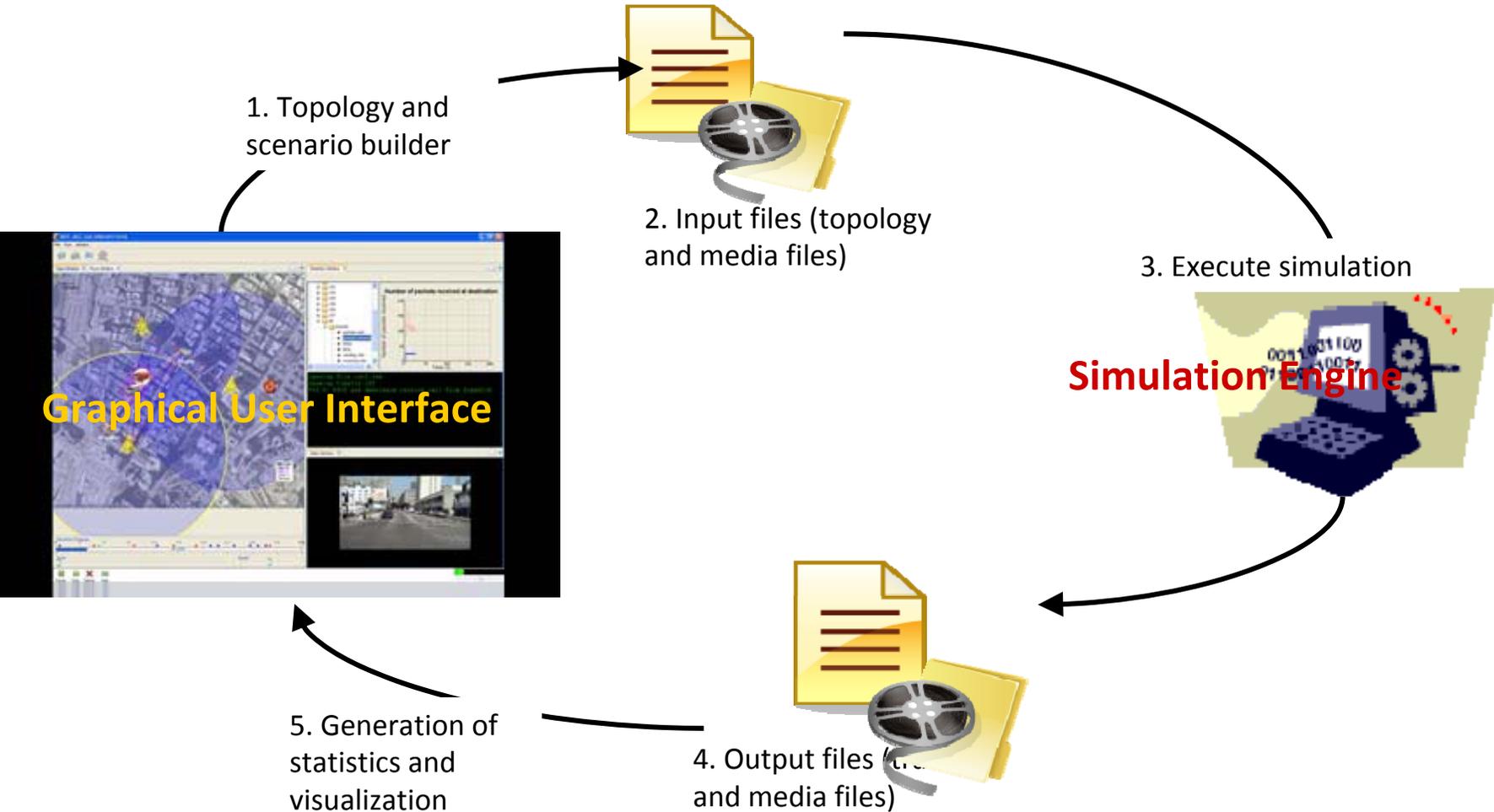
Server



Simulation tool:

- Linux
- ISSI modeling tool (NS-2)
- FFMPEG, GPAC
(for audio support)

Major Building Blocks



Input File

```
set homeB [$ns node 3.0.0]
$homeB set X_ 600
$homeB set Y_ 400
$homeB set Z_ 0
#GUI: use_icon homeB router.png
#GUI: set_description_font_size homeB 14
#GUI: node_color homeB black

set serving3 [$ns node 5.0.0]
$serving3 set X_ 800
$serving3 set Y_ 300
$serving3 set Z_ 0
#GUI: use_icon serving3 router.png
#GUI: set_description_font_size serving3 14
#GUI: node_color serving3 black

##links
$ns duplex-link $serving0 $homeA 100Mb 10ms DropTail 1000
$ns duplex-link $serving1 $homeA 100Mb 15ms DropTail 1000
$ns duplex-link $homeA $homeB 100Mb 10ms DropTail 1000
$ns duplex-link $serving2 $homeB 100Mb 15ms DropTail 1000
$ns duplex-link $serving3 $homeB 100Mb 25ms DropTail 1000

##Configure the nodes with the protocol stack for ISSI
set rfgA [new ISSIControlFunction $homeA 2 0 2 ]
set rfgB [new ISSIControlFunction $homeB 3 0 3 ]
set rfg2 [new ISSIControlFunction $serving2 4 0 4 ]
set rfg3 [new ISSIControlFunction $serving3 5 0 5 ]
```

NS-2 Simulation platform

- Discrete event simulation engine
 - Publicly available and open source
 - Extended to support ISSI protocol
- Library of models:
 - Access technologies: Ethernet, Wi-Fi, WiMAX
 - Transport protocols: UDP, TCP, SCTP
 - Applications: CBR, VBR, video, voice, FTP

Simulation Execution

```
bash-3.2$ ns group_registration.tcl
```

```
At 10.000000000 UMMF in 00.000.00000. sending registration request
p25group argc : 7
At 10.000000000 GMMF in 00.000.00000. sending Group registration request
At 10.010020480 Mobility PE in 02.000.00002. received a packet
    REGISTER with expire= 330.000000
At 10.010020480 UMMF in 02.000.00002. received SU registration request
    I am the home RFSS for this SU (00002000000000)->send ok message
At 10.010040480 Mobility PE in 02.000.00002. received a packet
Parsing sgid 00002000000A
    REGISTER with expire= 330.000000
At 10.010040480 GMMF in 02.000.00002. received Group registration request
    I am the home RFSS for this Group->send ok message
At 10.020043680 Mobility PE in 00.000.00000. received a packet
At 10.020043680 UMMF in 00.000.00000. received SU registration success
At 10.020066400 Mobility PE in 00.000.00000. received a packet
Parsing sgid 00002000000A
At 10.020066400 GMMF in 00.000.00000. received Group registration success
SU registration
SU 3 0 1
Setting role 0 for SU 000030000000001
creation su 0x1913610 0x19060a0
At 11.000000000 UMMF in 04.000.00004. sending registration request
p25group argc : 7
At 11.000000000 GMMF in 04.000.00004. sending Group registration request
At 11.015020480 Mobility PE in 03.000.00003. received a packet
    REGISTER with expire= 330.000000
```

Trace File

```
L 15.260108 ISSI s 2 -HI- 101 0 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 401
+ 15.260108 2 0 SIP 232 I----- 0 2.0.0.0 0.0.0.1 -1 20 2 0 180 0 104 000020000000000@p25dr 000030000000001@p25dr
- 15.260108 2 0 SIP 232 I----- 0 2.0.0.0 0.0.0.1 -1 20 2 0 180 0 104 000020000000000@p25dr 000030000000001@p25dr
r 15.270127 2 0 SIP 232 I----- 0 2.0.0.0 0.0.0.1 -1 20 2 0 180 0 104 000020000000000@p25dr 000030000000001@p25dr
L 15.270127 ISSI r 0 S-I- 101 0 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 401
L 15.435071 ISSI s 4 S--D 101 2 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 403
L 15.460117 ISSI r 2 -HI- 101 2 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 402
L 15.460117 ISSI s 2 -HI- 101 2 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 401
+ 15.460117 2 0 SIP 290 I----- 0 2.0.0.0 0.0.0.1 -1 23 2 0 200 0 104 000020000000000@p25dr 000030000000001@p25dr
- 15.460117 2 0 SIP 290 I----- 0 2.0.0.0 0.0.0.1 -1 23 2 0 200 0 104 000020000000000@p25dr 000030000000001@p25dr
r 15.470141 2 0 SIP 290 I----- 0 2.0.0.0 0.0.0.1 -1 23 2 0 200 0 104 000020000000000@p25dr 000030000000001@p25dr
L 15.470141 ISSI r 0 S-I- 101 2 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 401
L 15.470141 ISSI s 0 S-I- 102 0 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 401
+ 15.470141 0 2 SIP 232 A----- 0 0.0.0.1 2.0.0.0 -1 24 0 2 4 0 104 000020000000000@p25dr 000030000000001@p25dr
- 15.470141 0 2 SIP 232 A----- 0 0.0.0.1 2.0.0.0 -1 24 0 2 4 0 104 000020000000000@p25dr 000030000000001@p25dr
L 15.470141 ISSI s 0 S-I- 206 1 00002000000000 000030000000001 33
+ 15.470141 0 2 RTP 99 ----- 401 0.0.0.2 2.0.0.1 0 25 0 2
- 15.470159 0 2 RTP 99 ----- 401 0.0.0.2 2.0.0.1 0 25 0 2
r 15.480159 0 2 SIP 232 A----- 0 0.0.0.1 2.0.0.0 -1 24 0 2 4 0 104 000020000000000@p25dr 000030000000001@p25dr
L 15.480159 ISSI r 2 -HI- 102 0 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 401
L 15.480159 ISSI s 2 -HI- 102 0 00002000000000 000030000000001 -c-i 0 -c-r 1 -c-prf 1 -c-d 1 -c-icr 0 -prio 0 402
+ 15.480159 2 3 SIP 232 A----- 0 2.0.0.0 3.0.0.0 -1 26 2 3 4 1 105 000020000000000@p25dr 000030000000001@p25dr
- 15.480159 2 3 SIP 232 A----- 0 2.0.0.0 3.0.0.0 -1 26 2 3 4 1 105 000020000000000@p25dr 000030000000001@p25dr
r 15.480167 0 2 RTP 99 ----- 401 0.0.0.2 2.0.0.1 0 25 0 2
L 15.480167 ISSI r 2 -HI- 206 -1 00002000000000 000030000000001 21
L 15.480167 ISSI s 2 -HI- 202 -1 00002000000000 000030000000001 21
+ 15.480167 2 0 RTP 69 ----- 401 2.0.0.1 0.0.0.2 0 27 2 0
- 15.480167 2 0 RTP 69 ----- 401 2.0.0.1 0.0.0.2 0 27 2 0
```

Graphical User Interface

- Display animated topology
 - Paths of active calls
 - Link capacity
- Facilitate the analysis of the network performance
 - Quantitative: Measurements for applications, RFSSs, network devices, and links
 - Qualitative: capability to listen to audio conversation

Graphical User Interface

The screenshot displays the NS2-Viz graphical user interface for a congestion scenario simulation. The main window shows a network topology overlaid on a satellite map of a coastal region. Nodes include serving stations (serving0-3), home nodes (homeA-C), and routers (router0-4). Traffic flows are visualized with colored lines connecting these nodes.

Topology Browser

- Topology
 - Links
 - Nodes
 - serving0
 - serving1
 - serving2
 - serving3
 - homeA
 - homeB
 - homeC
 - router0
 - router1

Node "homeB" Details:

Items	Value
Address	5.0.0
ID	5
Current Position	490, 90
MAC Type	Default in NS2
Transmission Range	-
Wired Routing	Yes
Multi-interface Node	No
Interface to other node	No
Image Name	Rfa.png

Statistics

- P25/ISSI
 - RFSS
 - SUs
 - Groups
 - SU-to-SU Calls
 - Group Calls
 - Traffic flows
 - Flow 300
 - All
 - Instant
 - packets sent
 - packets received
 - delay
 - jitter
 - sending rate
 - receiving rate

Number of packets received at destination

Graph showing the number of packets received over time (0 to 148 seconds). The y-axis ranges from 0.0 to 168. Multiple colored lines represent different traffic flows, showing a peak in packet reception around 37 seconds followed by a decline and stabilization.

Status

```

Opening file out.res
Pausing time=13.503
*** T=14.0: SU0a starts PTT spurt
*** Going back in time from 16.814151763910016 to 15.040875434875488
T=18.0: Start audio call
T=20.0: SU2a starts PTT spurt
T=30.0: SU3a starts PTT spurt
T=40.0: SU4a starts PTT spurt
T=50.0: SU5a starts PTT spurt
T=60.0: SU6a starts PTT spurt
    
```

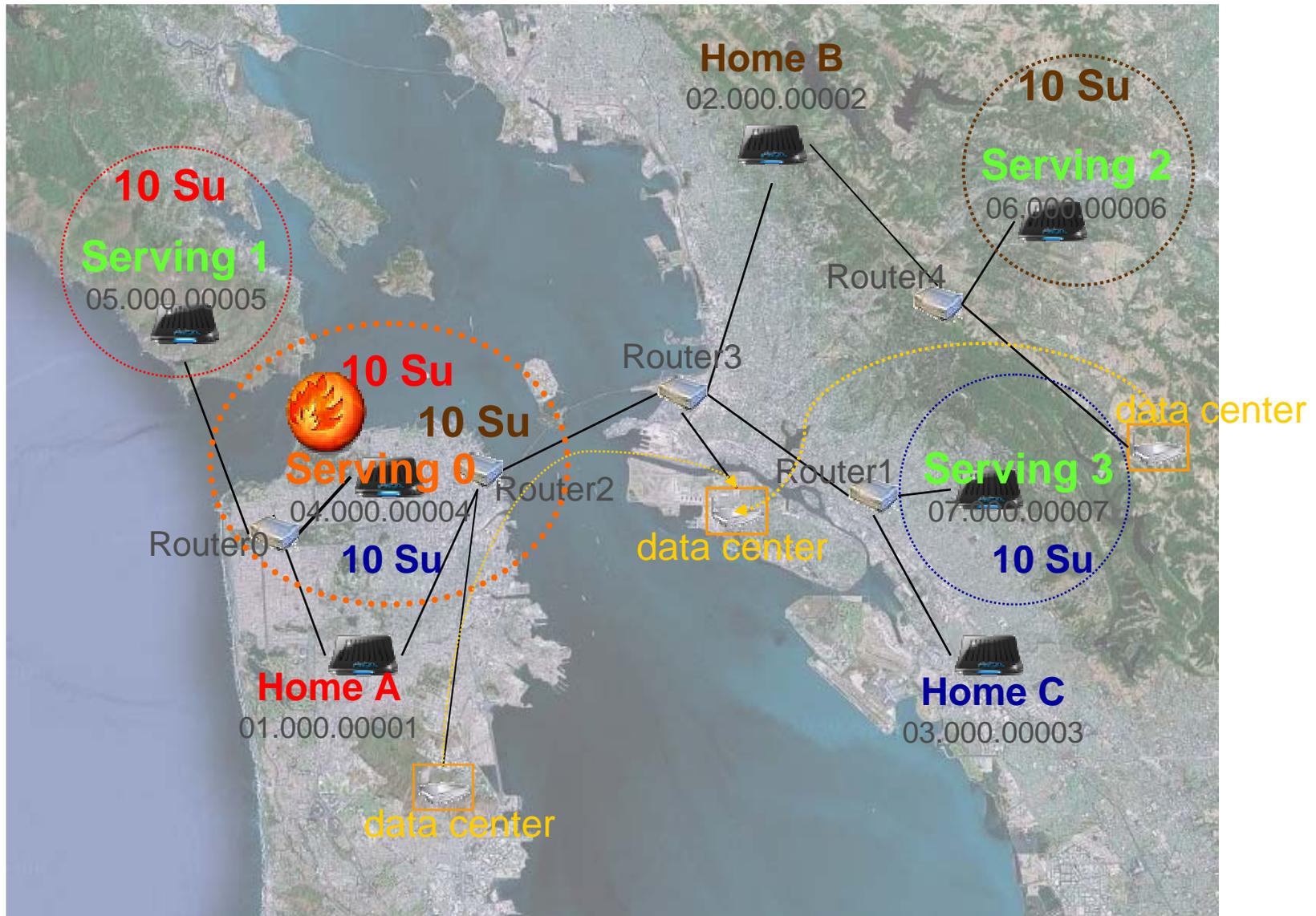
Simulation Progress

Timeline from 0 to 149 seconds. Current time is 78.63493 seconds. Controls include Zoom, Speed (Slow, Real Time, Fast), Resume, and stop buttons.

Video

Video playback controls showing 78 / Total 148 seconds.

Example Network Topology



Incident Scenario

- A large incident occurs requiring all available emergency personnel to move to the incident area.
- 30 units arrive on the site of the incident from three different jurisdictions
- The SUs at the incident site register with the nearest serving RFSS
- Calls are placed from SUs at the incident to other units in other jurisdictions.

Topology and Traffic Parameters

Parameter	Value
Topology	
Number of Home RFSS	3
Number of SUs per Home RFSS	20
Number of Serving RFSS	4
Link data rate (Mbit/s)	1
Link delays (s)	0.015
Link Queue type	Drop tail
Link Queue length (packet)	100

Parameter	Value
Voice traffic	
Packet size (byte)	87
Packet interval (s)	0.02
Data traffic	
Packet size (byte)	1000
Packet interval (s)	0.008

NIST_NS2_GUI 200610171010

File Run Window

Topo Window x Flow Window x

TopoBrowser Window x

Node "homeA" Details:

Items	Value
Multi-interface Node	No
Interface to other node	No
Image Name	Rfg.png
Is RFG	Yes
DNS name	router0
rfss-id	01
rfss-name	01.000.00001.
system-id	000
system-name	000.00001.
wacn-id	00001

Statistics Window x

Number of packets received at destination

```

Opening file out_issi-rtp.res
Parsing time=34.224
P=5.0: priority for all traffic flows
T=80.0: traffic assigned higher priority
  
```

Simulation Progress

Zoom Speed

Play stop

Go to 0 seconds +10s -10s 161 / Total 161 sec...

start mist_gui NIST_NS2_GUI 2006... 10:11 AM

Live Demonstration of the ISSI Simulation Tool

Problems Uncovered by the Network Simulation

- Congestion on the link due to limited resources (bandwidth)
- High number of packets dropped
- High latency
- Poor audio quality