Network Modeling and Simulation of Mine Communication Systems

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Disclaimer: The National Institute of Standards and Technology (NIST) does not endorse any commercial software product mentioned in this presentation.

Network Modeling and Simulation (NMS)

- What is it good for?
  - Facilitate design and development of communications & networking products.
  - Size up, deploy, and configure a communication network at a particular site to meet performance requirements.
    - Connectivity
    - Quality of Service (QoS)
    - Network Capacity / Blocking Probability
  - Assess fault-tolerance and self-healing capabilities of the network.

Network Modeling and Simulation (NMS)

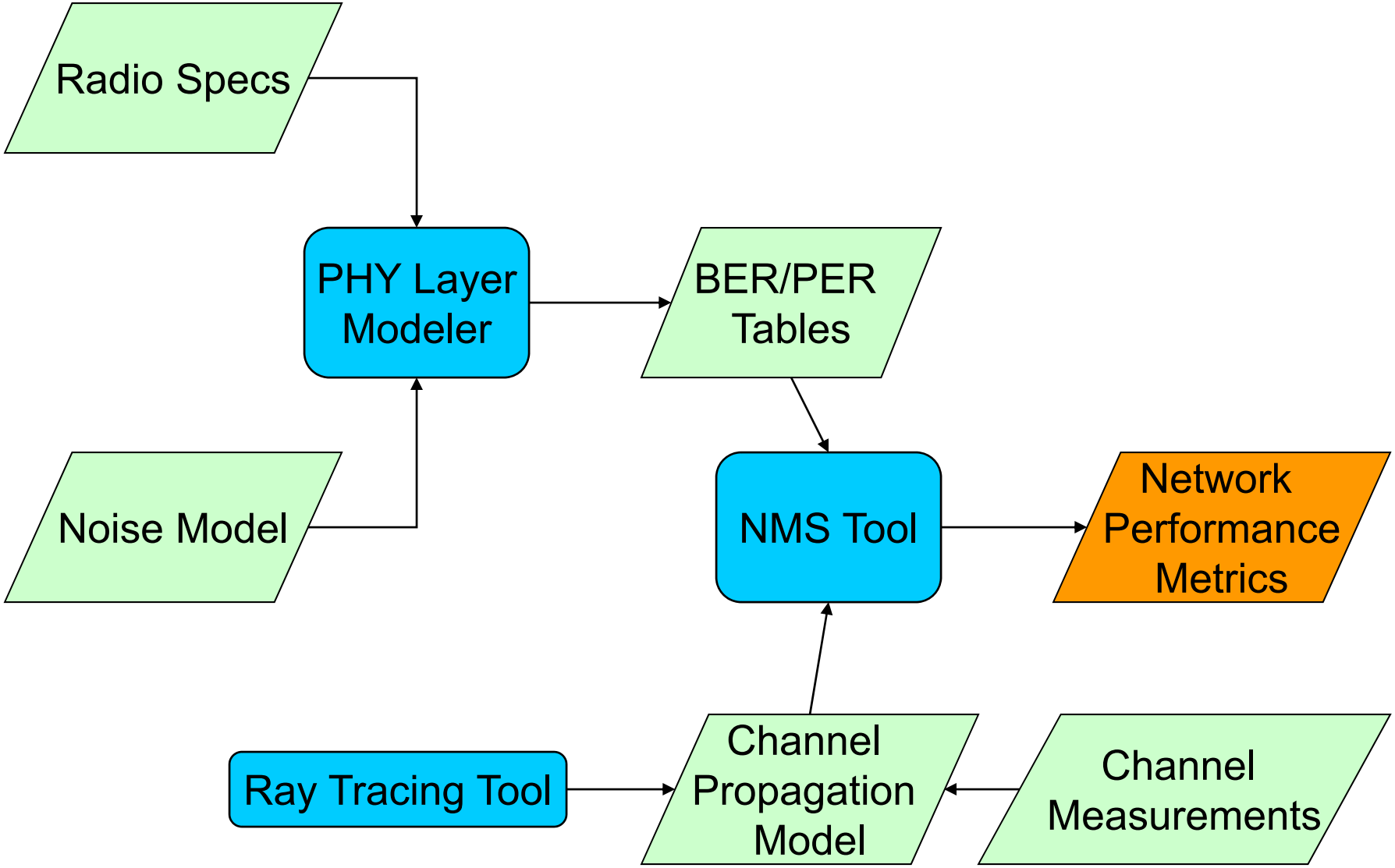
- What does it take to do NMS?
  - Complete technical specifications of communication devices and networking protocols that run on them.
  - Knowing how to use the NMS tool and a lot of man-hours; NMS is resource-intensive!
- What are the caveats?
  - Fidelity of the models; there will always be some abstraction in any modeling effort.

Types of Modeling and Simulation

- For characterizing the communication channel
  - e.g. ray tracing for modeling RF channels
- For designing point-to-point communications equipment
  - e.g. MATLAB or SPW for detailed modeling and simulation of the physical (PHY) layer
- For assessing the performance of the network
  - e.g. OPNET for detailed modeling of the network and performance evaluations

- To keep the computational complexity manageable, it is typically not possible to run a simulation that uses all three components simultaneously and jointly.

Overview of Simulation System



NMS Tool Components

- Network Topology Modeler
  - mine layout
  - Initial node positions
- Node Mobility Modeler
- Traffic Generator
  - voice / data / video
  - constant / variable bit rate (CBR/VBR)
- Network Node Modeler
  - models for various layers of the protocol stack (PHY, MAC, network, application, etc)
- Performance Evaluation Tools
  - performance metrics (packet delivery ratio, delay, jitter, blocking probability)
- Visualization Tools
- Support for data archival

Popular NMS Tools

- OPNET
  - most commonly used NMS tool
  - has the largest repository of models
- ns2 / ns3
  - free and open source
  - initially intended for wired networks; large set of wireless models available now
  - no extensive visualization aids or technical support
- QualNet
  - about 10 years old
  - originally advertised as more scalable than OPNET

More on NMS Tools

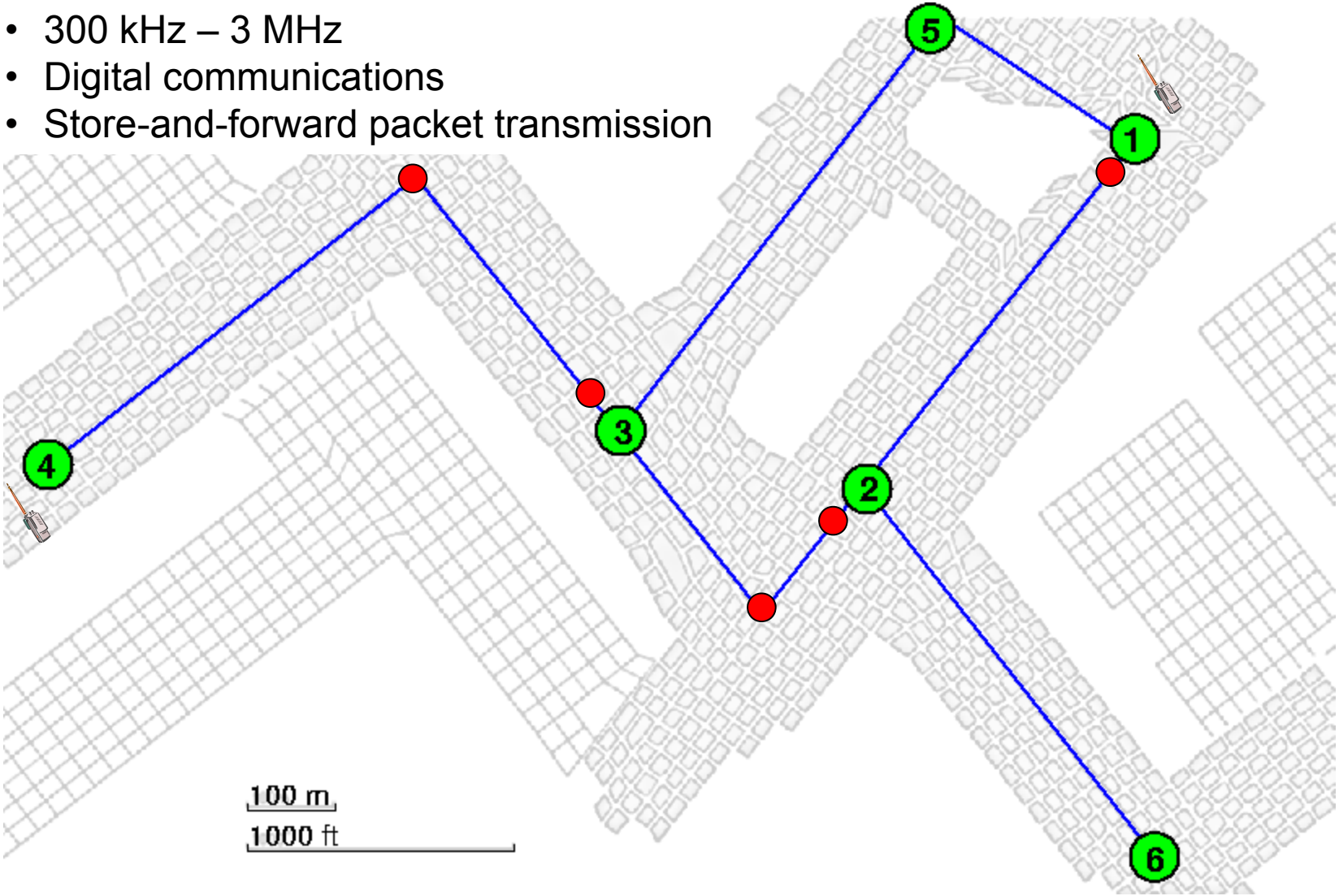
- In addition to network models that come with any of these tools, the user can develop his/her own models using C/C++.
- It takes some effort to learn how to use any of these tools, let alone develop your own models and link them to the tool.

NMS Example

- In 2008-2009, NIST developed models for the MF mesh networking solution (secondary communication system) developed by Kutta Technologies under order from NIOSH and as a result of the 2006 MINER Act.
- Details of this network modeling and simulation effort are given in the next dozen slides along with some performance evaluation results.

Medium Frequency Mesh Network

- 300 kHz – 3 MHz
- Digital communications
- Store-and-forward packet transmission



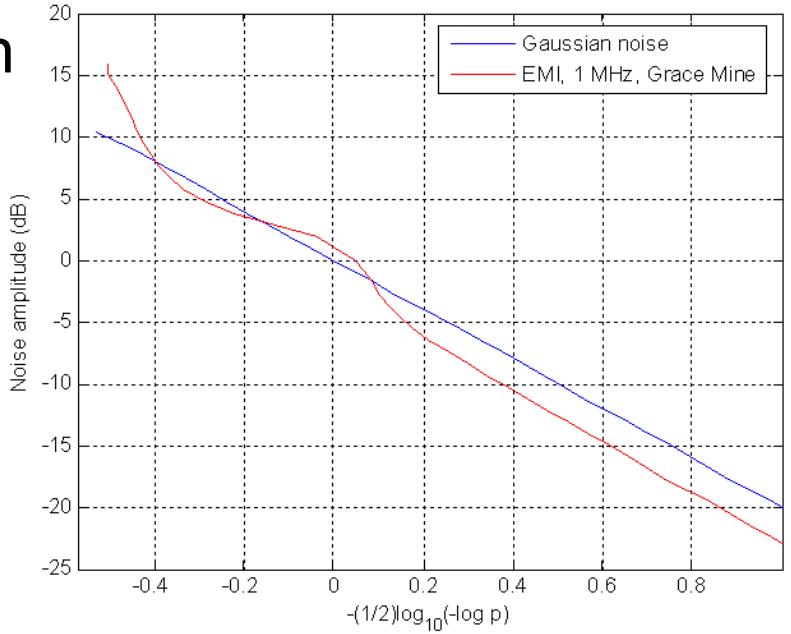
Evolution of Mesh Node Model

	v. 1	v. 2	v. 3
Routing	AODV	Simple Flooding	Proprietary
MAC	CSMA/CA	CSMA/CA	Relative TDMA
Modulation	QPSK	MSK	MSK
FEC	RS + CC	CC	None
Data Rate	30 kb/s	10 kb/s	26 kb/s

Components of model discussed today

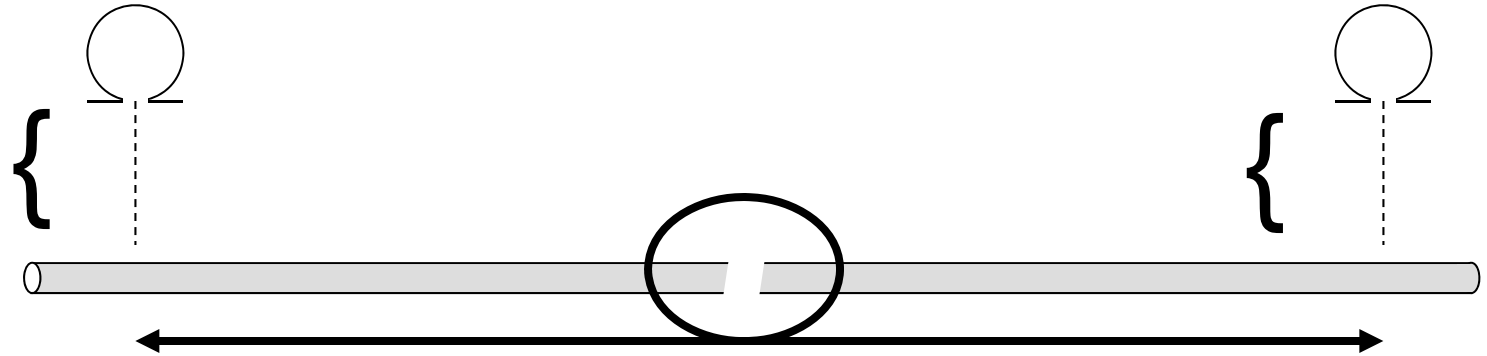
Noise/Interference Model

- Background noise
  - Additive white Gaussian noise (AWGN): model for post-accident scenario
  - Electromagnetic interference (EMI)
    - Generated by mine machinery
    - Model for normal operations
    - More impulsive distribution
- Multiple access interference
  - Simultaneous transmissions by two or more nodes



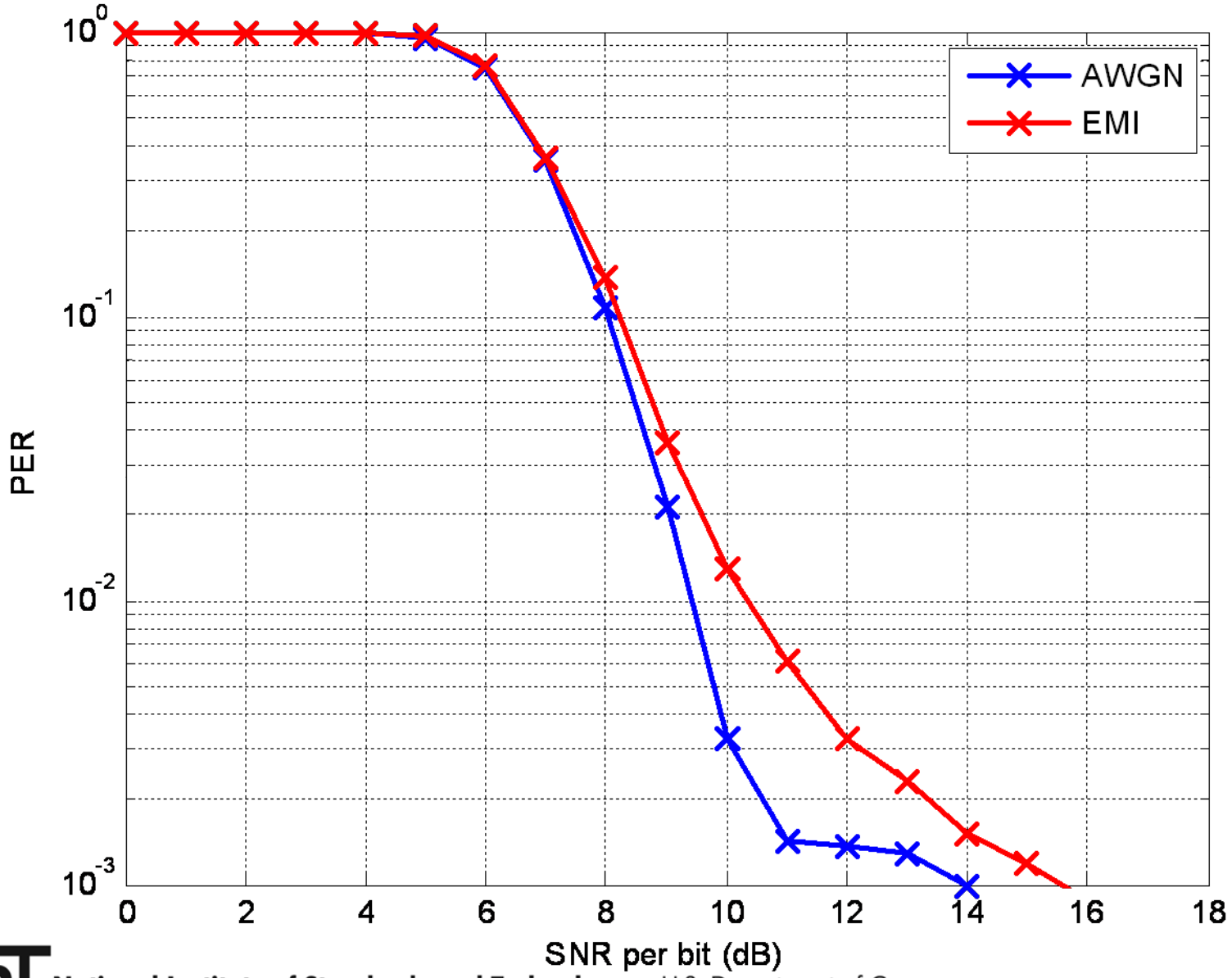
Channel Propagation Model

- MF signal attenuation due to:
  - Length of conductor
    - X dB per 305 m (1000 ft) where $3 \leq X \leq 24$
  - Inductive coupling
    - 30-40 dB over 0.305 m (1 foot)
    - $1/r^4$ power loss with distance
  - Breaks/gaps in conductor

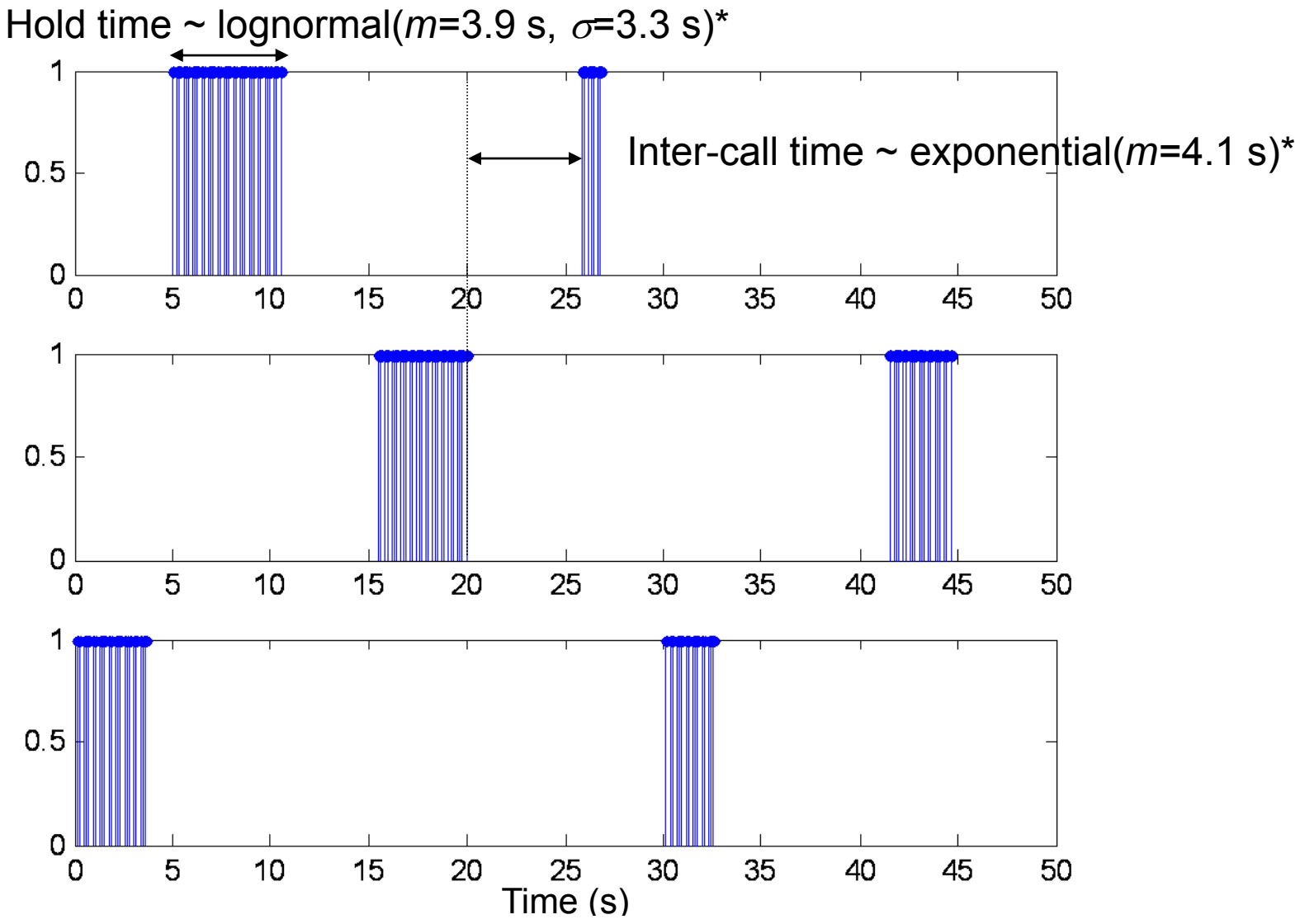


NIOSH is currently researching an improved MF propagation model.

Packet Error Rate of Uncoded MSK: 568-bit Packets

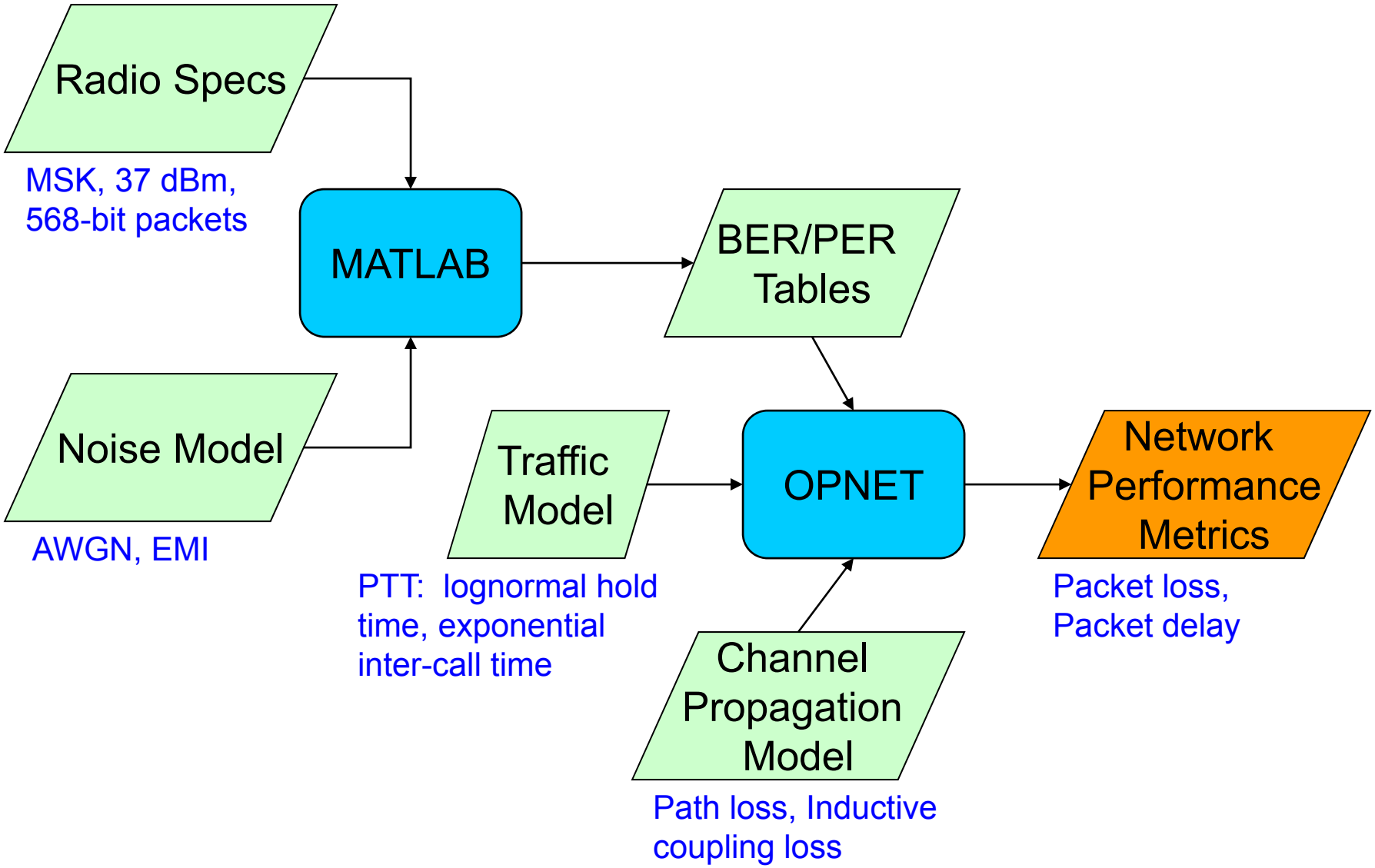


Push-to-Talk Voice Traffic Example: 3 Sources

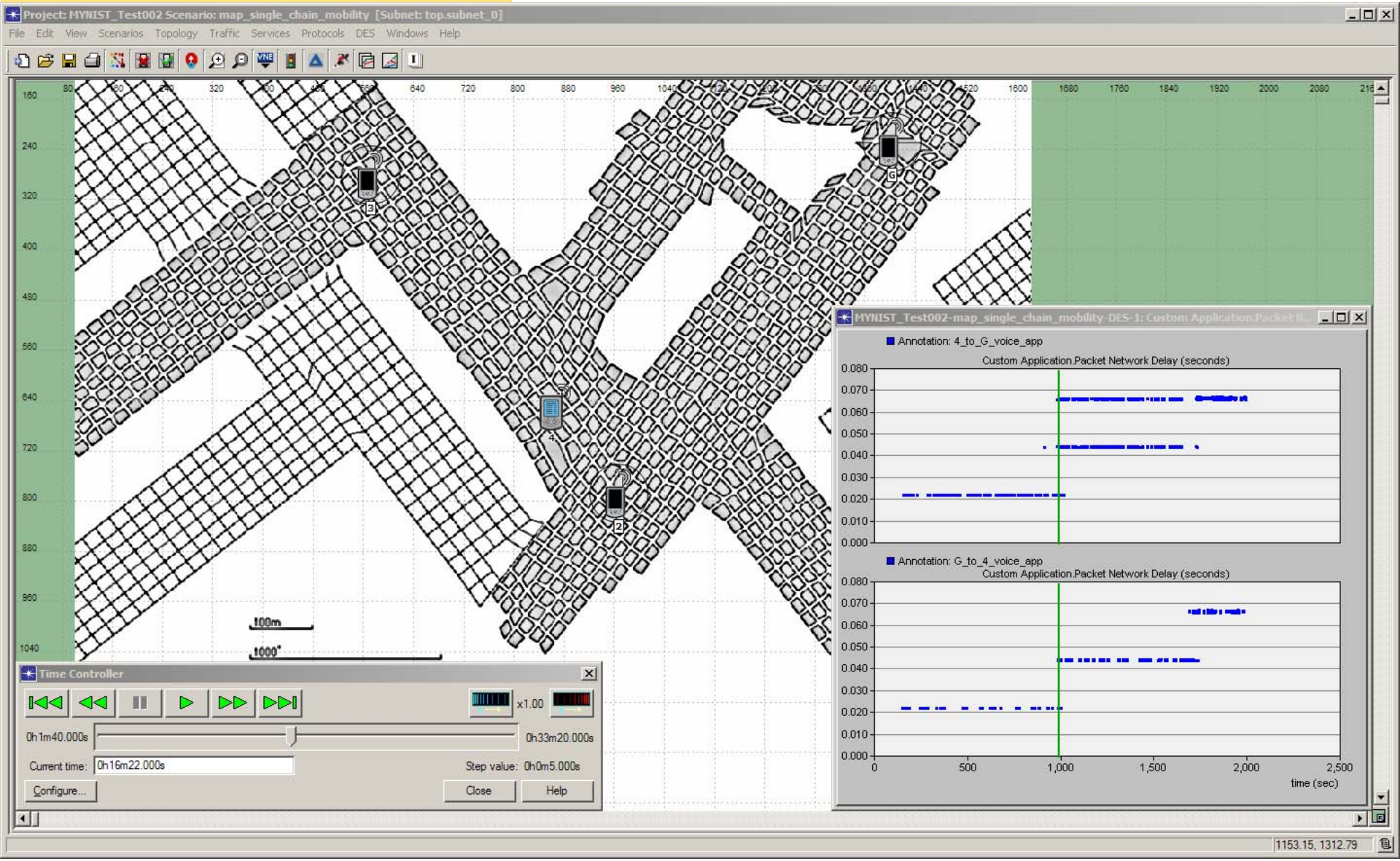


* D. S. Sharp et. al., "Analysis of Public Safety Traffic on Trunked Land Mobile Radio Systems," *IEEE Journal on Selected Areas in Communications*, vol. 22, no. 7, Sept. 2004, pp. 1197-1205.

MF Mesh Network Simulation System



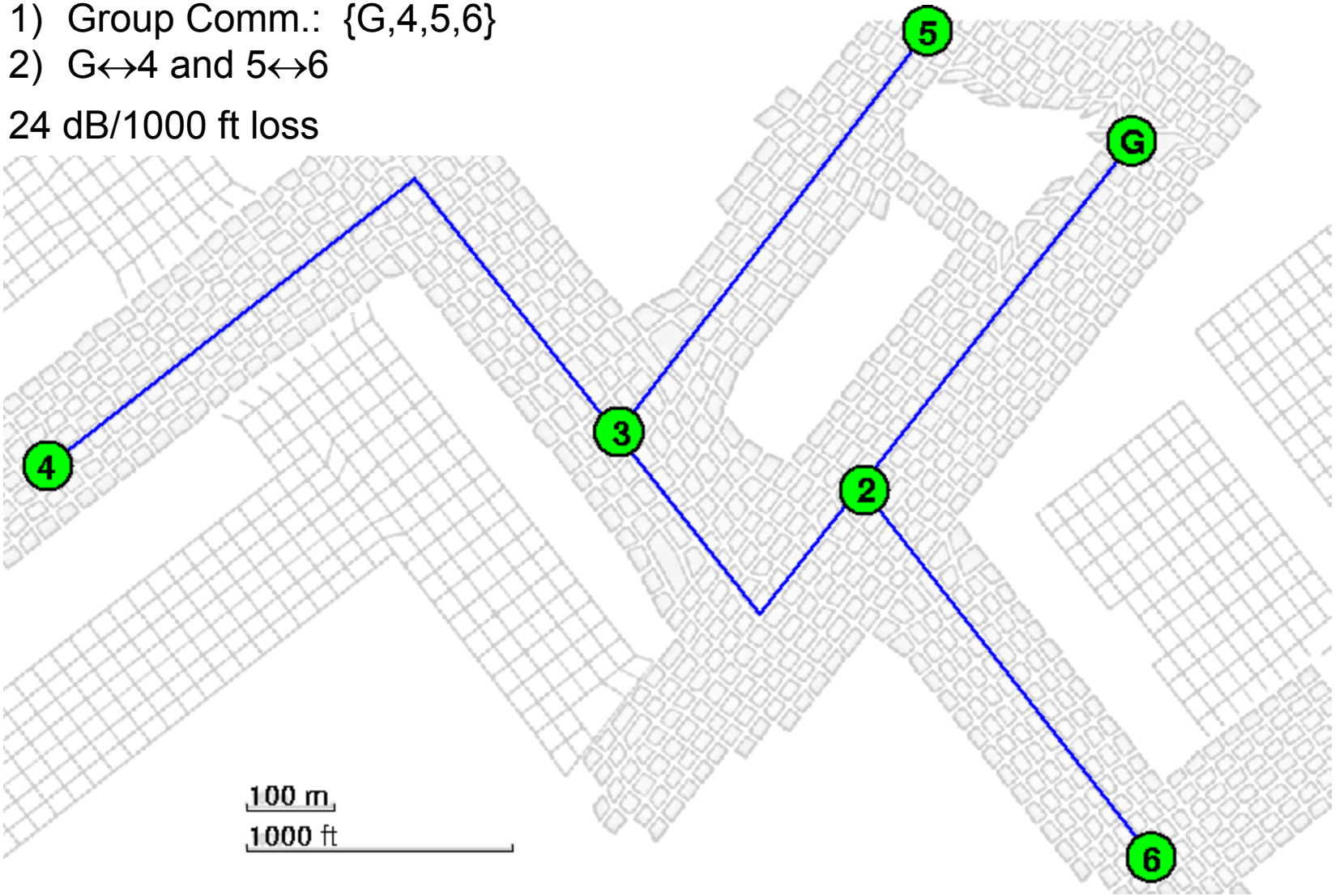
OPNET Screenshot: Mobile MF Node Example



MF Static Network Example

1) Group Comm.: {G,4,5,6}
2) G↔4 and 5↔6

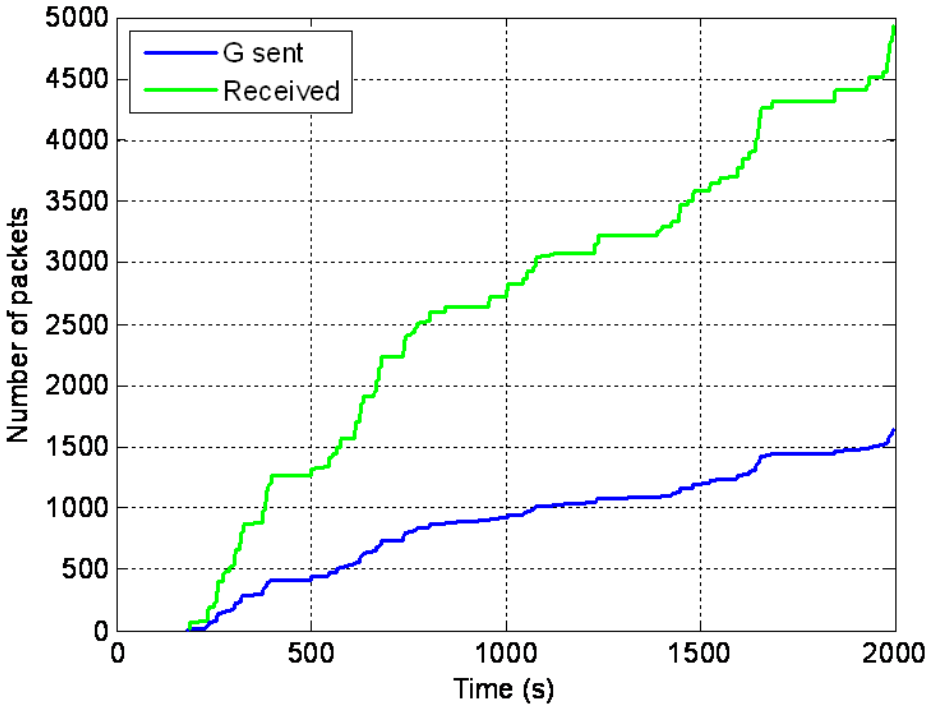
24 dB/1000 ft loss



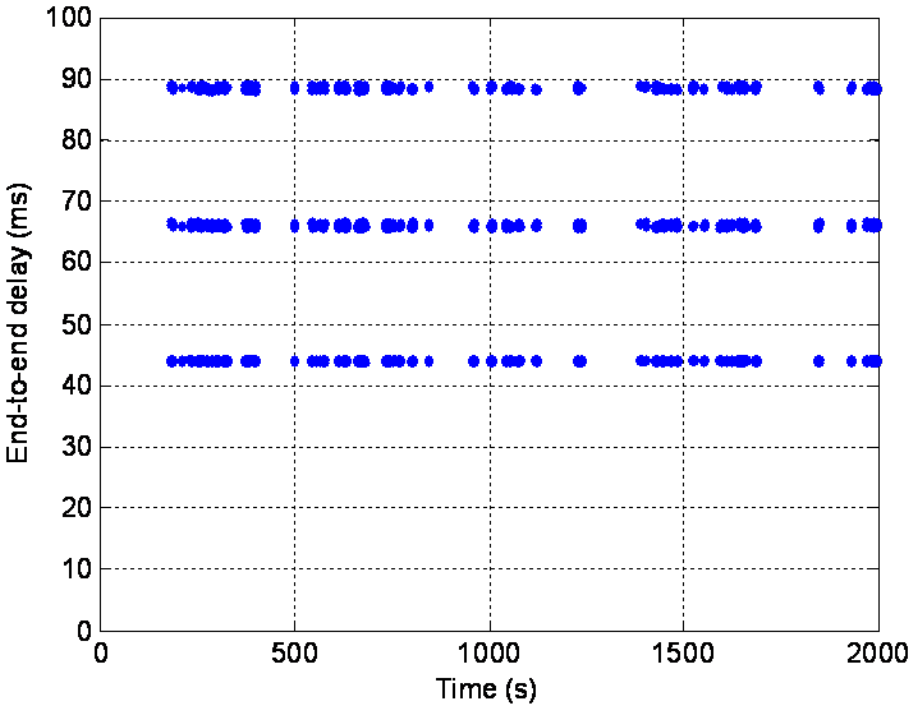
Group Communication Results

$G \rightarrow \{4,5,6\}$

Packets Sent/Received



Packet Delay

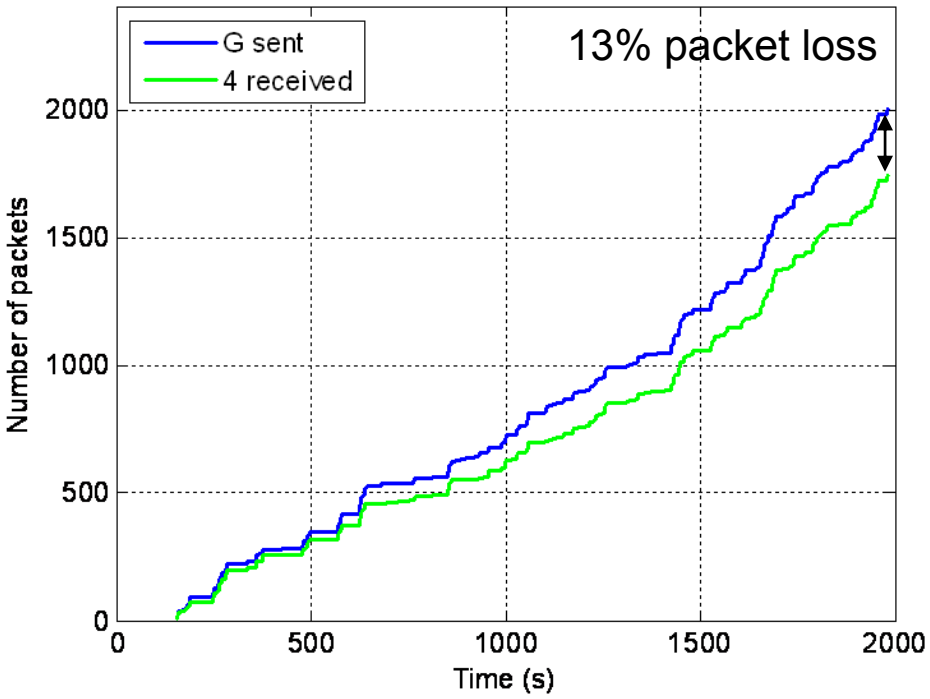


<1% packet loss

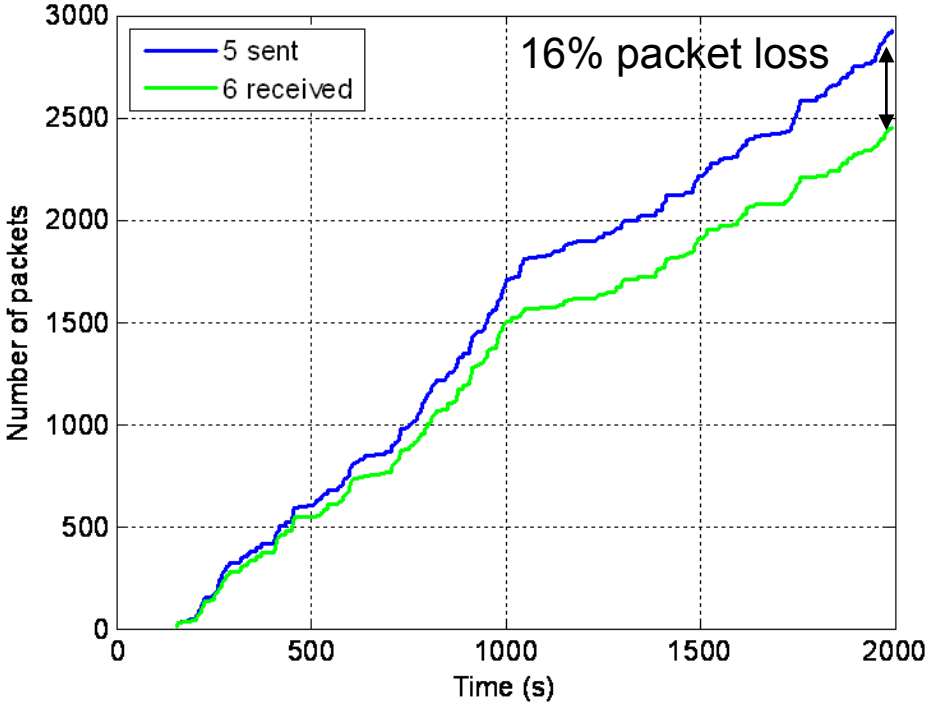
Point-to-Point Communication Results

Packets Sent/Received

G → 4



5 → 6



NMS for Interoperability Testing

- One way of achieving interoperability is through use of gateways / bridges between the primary and secondary system(s).
- It is straightforward to develop models for such gateway / bridge nodes and carry out simulations to assess network performance when the primary system is no longer available in the aftermath of a mine incident.
- Need to know how many such nodes should be deployed and where.
- Can evaluate various traffic management and prioritization algorithms.
- Can determine how much storage is needed at a gateway / bridge for store / forward scenarios.

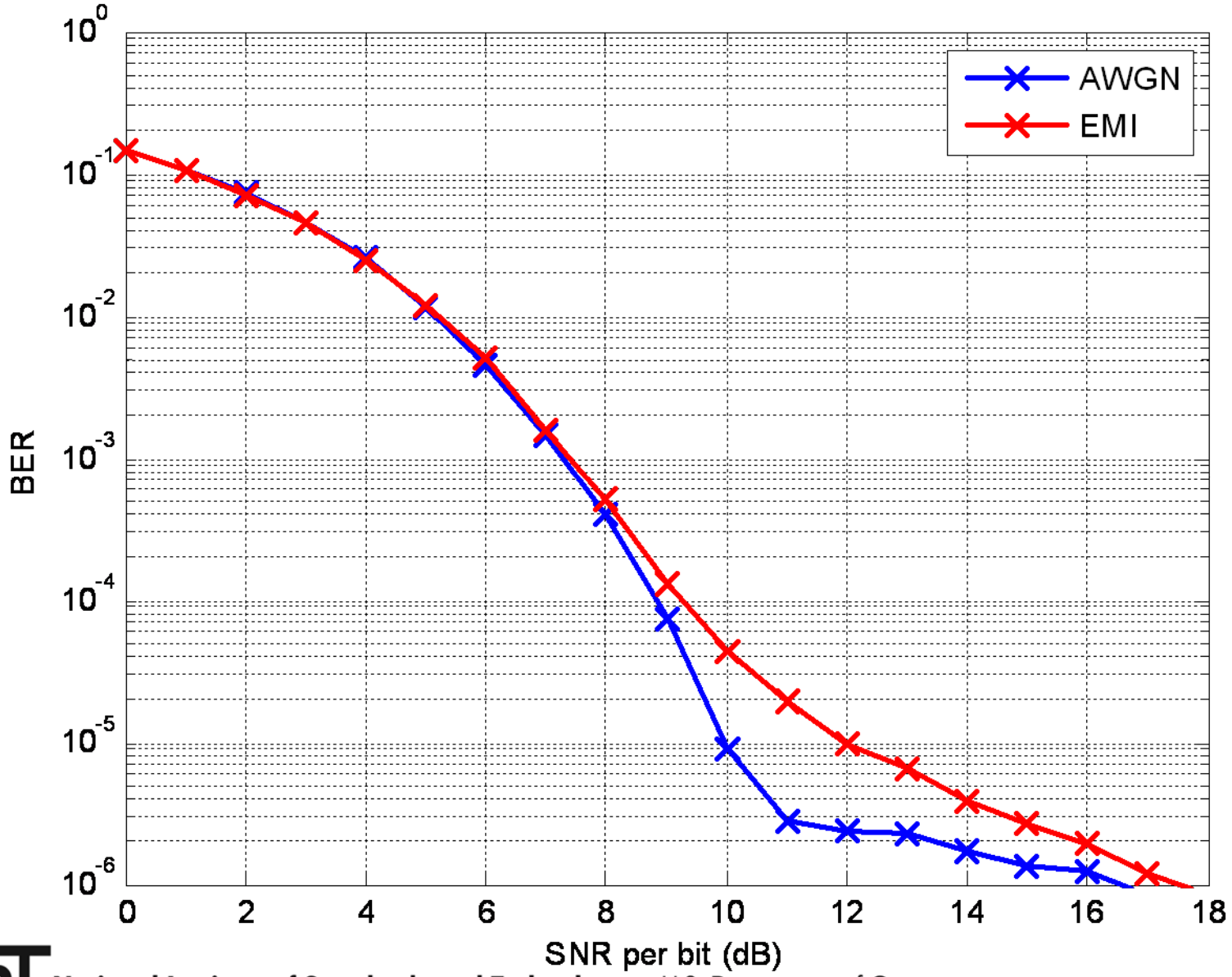
Extra Slides

Packet Format

Length	Node Coverage	*Spare*	Dst Addr	Seq Num	Last Src	Orig Src	App Payload
1 byte	*2 bytes*	*1 byte*	*1 byte*	*2 bytes*	*1 byte*	*1 byte*	*52 bytes*

Voice (2400 bps codec)	**Text**
@ 8 frames/packet	@ 48 characters/packet
= 48 Bytes	= 48 Bytes
+ 4-byte application header	
+ 9-byte frame overhead	
= 61 Bytes	
+ 8-byte preamble/sync + 2-byte CRC	
= 71 Bytes (568 bits)	
21.8 ms @ 26 kb/s	

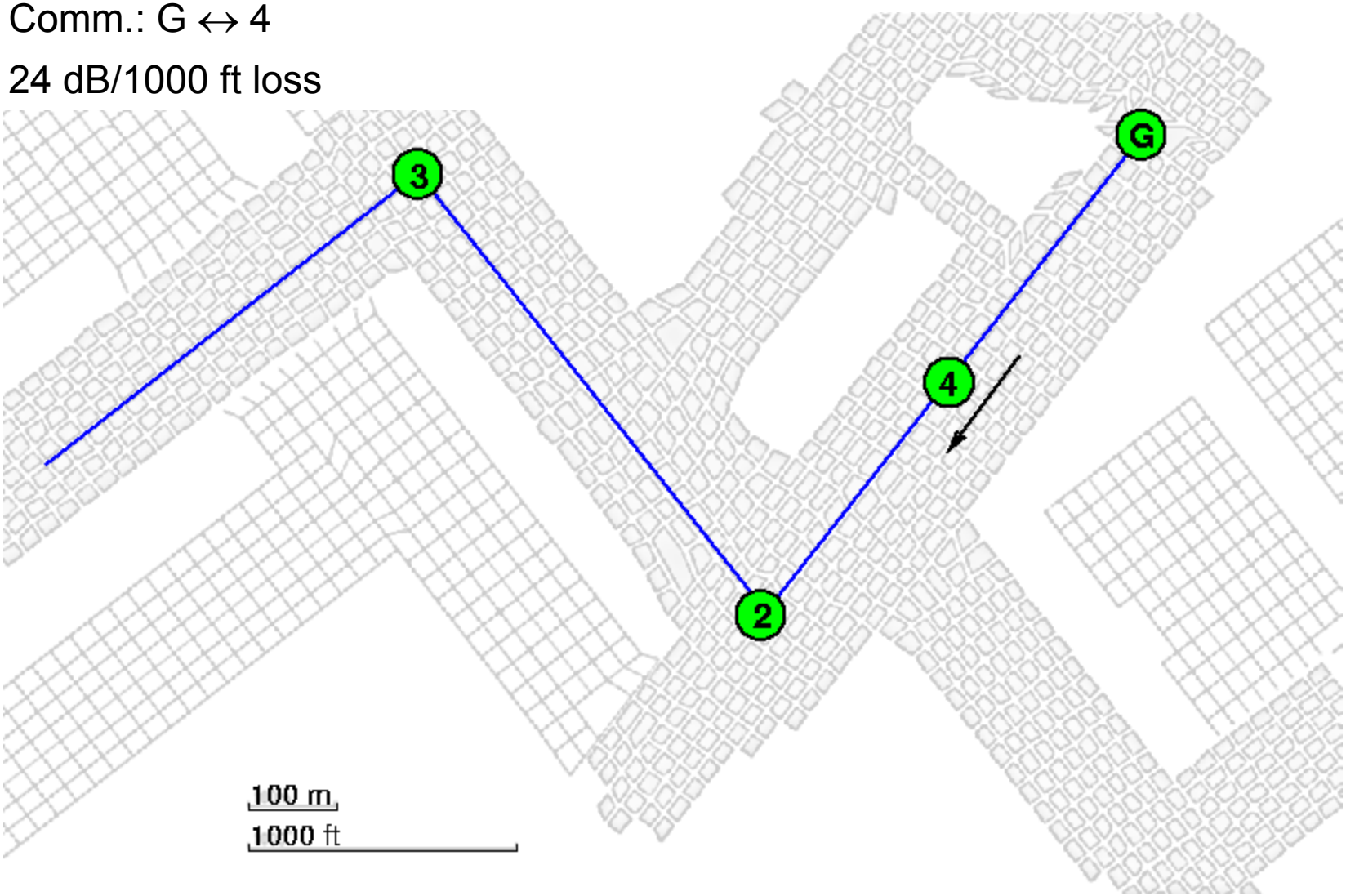
Bit Error Rate of Uncoded MSK: AWGN vs. EMI



Mobile MF Node Example

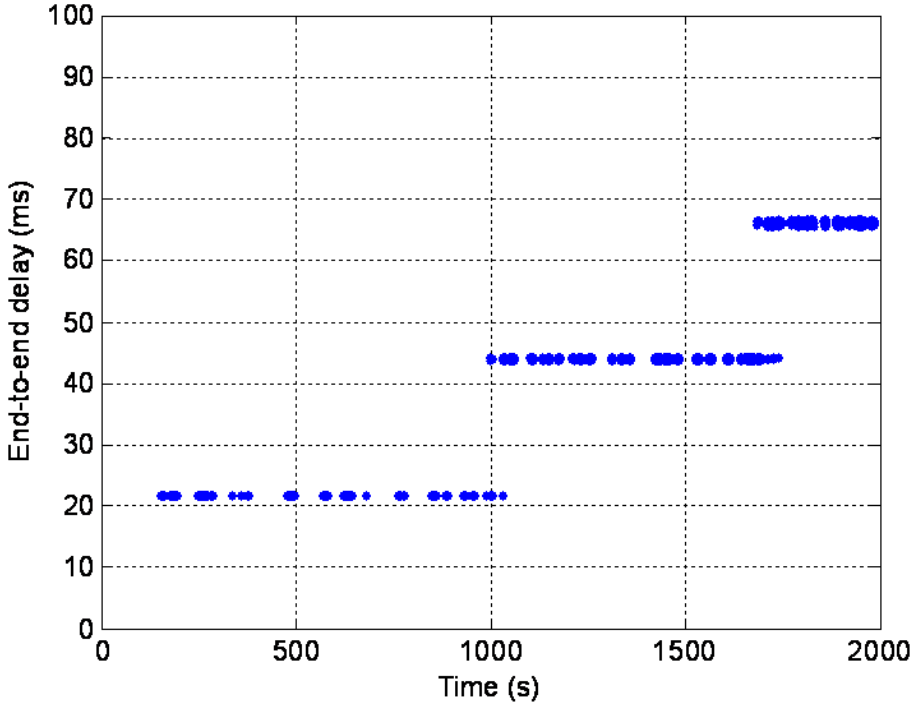
Comm.: G ↔ 4

24 dB/1000 ft loss

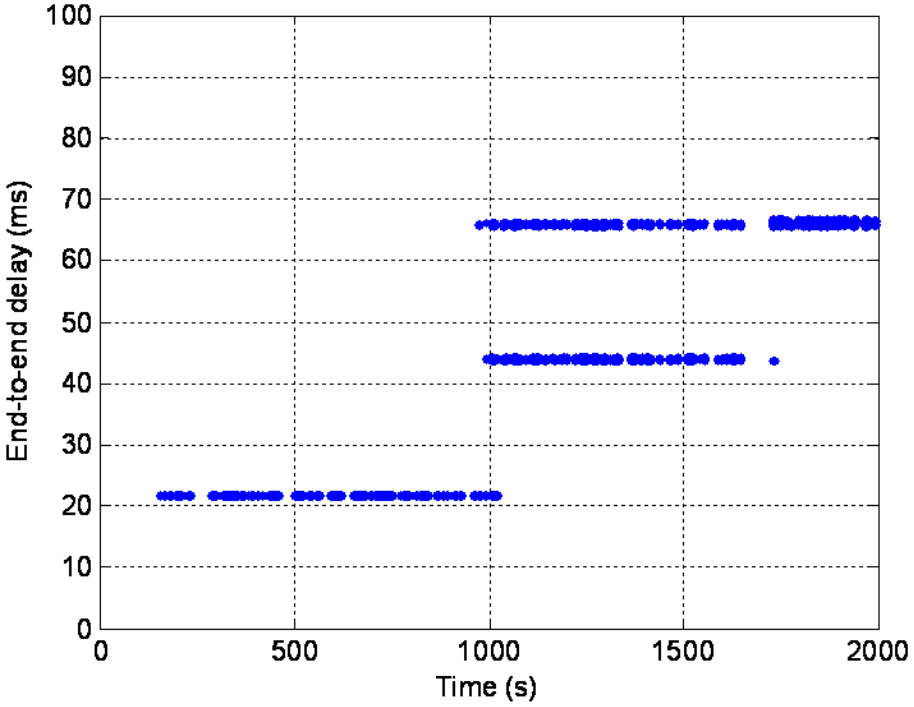


Mobile MF Node Results

Delay G → 4



Delay 4 → G



Summary of Simulation Capabilities

- Applications: PTT Voice, Text (unicast and group multicast)
- Routing: Simple flooding, AODV, …
- PHY modulation: MSK, QPSK, …
- PHY FEC: Convolutional, Reed Solomon, Turbo, …
- Channel model:
  - Conductor loss, inductive coupling loss
  - AWGN, EMI
- Performance measures: Packet loss, end-to-end delay, throughput, etc.