

Modeling and Simulation of Wireless Networks

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APL

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Agenda

- **101: M&S of Wireless Networks I** **10:15 – 12:15**
 - **Modeling and Simulation of Wireless Networks** **10:15 – 11:00**
 - **Break** **11:00 – 11:15**
 - **Wireless MAC and PHY M&S** **11:15 – 12:15**

- **102: M&S of Wireless Networks II** **14:00 – 16:00**
 - **RF Propagation M&S** **14:00 – 14:30**
 - **Wireless Network M&S** **14:30 – 15:00**
 - **Break** **15:00 – 15:15**
 - **Distributed Simulation** **15:15 – 16:00**



M&S - Definition

- **Generally, simulations are usually software, written to gain insight into system behavior and performance**
- **Consist of a typical set of inputs, some algorithms/routines to model the system behavior of interest, and output**
- **Can be as simple or as complex as the user requires**

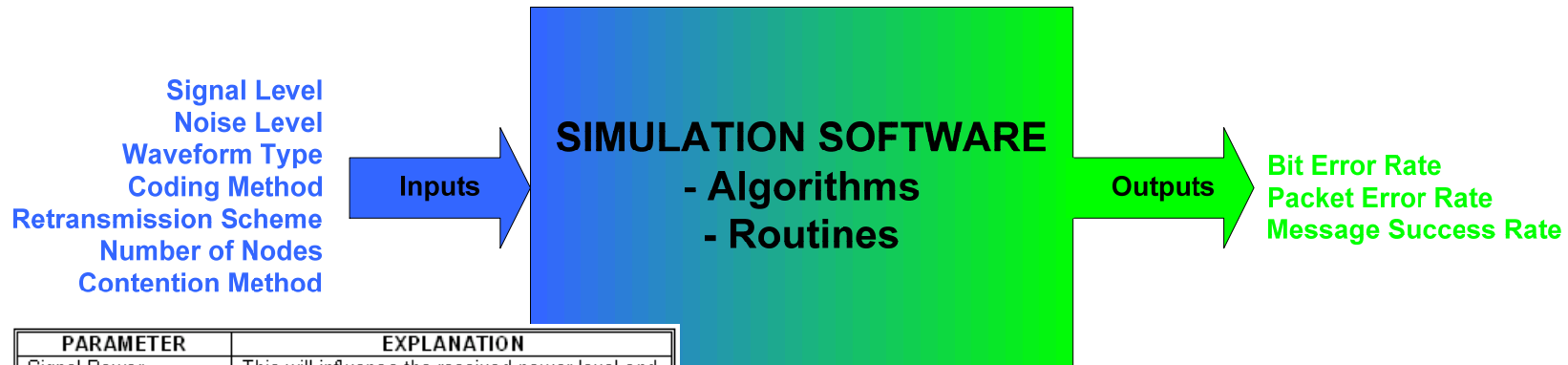
M&S – Definition (continued)

- **M&S often viewed as a single term/entity**
- **However, models and simulations are distinctly different**
 - **Model:** A logical representation of a complex entity, system, phenomena, or process. Within the context of communications and networking, a model is often an analytical representation of some phenomena (e.g. a mathematical representation for the output of a system component) or a state machine representation. This analytical representation can either be in a closed form or an approximation obtained through assumptions.
 - **Simulation:** An imitation of a complex entity, system, phenomena, or process meant to reproduce a behavior. Within the context of a communications network, a simulation is most often computer software that to some degree of accuracy functionally reproduces the behavior of the real entity or process often through the employment of one or more models over time.
 - **Emulation:** An imitation of a real complex entity or process meant to perfectly reproduce a behavior or process. Emulation can be thought of as perfect simulation of something such that it is equivalent to the original entity.

Difference between Modeling and Simulation: An Example

- **Consider a simple signal detection circuit**
- **Simulation:** Imperfectly mimic the various actions of the detection circuit to determine a likely outcome for a given set of inputs
- **Model:** a mathematical algorithm that would produce (either perfectly or imperfectly) an output for a given input

Example: General RF/Network Sim



PARAMETER	EXPLANATION
Signal Power	This will influence the received power level and consequently the Bit Error Rate (BER) and Packet Error Rate (PER) performance of the wireless link.
Waveform Type	This will influence the BER and PER performance of the wireless link in a given channel.
Forward Error Control Coding Method	This will influence the BER and PER performance of the wireless link in a given channel.
Retransmission Protocol	This will affect the throughput and delay performance of the wireless link.
Contention Method	This will influence BER, PER, throughput, and delay performance of the wireless link in a given channel.
Channel Model	This will determine the performance of a given wireless link.
Mobility Model	This will impact the performance of the MAC layer protocol and of the higher layers (e.g. IP routing).
Traffic Model	This will impact the performance of the MAC layer protocol and of the higher layers (e.g. IP routing).
Network Topology	This will impact the performance of the MAC layer protocol and of the higher layers (e.g. IP routing).

PARAMETER	EXPLANATION
Bit Error Rate	The fundamental performance metric of a communications link.
Packet Error Rate	Often considered the most important performance metric in a packet-switched network.
Throughput	The data rate supportable by the wireless network.
Goodput	The useful data rate supported by the wireless network (i.e. data rate as available by the application).
Latency	The end-to-end delay that an application or user will experience across the wireless network.

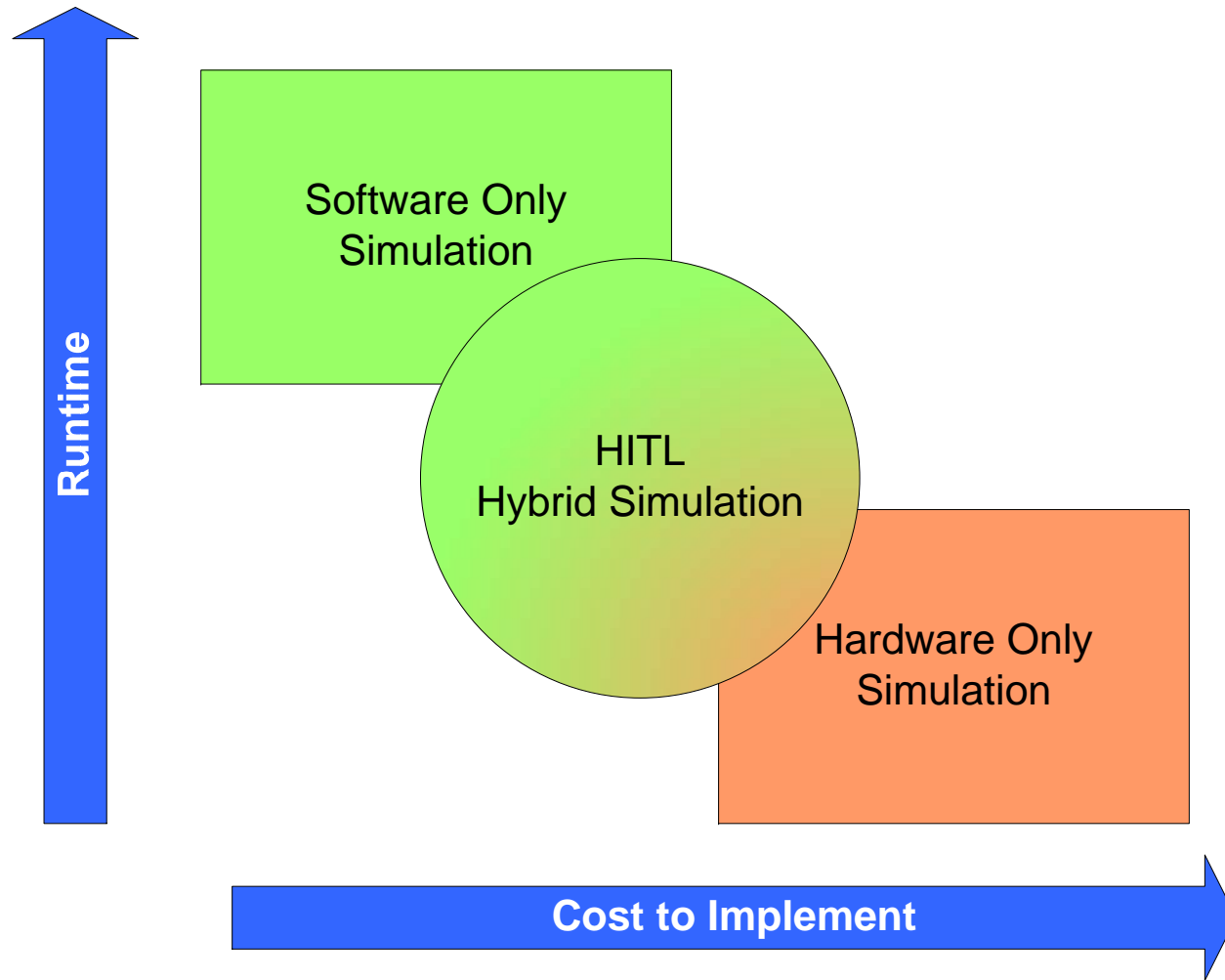
M&S – Why do we care?

- **Many tools in our toolkit as network designers to help make performance predictions**
 - **Theoretical / analytical methods**
 - **Empirical methods**
 - **Modeling and simulation (M&S)**
- **But like any tool, it has strengths and weaknesses...**
 - **Advantages of M&S**
 - **Ability to exercise scenarios not easily achievable through empirical methods**
 - **Only viable tool at our disposal to gain insight into large-scale performance**
 - **Very valuable in sensitivity and trend analysis**
 - **Disadvantages of M&S**
 - **It's not real – great care must be taken at understanding model, its limitations, and its results**

Simulation Types

- **Software**
 - **Allows insight into conceptual system performance and may shed light on issues before hardware development/deployment takes place**
 - **Ease of change to code to model various aspects of system and allow for future modifications based on new technology**
 - **May be very slow**
 - **Distributed computing may provide benefit in computational speed**
- **Hardware**
 - **Usually faster than software-only method**
 - **May be much more expensive to develop compared to software-only sim**
 - **Hardware costs (ASIC, FPGA, VLSI, circuit board design) and development may exceed total cost of software design (C++ IDE and coding labor)**
 - **Changes to simulation may or may not be simple**
 - **Some features of a hardware-based SIM may be hard-coded and require significant investment to modify**
- **Hybrid/HITL**
 - **A combination of both software and hardware**
 - **Very useful to test existing hardware performance characteristics by precise control of the simulation environment**
 - **Usually a compromise in price between software and hardware, depending on application**
 - **Useful for reverse-engineering or characterizing hardware product behavior**

Simulation Tradeoffs





M&S – Attributes

- **Stochastic vs. Deterministic**

- Deterministic models have no randomness
- Deterministic models can be defined as a state machine
- Stochastic models do not have a unique input-to-output mapping
- Deterministic models are the most common type
 - Stochastic models can lead to unpredictability in execution
 - Simulations made to act in pseudo-random manner, but still deterministic in nature

- **Steady-state vs. Dynamic**

- Steady-state finds input-to-output relationship in steady-state equilibrium conditions
- Steady-state often used to provide simplified model prior to dynamic simulation development

M&S – Attributes (continued)

- **Continuous vs. Discrete**

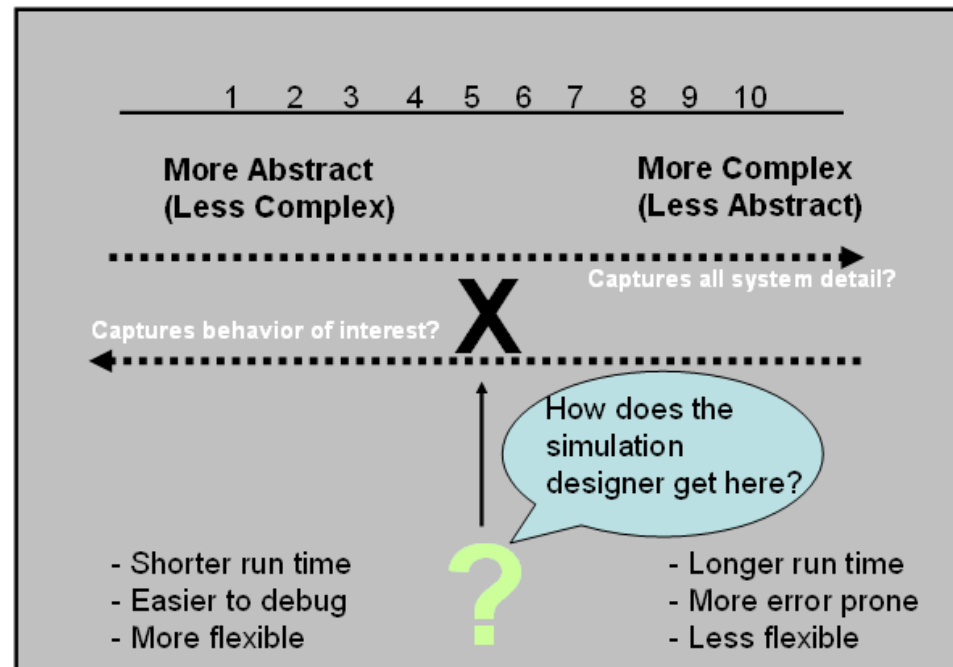
- Discrete model considers only discrete moments in time that correspond to significant events that impact the output or internal state of the system
- Jumps between discrete moments in time are instantaneous with nothing modeled between these moments
- Continuous models consider all points in time (within the resolution of host hardware limitations).
- Discrete Event (DE) methods are the most common

- **Local vs. Distributed**

- Distributed simulation across multiple computer platforms that are interconnected through a computer network to work together to conduct a simulation
- Local simulation resides on a single host platform
- Historically local simulations the most common
- Increasing complexity of systems are increasingly leading to more complex distributed simulation methods

M&S – Dimensions of Performance

- **Scalability**
 - Number of nodes
 - Traffic loading
 - Execution speed
 - Fidelity
 - Cost
- **These are conflicting goals!**
- Pick three



- Beware over-simplification of model to improve scalability and/or execution speed
 - An over-simplified simulation generally provides a useless result!

M&S – Commercial Tools

- **Two forms of M&S:**
 - **Home-grown**
 - **Primary advantage – you know exactly what you have**
 - **Primary disadvantage – costly development time**
 - **Use of publicly-available simulation tool/package**
- **Continuously increasing scope of network solutions makes home-grown solutions increasingly prohibitive**

M&S Tools – Which do I choose?

- There are hundreds of network-related models and simulation tools available either as a commercial offering or in the public-domain
- Knowing which tool(s) to choose can be a daunting task
- Models and simulations vary in many ways:
 - Feature set
 - User experience
 - Performance
 - Cost
- EVERY model or simulation has advantages and disadvantages for a given problem space
 - Assumptions, limitations
- There is NO one-size-fits-all ‘silver bullet’ solution
 - “Only a Sith deals in absolutes” - Obi Wan Kenobi



Goals of this Session

- To familiarize the audience with many of the models and simulation tools that exist as either commercial offerings or in the public domain
- To illustrate the strengths and weaknesses of many of these tools
- *To arm you, the network designer and developer, with information that will be useful to you in your job*

The Perils of Successful M&S

- **Validation, validation, validation**
 - **Models come by the dozen, but valuable models are far too rare!**
 - **ANY model will have inaccuracies**
 - **Remember, its not real!**
 - **Must understand limitations of models and simulation**
 - **Must understand achievable accuracies and uncertainties of models and simulations**
- **Data collection, data collection, data collection**
 - **Critical to building confidence in M&S results**
- **M&S is NOT a replacement for empirical methods**
 - **Prototyping, lab testing (i.e. hardware-in-the-loop), field testing all critical components of successful design**

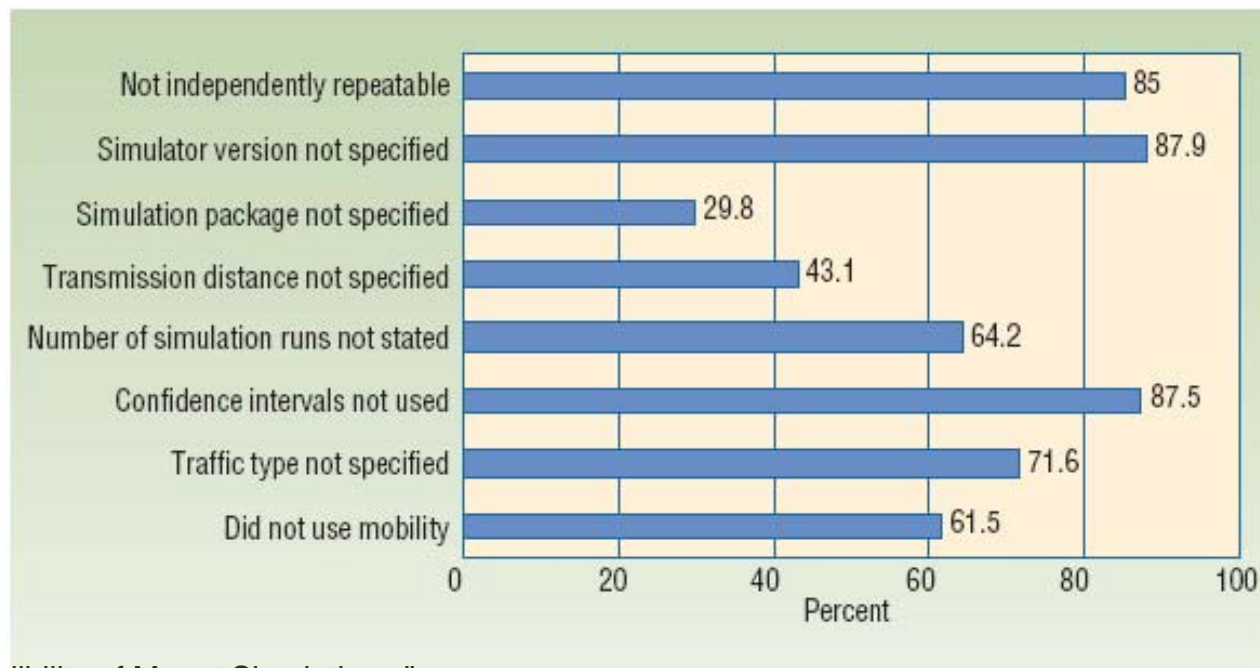


Key to Success...

- **Be skeptical and distrustful of a simulation result**
 - **Be distrustful of what your simulation tells you**
 - **Even (especially) if using existing implementations**
 - Many have errors or may not be modeling what you are even interested in
 - **Validation, validation, validation**
- **Many will inherently distrust M&S results**
 - **Be vigilant to ensure their distrust is unfounded**

Additional Keys to Success...

- **Thorough documentation**
 - **The only good M&S result is one that can be independently repeated**



From "On the Credibility of Manet Simulations,"
Todd R. Andel and Alec Yasinac, Computer, July 2006.

Cost – The least understood metric

- **There is much more to cost than initial purchase price:**
 - **Upgrade and maintenance costs**
 - **Platform costs**
 - **Productivity and staff power considerations**
 - **‘The tech support hotline’**
- **This should all be factored into any final decision**

The Importance of Requirements

- **What are you trying to model?**
 - Not all tools have the same inherent capabilities
 - Are you interested in a technology specification or a specific device? The two are rarely the same
- **What are the metrics of interest?**
- **What is the required performance of the model?**
 - Execution speed, platform requirements, scalability
- **Ultimately, what would constitute success?**

- **These questions all seem obvious, but failing to adequately answer these are the most common cause of M&S failures**
 - Note that none of these relate to the actual implementation

- **What does this mean?**
 - Before writing a single line of code:
 - Define requirements
 - During implementation of model:
 - Map requirements to implementation
 - After implementing model:
 - Revisit requirements and ensure

- **This isn't fun, but it is a requisite to consistent success**



The Importance of Understanding

▪ **Model only what you understand**

- If you don't have a fundamental understanding of a technology, there is no way you can effectively model or simulate that technology
- This step cannot be skipped in a successful M&S effort

- **Wealth of resources exist for commercial technologies**
 - Online tutorials
 - Text books
 - Conference and journal papers
 - Standards
 - Subject matter experts

The Importance of Understanding (2)

▪ Only use tools that you understand

- If you use a pre-existing off-the-shelf or open source implementation, look under the hood and ensure you know exactly what it is doing
 - Most simulation code have errors
 - New simulation implementations almost guaranteed to be riddled with mistakes
 - Models sometimes do not even consider what you are interested in
 - No better way to lose credibility than to not be able to answer questions regarding your own results
-
- **There are resources available to help with this**
 - Technical support
 - Online newsgroups / user forums
 - Contact the author directly!

The not-so-obvious consideration...

- **Productivity (i.e. return on investment of labor cost) could be strongly influenced by proper choice of models and simulation tools**
- **Many factors at play here:**
 - The obvious: matching the right tool with the right capabilities to the right problem
 - The less obvious: human factors, GUI preference, platform preference, programming language preference
 - This is more than just training or new skill, but can also be evangelical/philosophical
 - A happy engineer is a productive engineer

Common Pitfalls Unique to Wireless Network M&S

▪ Channel models

- Plethora of highly complex models of wireless networks that are evaluated only in AWGN channels or simple two-ray propagation models
 - This is fine for many cases, but do not expect to model an omni-directional antenna wireless network in AWGN conditions and be able to say anything intelligent about how it will behave in urban environments
- It is sometimes a daunting task to provide high-fidelity channel models in large simulations, but it is important to understand the limitations of the model to constrain performance statements

▪ Mobility models

- These are arbitrary, hardly ever reflect reality, and have profound impact on performance of network
- Do your homework – simplistic assumptions will haunt you!

▪ Traffic models

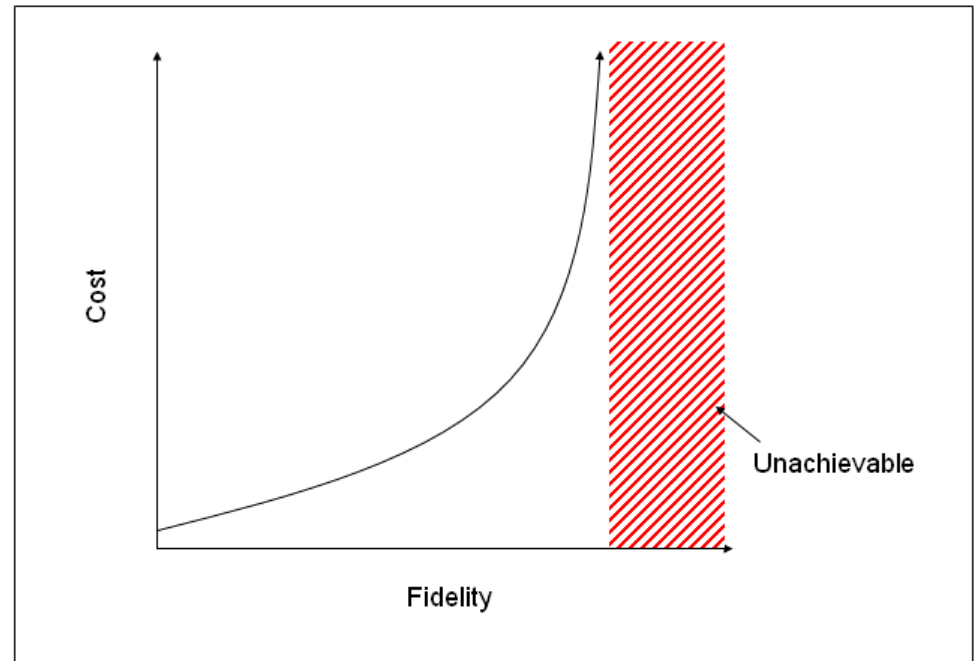
- These are arbitrary, hardly ever reflect reality, and have profound impact on performance of network
- Furthermore, guaranteed not to reflect future conditions!
- These are guesses, best case. Be cognizant of that.
- Do your homework – simplistic assumptions will haunt you!

Common Pitfalls Unique to Wireless Network M&S (2)

- **Over-reliance on link budget methods**
 - Typically, complex factors are boiled down to ‘losses’ in link budgets
 - Beware that losses are often scenario dependent
- **Overly-simplistic modeling of radio layers**
 - Many network M&S tools do not perform true bit-level simulation
 - Radio layers abstracted into ‘cloud’
 - Beware: this ‘averaging’ can give misleading results
 - Things like antenna pointing algorithms, timing and frequency synchronization, etc., are typically not static in terms of performance

Common Pitfalls Unique to Wireless Network M&S (3)

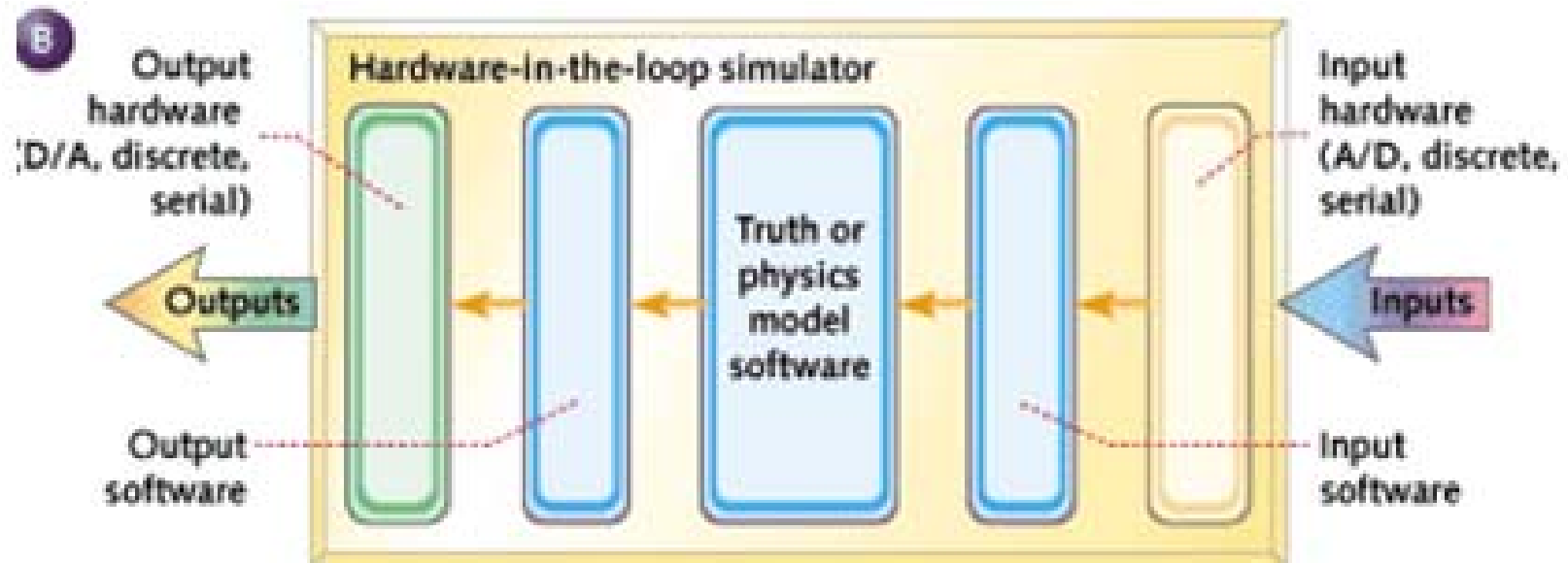
- **M&S when M&S doesn't make sense**
 - If a model includes every detail of a technology down to every bit, byte, protocol, and state machine, then you probably should have just implemented it and tested it empirically
- **M&S and implementation disjoint efforts**
 - A bit-true simulation can be a great interim milestone towards a real-world implementation
 - Has the leave-behind value of higher-fidelity models



A HITL case study - JHU/APL ACTION

- **HITL testbed solution**
 - **Primarily for testing wireless network standards**
 - **E.g. 802.11, 802.16, Bluetooth**
 - **Comprised of discrete components that modify amplitude, phase, and frequency of a signal**
 - **Modifies, combines and splits signals based on various inputs to create a Simulated Wireless Network Environment**
 - **Designed with the purpose of evaluating mobile nodes and handoff performance in a simulated wireless network environment**
- **Benefits**
 - **Isolation from interference**
 - **More precise and accurate mechanism to control signal characteristics than over-the-air testing**
 - **Enables characterization of real hardware**

HITL Concept



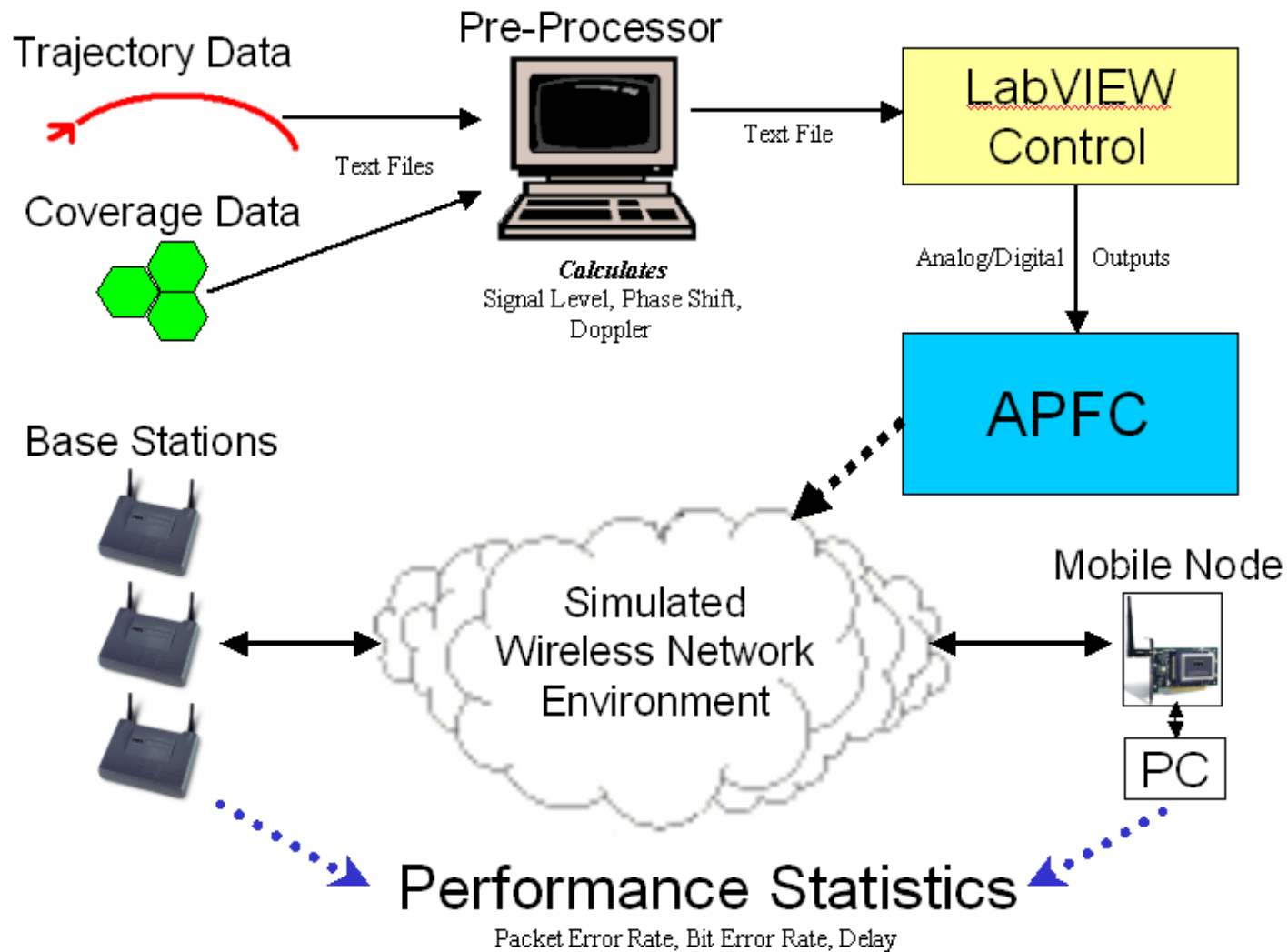
M. Gomez, "Hardware-in-the-Loop Simulation", Embedded Systems Programming, www.embedded.com



HITL Components

- **System under test**
 - **Networking hardware (radios, routers, ethernet cables)**
- **Simulation software**
 - **LabVIEW, C++, MATLAB, Packet Generator**
- **Environment hardware**
 - **A/D, D/A, digital output, digital input**
 - **Power splitters, combiners**
 - **Noise/Signal generators**
 - **Connects to system under test**
 - **May modify signal levels, frequency shift**

Conceptual View



ACTION I/O

User Inputs

Wireless Channel Model

Outputs

of base stations and their coordinates
(latitude, longitude, altitude)

Antenna patterns for base stations

Mobile trajectory
(latitude, longitude, altitude, time)

Specify IEEE 802.11 WLAN standard
(e.g. 802.11 a, b, etc.)

EIRP

Receiver Sensitivity
(G/T) r

Select environment
(in terms of path loss exponent n)

Select season: summer or winter
(for Rician K -factor selection) *

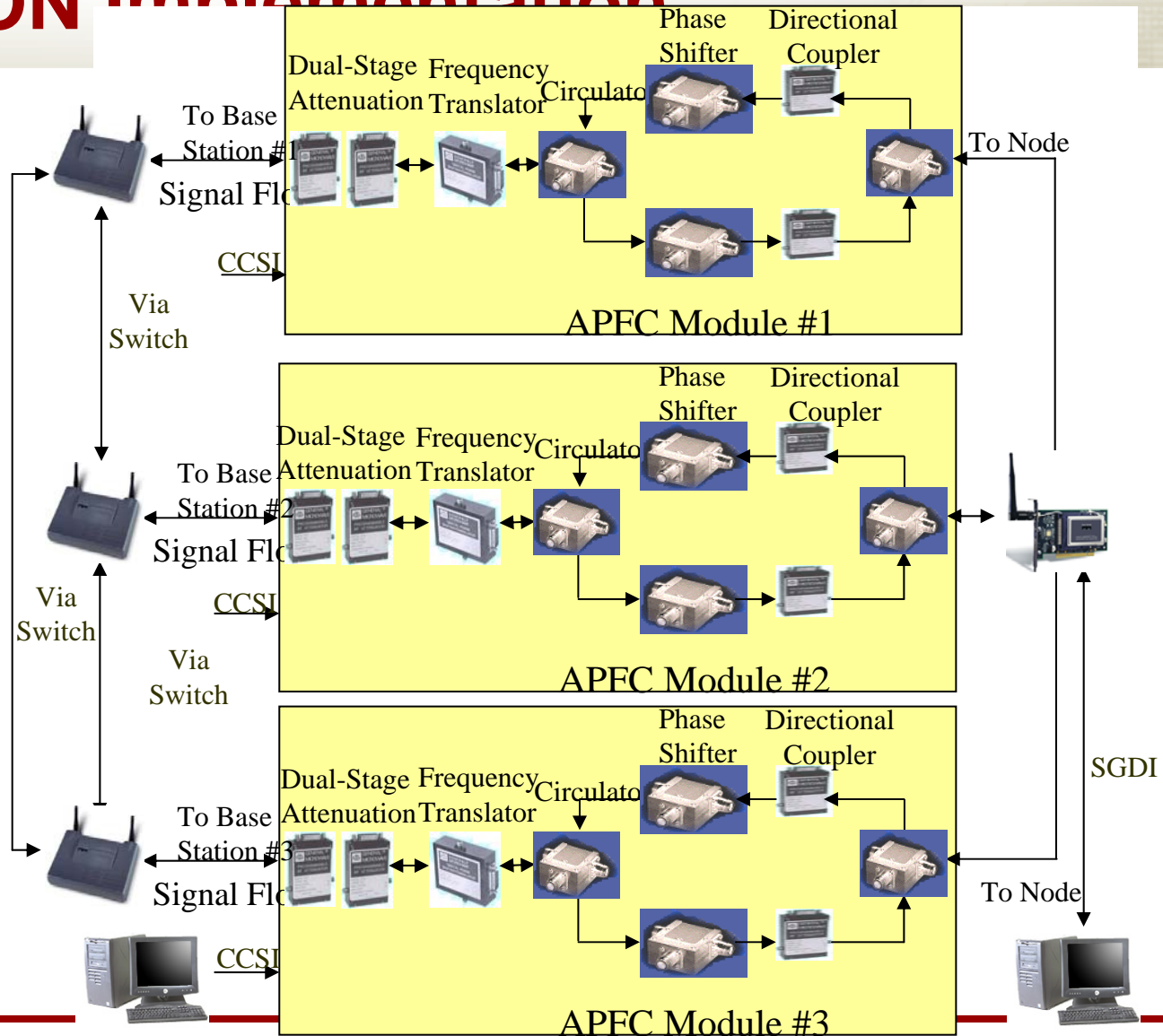
Large-Scale
Fading
(Log-distance
Path Loss
Model + Log-
normal
Shadowing)

Small-Scale
Fading
(Rician fading
Channel)

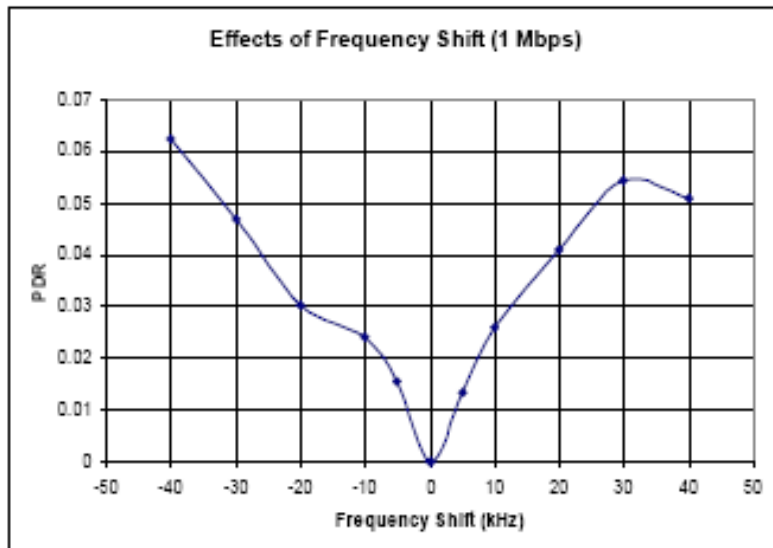
Total faded signal in terms of the
received power vs. time and T-R
distance

Doppler shift / Doppler rate vs. time

ACTION Implementation

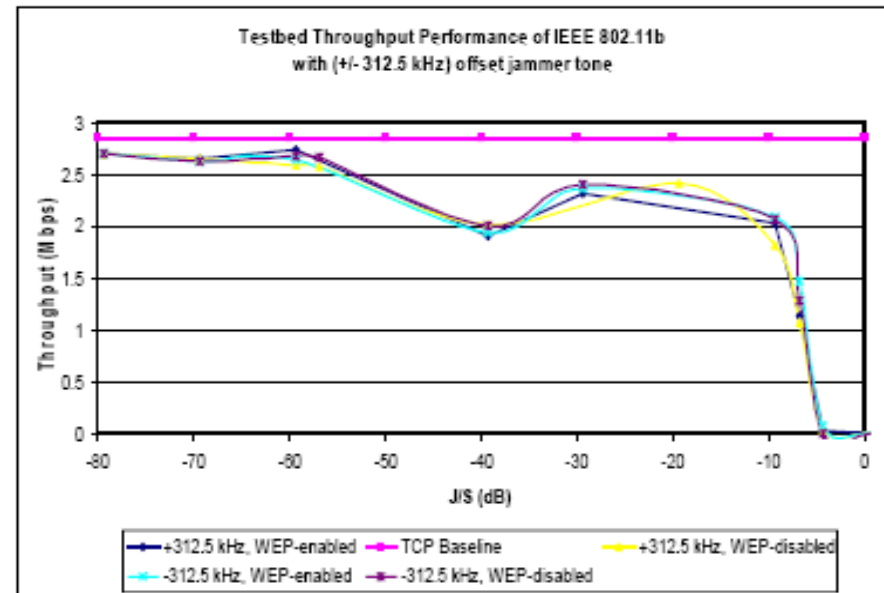


Some Results from ACTION



- Throughput performance in the presence of noise

- Frequency Shift (Doppler Model) Performance



Upcoming Resources

- **“Modeling and Simulation: A Practical Guide for Network Designers and Developers,”** Feature Issue of the IEEE Communications Magazine (March 2009)



- **“Modeling and Simulation of Wireless Networks: A Practical Guide,”** Upcoming IEEE Press publication



Questions so far?



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