Modeling and Simulation for RF Propagation

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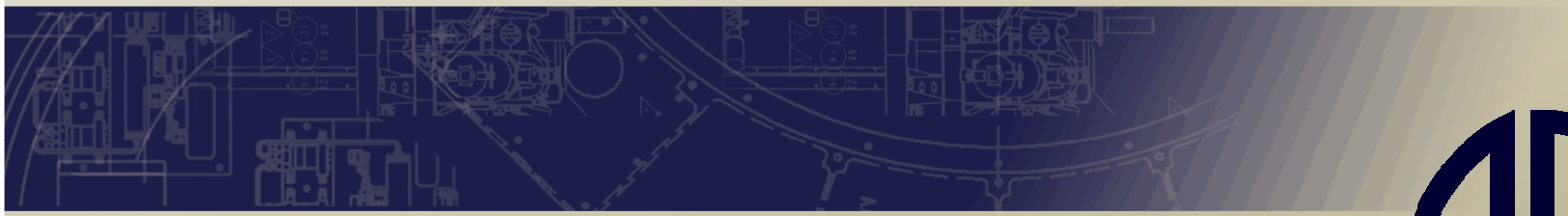

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- **Jack Burbank served as guest editor for the March 2009 edition of the IEEE Communications Magazine on Modeling and Simulation (M&S)**
  - Jon Ward and Bill Kasch also contributed an article to this edition, based largely on previous Globecom D&D Forum presentations
- **We completed and submitted a first draft book to IEEE Press on practical Network M&S for the working engineer**
  - We hope this will be available in late 2010

Outline

- What is RF propagation?
- Why does the network simulation designer care about RF propagation?
- What are the existing RF propagation models available?
  - Analytical (large and small scale fading)
  - Simulation tools (large and small scale fading)
- Where does network simulation meet RF propagation?
- What are general limitations, pitfalls, and lessons learned?

What is RF propagation?

- **All transmitted RF energy incurs path loss as electromagnetic waves propagate from source to destination (e.g., reflection, diffraction, and scattering)**
  - A flat, dry, desert environment exhibits different propagation characteristics than a hilly, wet, jungle environment
  - A sparsely populated rural environment exhibits different propagation characteristics than a densely populated urban environment
  - Even the same environment surveyed under different weather conditions exhibits different propagation characteristics
- **RF propagation is difficult to precisely characterize generically through analytical solutions and M&S**

Why does the Network Simulation Designer Care about RF Propagation?

- **If data transmitted to the receiver are to be received correctly, a sufficient Signal to Interference Noise Ratio (SINR) must be maintained at the receiver**
  - The SINR fluctuates depending on the propagation environment
- **In cellular communications, there is generally margin in 'S' since the basestation (BTS) is connected to an "unlimited" power source**
  - Although 3G systems based on CDMA technology must carefully control 'S,' since increasing 'S' essentially increases the interference for all other users
- **Power-limited wireless networks must carefully manage 'S' to maintain increased battery life**
- **The answer is ultimately application-dependent since the impact of RF propagation on system performance depends on how much margin is built into the link budget**

Large Scale and Small Scale Fading

- **RF propagation models generally characterize two aspects of RF propagation: large scale and small scale fading**
- **Large Scale propagation models predict the mean signal strength for a given transmitter and receiver separation distance and are used to predict RF coverage**
  - Friis Free Space Path Loss Model
  - Two Ray Ground Reflection Model
  - Log Distance Path Loss Model with Shadowing
- **Small scale propagation models characterize the rapid fluctuations of received signal strength over short distances or a short time duration**
  - Small-scale models are generally associated with predicting multipath fading

Large Scale Fading – Friis Free Space Model

- **This model is used for simple path loss estimations because of its simple form and limited number of required parameters**

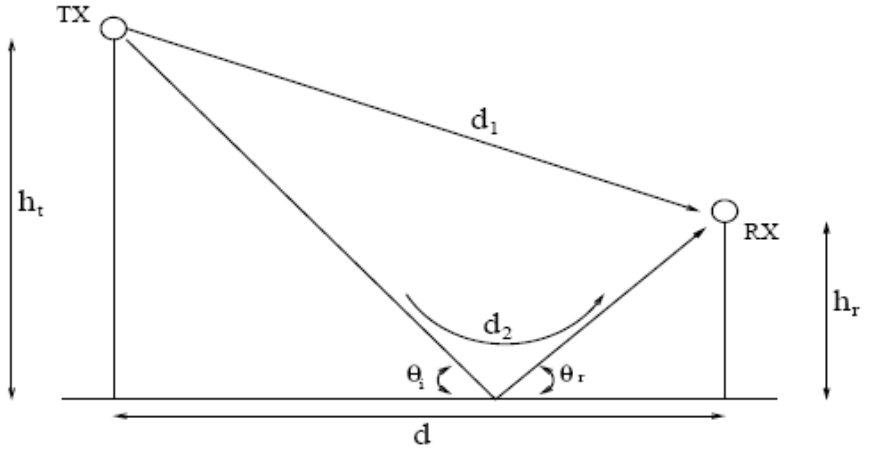
$$FS(dB) = 10\log_{10}\left(\left(\frac{\lambda}{4\pi d}\right)^2\right)$$

$$P_r(dB) = P_t + G_t + G_r - FS(dB)$$

- **This model should only be applied where significant margin is built into a link budget**
  - Many propagation characteristics that impact loss are not accounted for in this equation

Two Ray Ground Reflection Model

- **The two-ray model is a commonly used propagation model because it accounts for a ground-reflected path between transmitter and receiver in addition to the LOS component**
- **The two-ray model has been shown to produce more accurate path-loss estimates at long distances than Friis Free space Equation**
  - It accounts for antenna height differences at the transmitter and receiver, which is not considered in the Friis equation



$$PL(dB) = 40\log_{10}(d) - (10\log_{10}(G_t) + 10\log_{10}(G_r) + 20\log_{10}(h_t) + 20\log_{10}(h_r))$$

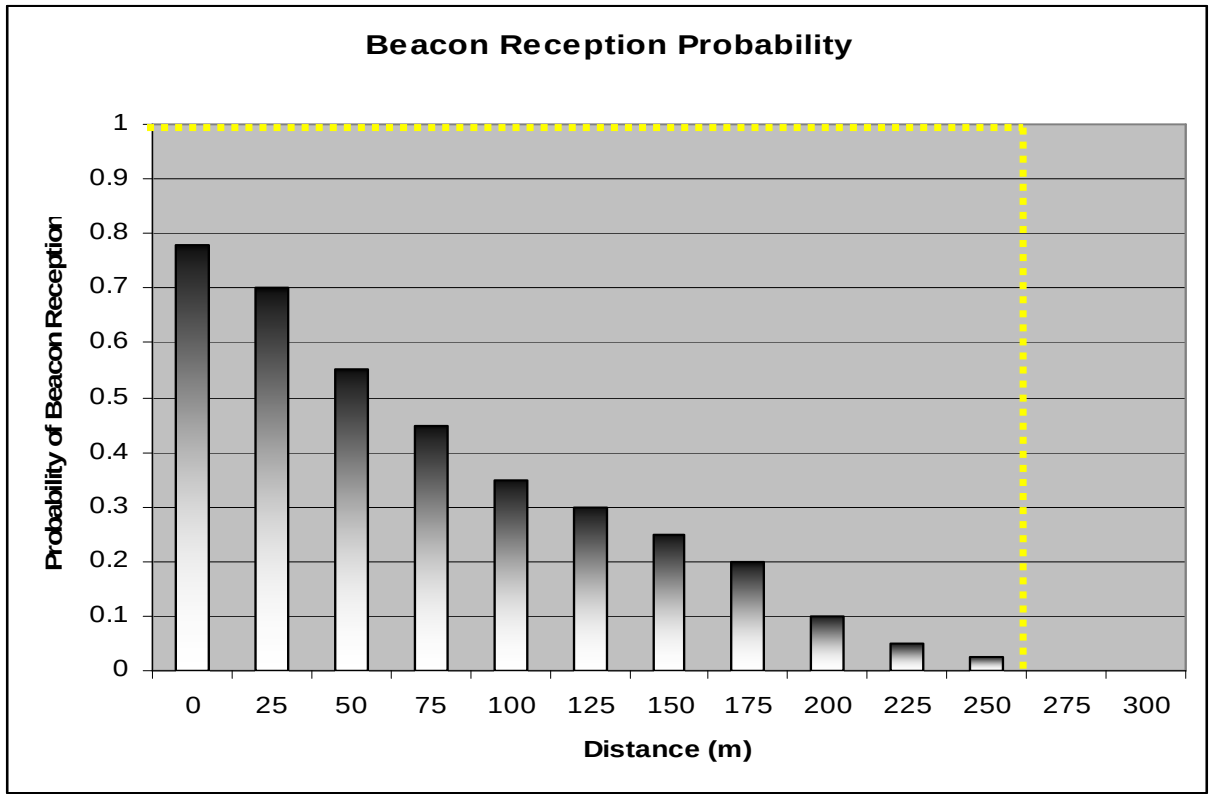
Log Distance Path Loss Model with Shadowing

- **Theoretical and measurement-based propagation models indicate that average received power decreases logarithmically with distance**
- **A lognormally distributed random variable can be used to characterize the shadowing effects that occur with mean value determined by the transmitter and receiver separation distance**
- **The lognormal distribution means that in units of dB, X_σ follows a Gaussian distribution**

$$L(dB) = FS(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma$$

How Important is the Inclusion of Large-Scale Fading on the Simulated Output?

- One common simulation assumption is that if the receiver receives the transmitted signal at all, it is received perfectly [9]
- Clearly this is not an accurate assumption!



Large-Scale Fading in Common M&S Packages

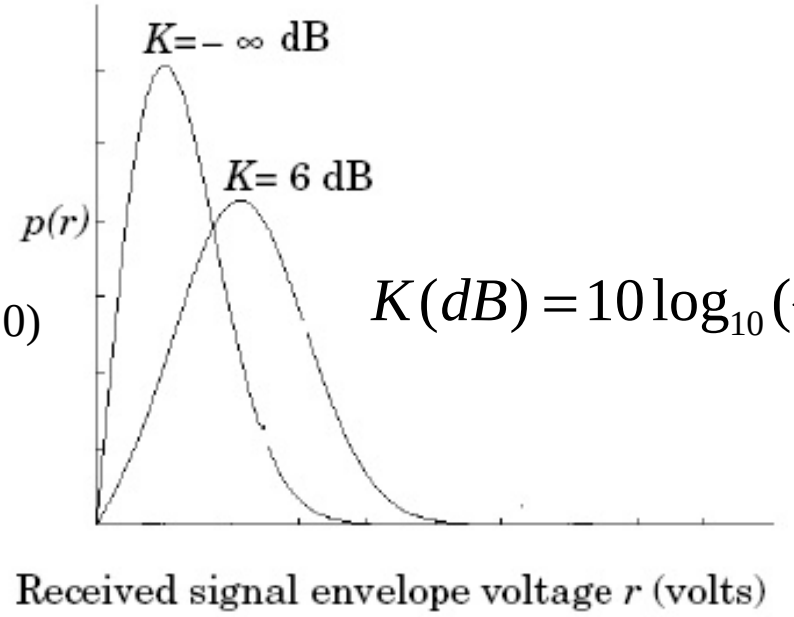
- Various large-scale fading models are supported by common M&S wireless network platforms
- The network designer must choose the model that best fits his or her application and understand any associated limitations

GloMoSim (v.2.03)	NS-2 (v. 2.1b8)	OPNET	QualNET
Free Space, Two Ray [4]	Free Space, Two Ray, Lognormal Shadowing, Nakagami [3]	Free Space, Two Ray*, TIREM, Longley-Rice, CCIR, Hata, Walfisch-Ilegami [5]	Free Space, Two Ray, TIREM, COST 231-Hata, COST 231-Wi, Longley-Rice [6]

Small-Scale Fading – The Ricean Distribution

- **Small-scale fading models are stochastic and based on the work of previous researchers that matched empirical data from various measurement campaigns to statistical random variable distributions to find curves that best fit**
- **The Ricean distribution is widely accepted by researchers as representative of fading scenarios where a LOS component is present in the signal of interest**

$$p_{Ricean}(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_0\left(\frac{A_r}{\sigma^2}\right) & for(A \geq 0, r \geq 0) \\ 0 & for(r < 0) \end{cases}$$

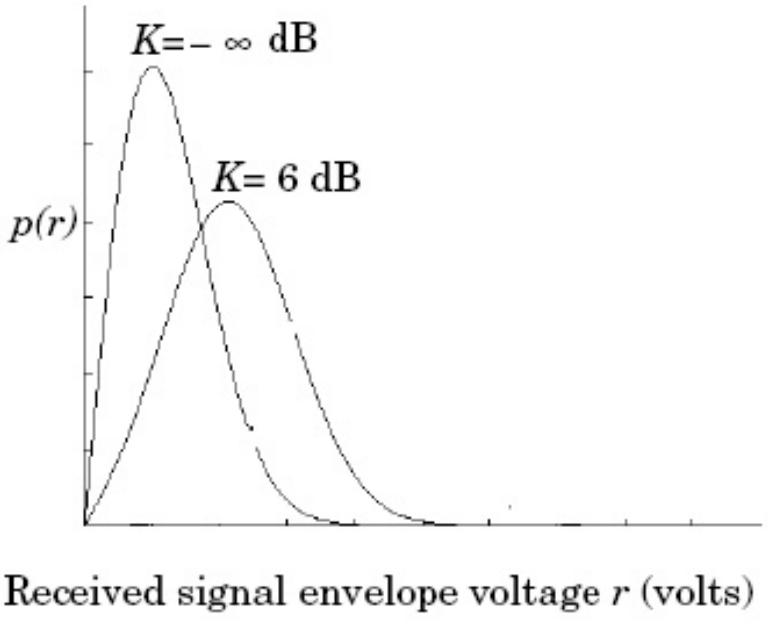


$$K(dB) = 10\log_{10}\left(\frac{A^2}{2\sigma^2}\right)$$

Small-Scale Fading – The Rayleigh Distribution

- **The Rayleigh distribution is widely accepted by researchers as representative of fading scenarios where NO LOS component is present in the signal of interest**
- **The Rayleigh distribution is a special case of the Ricean distribution, when the K factor amplitude A is set to zero**

$$p_{Rayleigh}(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}} & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases}$$



Small-Scale Fading in Common M&S Packages

- **Both Ricean and Rayleigh fading models are supported by common M&S wireless network platforms**
- **Again, the network designer must choose the model that best fits his or her application and understand any associated limitations**

GloMoSim (v.2.03)	NS-2 (v. 2.1b8)	OPNET	QualNET
Ricean, Rayleigh [4]	Ricean, Rayleigh [3]	Ricean, Rayleigh * [5]	Ricean, Rayleigh [6]

* denotes this model and support as being provided by user community

RF Propagation Simulators

- **Depending on the project and required fidelity, the network model designer may be able to capture the necessary RF propagation effects with one of the aforementioned network simulators**
- **Some applications require higher fidelity modeling of a given electromagnetic environment**
  - These can be more general than networking scenarios such as modeling the path loss at a given frequency over three city blocks
- **These RF propagation simulators are frequently used by network service providers to predict service coverage**
- **A summary of some of these tools is provided in the next two slides as a reference**

Survey of RF Propagation Tools

Tool Name	Company	URL
Wireless InSite *	Remcom, Inc,	http://www.remcom.com/wireless-insite/overview/wireless-insite-overview.html
Atoll	Forsk[w1]	
Athena *	Wave Concepts	http://www.waveconceptsintl.com/athena.htm
CellOpt *	Actix	http://www.actix.com/main.html
Comstudy *	RadioSoft	http://www.radiosoft.com
EDX SignalPro *	EDX Wireless	http://www.edx.com/products/signalpro.html
ENTERPRISE Suite *	AIRCOM International	http://www.aircominternational.com/Software.html
LANPlanner *	Motorola, Inc.	http://www.motorola.com
Mentum Planet *	Mentum S.A.	http://www.mentum.com
NP WorkPlace *	Multiple Access Communications Ltd	http://www.macltd.com/np.php

Survey of RF Propagation Tools (cont)

Tool Name	Company	URL
Pathloss *	**Contract Telecommunication Engineering**	**http://pathloss.com/**
PlotPath *	**V-Soft Communications LLC**	**http://www.v-soft.com/web/products.html**
Probe *	**V-Soft Communications LLC**	**http://www.v-soft.com/web/products.html**
Profiler-eQ *	**Equilateral Technologies**	**http://www.equilateral.com/products.html**
RFCAD *	**Sitesafe**	**http://www.rfcad.com/**
RPS *	**Radioplan GmbH**	**http://www.radioplan.com/products/rps/index.html**
Volcano *	**SIRADEL**	**http://www.siradel.com**
Wavesight *	**Wavecall**	**http://www.wavecall.com**
WinProp *	**AWE Communications**	**http://www.awe-communications.com/**
Interactive Scenario Builder	**US Naval Research Laboratory**	**https://builder.nrl.navy.mil/**

Limitations, Pitfalls, and Lessons Learned

- **The four network simulators (GloMoSim, QualNET, OpNET, and NS-2) support the common large and small scale fading models**

- **So….which is the best and how much detail is required?**
  - The network designer should choose a platform with which he or she is comfortable and supports all required modeling components
  - Each modeling project has different requirements, so one size does not fit all
  - The amount of detail required depends on the designer's requirements and objectives

- **If a sufficient SINR margin is built into the link budget, small scale fading may not be important or Friis equation may be sufficient**

Limitations, Pitfalls, and Lessons Learned (cont)

- **If a wireless networking scenario must be characterized with a link budget containing less than 10 dB, then care must be placed in the chosen large and small scale models**

- **Consider papers such as [7] and [8] that compare the accuracy of simulated results**
  - Model results will vary from model-to-model and model-to-real world

- **For the designer that requires RF propagation software, a few specific suggestions are derived from lessons learned**
  - Make use of technical support provided with a model package
  - Beware of excessive computational time, unspecified boundaries, and general lack of documentation
  - Models may not necessarily scale in computational time as would be expected – worst case anticipated completion time should be doubled

QUESTIONS?

References

- [1] W.T. Kasch, J.R. Ward, J. Andrusenko, "Wireless Network Modeling and Simulation Tools for Designers and Developers," IEEE Communications Magazine, March 2009, Vol. 47, No. 3.
- [2] T.S. Rappaport, "Wireless Communications: Principles and Practice," Prentice Hall PTR, Upper Saddle River, NJ, 2001
- [3] The Network Simulator ns-2: Documentation, http://www.isi.edu/nsnam/ns/ns-documentation.html
- [4] Jorge Nuevo, A Comprehensible GloMoSim Tutorial, www.ccs.neu.edu/course/csg250/Glomosim/glomoman.pdf
- [5] OPNET Discrete Event Simulation Model Library http://www.opnet.com/support/des_model_library/index.html
- [6] Scalable Network Technologies – QualNET Model Libraries: http://www.scalable-networks.com/products/libraries/models.php?lib=1 and http://www.scalable-networks.com/products/libraries/models.php?lib=9
- [7] David Cavin, et al., "On the Accuracy of MANET Simulators," Proceedings of the Workshop on Principles of Mobile Computing (POMC'02).
- [8] T.R. Andel, "On the Credibility of MANET Simulations," IEEE Computer Society Computer, July 2006, Volume 39, Issue 7.
- [9] D. Kotz, et. al, "Experimental Evaluation of Wireless Simulation Assumptions," Proceedings of the 7th ACM International Symposium of Modeling, Analysis and Simulation of Wireless and Mobile Systems, 2004.

Backup Slides

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RF Propagation Models (1)

- **CellOpt (SAFCO/ComOpt/Agilent Technologies)**
  - **3 Products:**
    - **AFP (Automatic Frequency Planning)**
      - **An optimization tool for operators in the wireless sector with the aim of increasing capacity and improving quality in the mobile net without any additional infrastructure costs**
      - **Generates implementation-ready frequency plans**
    - **ACP (Automatic Cell Planning)**
      - **Complements AFP**
      - **Optimizes the parameters that AFP provides, and adjusts the network and base-stations accordingly**
    - **MDA (Measured Data Analysis)**
      - **Complements AFP**
      - **Increases the effectiveness of the two previous products by offering higher precision and more possibilities to analyze the data generated by the network**
  - **Outdoor propagation only**
- **Wireless Insite (REMCOM)**
  - **A powerful tool for modeling the effects of buildings and terrain on the RF propagation**
  - **Can be used to predict how the locations of transmitters and receivers within an urban area affect the signal strength**
  - **30MHz-100GHz**
  - **Benefits:**
    - **Fast and easy to use**
    - **Models complex urban, rural and indoor structures**
    - **Accurate multipath predictions**
    - **Can import DTED, USGS Terrain Data and DXF Building Data**
    - **Propagation over Irregular Terrain**

RF Propagation Models (2)

- **WinProp (AWE Communications)**
  - A software suite ideally suited for propagation modeling in different environments (rural, urban, indoor, tunnels) and with outstanding features for 2G/3G radio network planning.
- **PathPro (MLJ Wireless Systems Engineering, Inc.)**
  - PathPro is an advanced RF design tool that supports cellular, paging, (E)SMR, PCS, GSM, DCS-1800 WLL for (N)AMPS, TDMA, CDMA, TACS and ETACS technologies.
  - PathPro provides drive test data analysis, model optimization, coverage analysis, best server analysis, traffic analysis, frequency planning, interference, handover, CDMA, planning and many other studies.
- **EDX SignalPro (EDX Wireless)**
  - An advanced, comprehensive, general-purpose software package offering a complete set of planning tools for wireless networks from 30 MHz to 60 GHz.
  - Performs multi-site coverage and interference analysis, single-point analysis, route analysis, multiple point-to-point link analysis, and point-to-multipoint analysis.
  - includes a comprehensive set of propagation models, full mapping capabilities, and full access to terrain, ground cover (clutter), building, demographic, traffic, and other databases.
- **Volcano (Siradel)**
  - A calculation engine that contains the most advanced wireless propagation models applicable to rural, suburban, urban and indoor environments.
- **SitePlanner (Wireless Valley)**
  - A powerful software application that enables you to design, measure and manage all of your indoor and campus-wide cellular, PCS, and 3G networks.
- **GRANET-eQ (Equilateral Technologies)**
  - A comprehensive software package that gives you a sizable competitive edge in efficiently designing and optimizing your networks.

RF Propagation Models (3)

- **Planet EV and deciBel Planner (Marconi)**
  - **With this software the RF engineer can perform the following:**
    - **Model RF propagation**
    - **Analyze multi-transmitter communication networks**
    - **Compare propagation results to field tests**
    - **Select transmission tower locations**
    - **Distribute critical geographical information to marketing, customer care, and strategic planning departments**
- **Comstudy (RadioSoft)**
  - **A suite of RF study tools, the primary functions of which are the prediction coverage and interference, along with the study of AM and FM allocations. The software also supports TV and land mobile.**
- **RFCAD (SiteSafe, Inc.)**
  - **Integrates scanned topographic maps for use as the base layer in system designs so that one can produce clear and easy-to-see RF coverage and analysis maps. Its Biby-C propagation model is based on more than fourteen years of engineering analysis and system design experience.**

RF Propagation Models (4)

- **Pathloss (Contract Telecommunication Engineering)**
  - **A comprehensive path design tool for radio links operating in the frequency range from 30 MHz to 100 GHz. The program is organized into eight path design modules, an area signal coverage module and a network module which integrates the radio paths and area coverage analysis.**
- **Probe (V-Soft)**
  - **Professional level RF propagation modeling, DTV/TV and FM interference analysis, produces spectacular "atlas" type maps. Integrates a 200,000 megabyte population database with polygon mapping. Includes Longley-Rice, Okamura-Hata, Cost-Hata, PTP #1 & #2, Line of sight, standard FCC methods and more. (TIREM is an option.)**
- **RPS-Radiowave Propagation Simulator (Radioplan)**
  - **A radio channel prediction solution that provides highly accurate channel data at extremely high computation performance.**
  - **The RPS technology is based on a superior ray launching approach.**
  - **RPS works extremely efficiently and owes its speed to a massive computation parallelism.**
  - **RPS is a fully GIS-enabled application with a wide range of data visualization, analysis, and post-processing functions.**

RF Propagation Models (5)

- **Wavesight (Wavecall)**
  - **A wave propagation prediction tool for wireless networks. It is specifically used to predict radio wave propagation for mobile communication networks in urban environments.**
- **Athena (Wave Concepts)**
  - **A wireless planning tool that utilizes the CRC-PREDICTTM model and statistical interference analysis techniques.**
  - **Accurate: typical standard deviations on the order of 5 dB or better.**
- **NP WorkPlace (Multiple Access Communications Ltd)**
  - **A high resolution coverage prediction tool for planning networks in urban environments. Using terrain and high resolution 3D building maps, it provides propagation predictions in 5 m bins at any height above the terrain (for antennas mounted at roof height), or can accurately predict the effects of urban canyons (for antennas mounted below roof height).**
  - **Outputs:**
    - **Signal strength**
    - **Path loss**
    - **Strongest server**
    - **Coverage overlap**
    - **Cochannel SIR**
    - **Adjacent channel SIR**
    - **Traffic Density**

RF Propagation Models (6)

- **ENTERPRISE Suite (AIRCOM International)**
  - **Offers combined radio and transmission planning, optimization, performance and parameter configuration management in a single integrated tool user environment.**
  - **Includes the following modules:**
    - **ASSET3G -** RF Planning Tool
    - **ARRAYWIZARD -** an Automatic Coverage & Prediction Tool
    - **CONNECT -** a Microwave Planning Tool
    - **DIRECT -** a Transmission Network Planning Tool
    - **ADVANTAGE -** an Automatic Cell Planning Tool
    - **TARGET -** a Process & Information Management System
    - **DATASAFE -** a Configuration Management Solution
    - **OPTIMA -** a Performance Management Solution
    - **QUALITA -** a Quality of Service Management Solution
    - **RANOPT -** a Post Processing & Analysis Tool
    - **WEBWIZARD -** an ENTERPRISE Wide Web Based GIS & Report Distribution System

Summary

- **18 commercially available software tools for RF propagation prediction were compared and contrasted**
- **Many more likely exist**
- **Network designers and developers must decide what software package suits their needs the best**

References

- **Radiowave Propagation in Wireless Communications Systems Design, *dmichelson@ieee.org*, obtained from: http://members.shaw.ca/propagation/planning.html.**