A COMMUNICATIONS ANALYSIS TOOL SET THAT ACCOUNTS FOR THE ATTENUATION DUE TO FOLIAGE, BUILDINGS, AND GROUND EFFECTS

G. Comparetto, J. Schwartz, N. Schult, J. Marshall
The MITRE Corporation
McLean, VA

ABSTRACT

The purpose of this paper is to describe a communications analysis tool, referred to as OPAR, that can be used in support of both in-field demonstrations and large-scale simulation activities. Using overhead imagery as a backdrop, OPAR provides a graphical user interface that allows the user to quantify the source/destination path attenuation in a mobile, ad-hoc communications network, taking into account obstructions due to foliage and buildings.

INTRODUCTION

Modeling and Simulation (M&S) techniques are increasingly being used to augment most current DoD programs in which new concepts in communications technology are being developed. One reason for this is the complexity of the operational environments in which the communications path technologies must operate - 100s of nodes, various levels of mobility, ad-hoc connectivity and rugged terrain and/or foliage. Of course, in-field demonstrations and experiments provide a more accurate estimate of achievable performance; however, high cost, equipment availability, and overall logistics tend to limit their usefulness to only limited scenarios. It would be helpful to have a capability that allows the user to capitalize on the advantages of both in-field demonstrations and large-scale simulation. The purpose of this paper is to describe a communications analysis tool set that accomplishes this goal.

The OPNET Path Attenuation Routine (OPAR) is a communications analysis tool set that quantifies the source/destination path attenuation in a mobile, ad-hoc communications network, taking into account obstructions due to foliage and buildings. OPAR includes a GUI-based tool, referred to as the OPAR Scenario Generation Tool (SGT), that allows the user to define areas of foliage and building obstructions on top of an overlaid overhead map, using a polygon representation that accounts for height and behavioral characteristics for each obstruction. The 3-D path loss is calculated between any two points taking into consideration ground effects, in additional to foliage and/or building attenuation. The

OPAR SGT also includes a number of support tools that allows the user to:

(1) calculate source/destination distances and lat/long points,

(2) visually depict the path attenuation between any two points as a function of transmitter and receiver antenna height and operational frequency,

(3) identify potential link connectivity between a set of nodes based upon path attenuation considerations, and

(4) generate a connectivity matrix for the set of nodes defined by the user that portrays the number of hops required to effect communications between each source/destination pair.

OPAR is applicable for frequencies up to 95 GHz – a limitation that arises from the Weissberger model applied to quantify the excess foliage attenuation data on a given path. OPAR also includes a S/W interface to OPNET that supports detailed simulations that account for ground effects, foliage and/or building attenuation for the scenario defined by the user via the OPAR SGT and applying the same algorithms in the OPNET Radio Pipeline stages that were developed for the OPAR SGT. Thus, the OPAR communications analysis tool set bridges the gap between supporting in-field demonstrations via the OPAR SGT and detailed discrete event simulation via the S/W interface to OPNET.

OPAR SCENARIO GENERATION TOOL

A screen shot of the OPAR SGT is shown in Figure 1 for the Lakehurst Naval Air Station (NAS) in New Jersey. This was the site of the first two in-field demonstrations performed in support of the DARPA Future Combat Systems Communications (FCS-C) program. Nineteen mobile ground nodes, plus one helicopter serving as a UAV-surrogate, were used to quantify the performance of the routing and MAC layer protocol technology developed via the FCS-C program to support mobile ad-hoc communications networks using directional antennas. The OPAR SGT was used by the Government technical

team to help design the demonstrations and was also used extensively by the FCS-C contractors to prepare for the in-field demonstrations and to support post-test data analyses.

The OPAR SGT allows the user to define areas of foliage and building obstructions on top of an overlaid overhead map, using a polygon representation that accounts for height and behavioral characteristics for each obstruction. It calculates the 3-D path loss between any two points, taking into consideration ground effects, foliage and/or building attenuation, and radio performance. The user can identify a set of waypoints, via point-and-click, or by directly specifying lat/long points, at which calculations can be performed. The user can also modify the parameters that effect the foliage and building attenuation models applied in calculating path loss.

Figure 2 shows several of the support tools provided by the OPAR SGT. The user can:

(1) calculate distance between any two points,

(2) identify the lat/long position of any point,

(3) calculate and visually depict the path attenuation between any two points as a function of transmitter and receiver antenna height and operational frequency,

(4) portray the change in path attenuation as the source and/or destination position is modified,

(5) identify potential link connectivity between a set of nodes based upon path attenuation considerations,

(6) generate a connectivity matrix for the set of nodes defined by the user that portrays the number of hops required to effect communications between each source/destination pair, and

(7) generate an animated set of output results that allows the user to perform sensitivity analyses for a variety of operational parameters.

FOLIAGE AND BUILDING ATTENUATION CALCULATIONS

OPAR first calculates the total source-to-destination path length and then determines whether the vector defined by the source and destination points passes through each of the *obstruction blocks* identified in the *scenario input file*. One of two cases can occur:

* Obstruction-Free Path: Vector does not penetrate any *obstruction blocks*
* Obstruction Block Penetration: Vector penetrates one or more *foliage obstruction blocks* and/or one or more *building obstruction blocks*

The calculations performed by OPAR to quantify the path attenuation for each of the two cases defined above are described in the following sections. (Note that the convention used in OPAR is to calculate the path attenuation as a "positive" value in dB.)
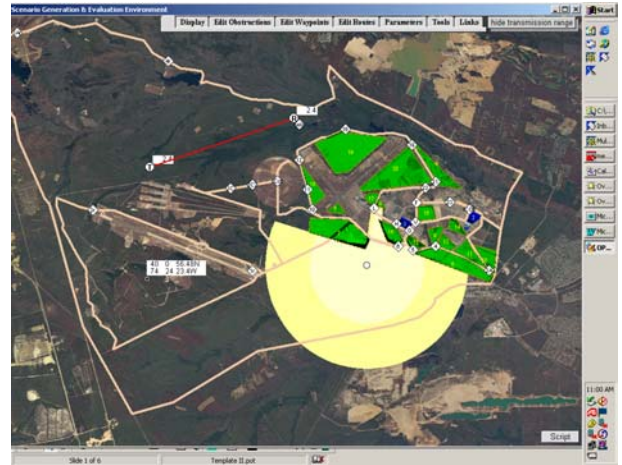

Figure 1: OPAR Scenario Generation Tool

Figure 2: The OPAR SGT Toolset

Obstruction-Free Path

The term "obstruction-free" implies that the source/destination vector does not pass through either a *foliage obstruction block* or a *building obstruction block*.

In this case, OPAR calculates the total path attenuation using both the Plane-Earth path attenuation equation [1] and the Free-Space attenuation equation and then chooses the larger value (in dB). The Plane-Earth and Free-Space equations used in OPAR are provided in equation (1) and (2) below, respectively:

$$L_p = 40Log(D) - 20Log(H_t) - 20Log(H_r) \qquad (1)$$

where

* L_p is the path attenuation using the plane-Earth model (dB)
* D is the total source-to-destination path length (meters)
* H_t and H_r are the transmit and receive antenna heights above ground level, respectively (meters)

$$L_{fs} = 32.45 + 20Log(D) + 20Log(f) \qquad (2)$$

where

* L_{fs} is the path attenuation using the Free-Space model (dB)
* D is the total source-to-destination path length (meters)
* f is the RF frequency (GHz)

Given equations (1) and (2) above, the total path loss is then calculated as follows:

$$L_{total} = max(L_p, L_{fs}) \qquad (3)$$

Obstruction Block Penetration

If a penetration is detected, OPAR calculates the path length through the obstruction. (D_f is the calculated path length through a particular *foliage obstruction block* and D_B is the calculated path length through a particular *building obstruction block*). If the penetration is through a *building obstruction block*, OPAR calculates the path attenuation term due to propagation through the *building obstruction block* as follows:

$$L_B = K_1(.6)^f + K_2 D_B \qquad (4)$$

where

* L_B is the path attenuation term due to propagation through a *building obstruction block* (dB)
* f is the RF frequency (GHz)
* K_1 is a constant used to map the first expression above to building penetration data reported by Parson in [1]. K_1=35.

* K_2 is a constant to account for the attenuation (per meter) of the signal within the building. K_2=1 (dB/m)
* D_B is the distance that the signal propagates through the building (meters)

The first term in the equation above accounts for the penetration "into and out of" the building by the signal and was derived from data reported by Parson [1] using a regression analysis technique. The second term in the equation above accounts for the attenuation "through" the building and is based on data reported by Willassen [3].

If the penetration is through a *foliage obstruction block*, OPAR calculates the "excess" path attenuation term using the Wiessberger model [2] as follows:

$$L_f = 1.33f^{0.284} \cdot D_f^{0.588}, \quad 14 < D_f \qquad (5a)$$

$$L_f = 0.45f^{0.284} \cdot D_f^{1.0}, \quad 0 \le D_f \le 14m \qquad (5b)$$

where

* L_f is the "excess" attenuation in dB due to signal propagation through the *foliage obstruction block*
* D_f is the distance that the signal propagates through the *foliage obstruction block* (meters)
* f is the RF frequency (GHz)

The term "excess" attenuation refers to the additional attenuation above the basic transmission loss, for a given path length, in the absence of foliage. OPAR applies equation (1) through (3) provided earlier to calculate the "basic transmission loss" for the link. Thus, the total path attenuation for the "obstruction penetration case" is calculated as follows:

$$L_{total} = max(L_p, L_{fs})_{Deff} + sum(L_f) + sum(L_B) \qquad (6)$$

where

* L_{total} is the total path attenuation from source-to-destination (dB)
* $max(L_p, L_{fs})_{Deff}$ means that this term is calculated at D_{eff}
* D_{eff} is the "effective" path length over which the Plane-Earth and/or Free-Space path attenuation model is applied and is equal to the total path length minus the sum of the *building obstruction block* path length segments or $sum(D_B)$
* $sum(L_f)$ is the sum of the "excess" attenuation terms in dB due to signal propagation through the *foliage obstruction block(s)* (dB)

* sum(L_B) is the sum of the path attenuation terms due to propagation through the *building obstruction block(s)* (dB)

OPAR/OPNET INTERFACE

OPAR is integrated into an OPNET network model via 3 components: a top-level standalone process model called opar_init, a new radio pipeline stage routine for the transmitter-based "channel match" stage defined in standard OPNET, and a new radio pipeline stage routine for the receiver-based "power" stage. The opar_init process model defines and initializes a set of OPAR-specific global variables. The new "channel match" stage routine includes the OPAR algorithms to determine path loss. The new "power" stage routine uses the OPAR-generated path loss value to compute received signal power. By including the top-level opar_init model and replacing the default "channel match" and "power" radio pipeline stage routines with the new OPAR-based routines, the OPAR functionality is essentially included in an OPNET network simulation model. These components are discussed further below.

The opar_init process model defines and initializes the OPAR global variables at the start of a simulation, which is used by the "channel match" pipeline stage to calculate path loss. To initialize these variables, a *scenario input file* is read in and parsed. This file defines the OPAR-specific parameters and a set of obstructions for a given scenario. It has a pre-defined format and can be automatically generated by the OPAR SGT (See Figure 3). The OPNET OPAR global variables include: the reference point for the obstructions defined in the file, the list of obstructions, and the set of OPAR parameter values.
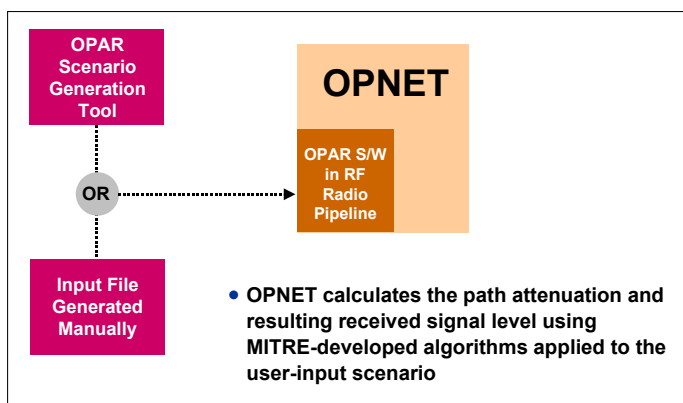

Figure 3: OPAR/OPNET Architecture

During the execution of the simulation, OPNET has a radio pipeline mechanism that is used to evaluate the wireless transmission of a packet by a given source. The pipeline consists of 14 stages, and most are executed on a per-receiver basis when a transmission occurs. The OPAR functionality is included in the "chanmatch" stage, because of the desire to eliminate unsuccessful packets as early as possible in pipeline calculations (it is 3rd). The "power" stage, which is the logical place for this functionality, is a later stage (7th).

For the "channel match" stage, a new routine was created to handle its calculations, which we call "wlan_chanmatch". The stage is responsible for determining whether a transmission is relevant with respect to its effect on a given receive channel – depending on its calculations, future stages for this receiver may not be executed. The calculations for this stage are illustrated in Figure 4, which determines the status of a given packet. A packet can only be assigned "VALID" if it has an overlapping frequency band, matches all of the appropriate attributes, and results in a path loss of less than 134 dB (The value of 134 dB can be modified by the user). Note that for those packets initially assigned "NOISE", an OPAR path loss calculation is made and if the path loss is less than 134 dB, then the packet status remains "NOISE" (otherwise it is changed to "IGNORE").

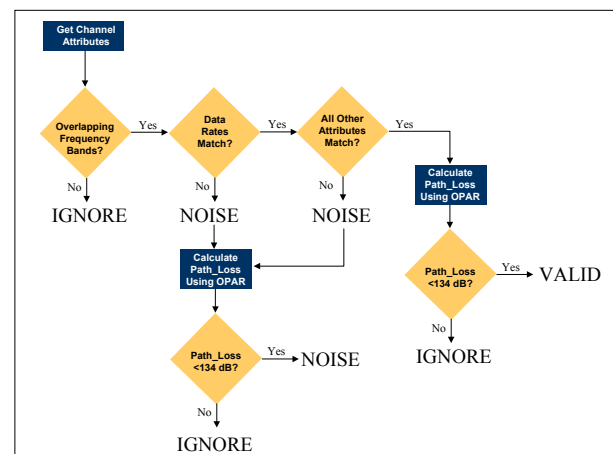
Figure 4: IGNORE/NOISE/VALID Attribute Assignment in wlan_chanmatch Routine

To calculate path loss, the OPAR algorithms require the following information:

* Height of transmit antenna (meters)
* Height of receive antenna (meters)

* Source latitude and longitude
* Destination latitude and longitude
* Frequency of operation (GHz)

These values are available and retrieved by the new routine, in order to compute the path loss.

The algorithms take into consideration foliage and/or building obstructions, defined in the global list of obstructions. The resulting path loss value is stored in a special OPNET-defined reserved Transmission Data Attribute (TDA) for path loss, which is later retrieved by the new routine defined for the "power" stage (which uses this value to compute "received power", instead of re-calculating path loss on its own).

STATUS AND FUTURE PLANS

OPAR has been used extensively in support of the DARPA Future Combat System Communications (FCS-C) program. The OPAR tool set was used on the Government side to help design the in-field demonstrations held in Lakehurst, NJ and Boise, ID during FY02 and FY03 and to predict anticipated communications network connectivity and performance data. It was also used on the contractor side by the technology developers to provide quantitative support for final design decisions and for post data analysis activities.

The OPAR functionality was significantly expanded in FY03 in order to produce a Communications Resource Planning Tool (CRPT) that enables the user to place vital communications resources in an area of operations that includes building and foliage, while taking into account all of sthe path attenuation characteristics addressed by OPAR in addition to the impact of jammers on link connectivity. The CRPT is described in a companion paper in the MILCOM 2003 conference.

REFERENCES

1. *"The Mobile Radio Propagation Channel" by David Parsons, Pentech Press, 1992*

2. *"An Initial Critical Summary of Models for Predicting the Attenuation of Radio Waves by Trees", ECAC Report Number ESD-TR-81-101, July 1982*

3. *"A method for implementing Mobile Station Location in GSM" by Svein Yngvar Willassen, 3 Dec 1998.*