GPS Distributed Aperture Positioning (GDAP)

Alison K. Brown, Bruce Johnson, and Rick Edwards
NAVSYS Corporation
14960 Woodcarver Road
Colorado Springs, CO 80921
(719) 481-4877

ABSTRACT

The GPS signal is subject to a variety of potential degradations, such as path loss (e.g., foliated or indoor environments), multipath (e.g., urban canyon or in-building), and interference (intentional or unintentional). There are many applications, both commercial and military, where a group of GPS users may operate together in a denied or degraded GPS environment. Using the traditional GPS receiver approach, individual or all users may be denied the ability to navigate in such an environment, even though each user may be intermittently receiving useful satellite signal information. To address this issue, NAVSYS developed a design for a GPS Distributed Aperture Positioning (GDAP) system which uses composite GPS and intra-network ranging measurements from a network of GPS users to combine the respective satellite signals they are tracking and allow operation in a degraded environment.

1 INTRODUCTION

GPS services can be denied or degraded for users operating under many conditions. GPS signals may be attenuated when operating under foliage, in an urban canyon, or inside a building to the extent that they cannot be detected by a conventional GPS receiver. GPS signals can be denied when in close proximity to a GPS jammer or interference source. GPS signals can be corrupted with multipath when operating in urban canyons. GPS navigation is not possible without sufficient satellites to provide good geometry (Position Dilution of Precision or PDOP).

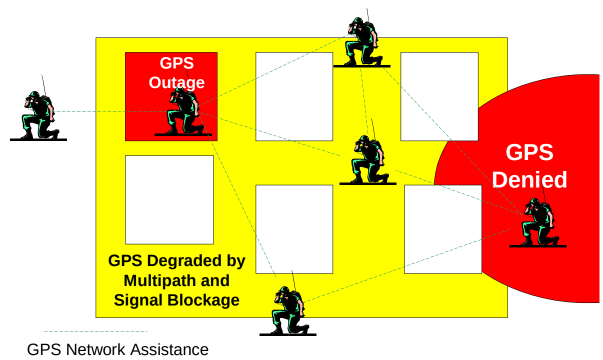

Figure 1-1 GPS Issues to be Overcome by Network Assistance

One solution for augmenting GPS coverage when GPS is denied is to use intra-network ranging using Time-Of-Arrival (TOA) observations using the network waveform[1]. Previous intra-network ranging approaches though have required significant infrastructure to assure that sufficient intra-network observations are available to allow positioning. With the GPS Distributed Aperture Positioning (GDAP) system approach, the combination of GPS and intra-network ranges across a sparse network of participants is used to calculate the ensemble of network locations even when no individual participant has sufficient GPS or intra-network ranges to calculate their own position. NAVSYS is implementing the GDAP positioning capability on a network of Software Defined Radios (SDRs).

2 GDAP SYSTEM CONCEPT

With the GDAP system concept, both GPS and intra-network range observations are combined across the network participants to compute a composite position solution. Figure 2-1 shows a typical scenario based on an urban navigation environment where the GPS satellite visibility was simulated for four users located in urban canyons. At each of these locations, only two or three GPS satellites were in view as shown in the individual sky plots in Figure 2-1. With the GDAP network augmentation, TOA observations are also made between the radios that provide a measure of the pseudorange (PR) between the users' individual locations. The GDAP algorithm combines these observations and computes a composite GPS/TOA solution using Distributed Aperture Positioning for the network ensemble of user locations.

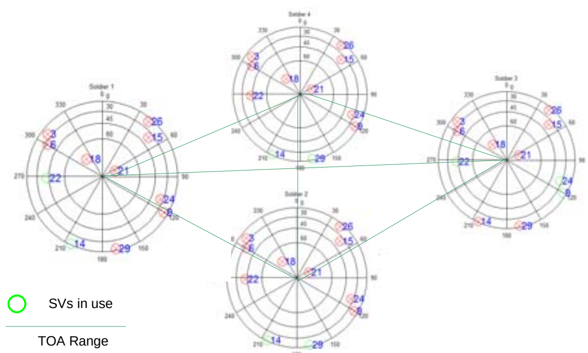

Figure 2-1 GDAP Combines GPS and Intra-Network Range Observations

3 GDAP SIMULATION TOOL

To evaluate the performance of the GDAP solution under representative scenarios, a sophisticated simulation tool was developed to simulate the availability of GPS and other augmentation signals in an urban environment. This tool uses urban models downloaded from Google's 3D warehouse combined with a Matlab ray propagation path tool to simulate where GPS, intra-ranges from the radio network, and other Signals of Availability (SOA), such as TV stations or WiMax transmitters, could be received that could also provide Time-Difference of Arrival observations to augment the GDAP solution. The simulation was used to generate the GDAP navigation solutions for different unit scenarios under test to evaluate the GDAP performance under different conditions in a dense urban environment.

The simulation used a ray-tracing model using 3D buildings downloaded through Google Earth (see Figure 3-1). The Google Earth models are then converted into a 3-D model file that can be read into Matlab as a Shape File (*.obj) as shown in Figure 3-2.

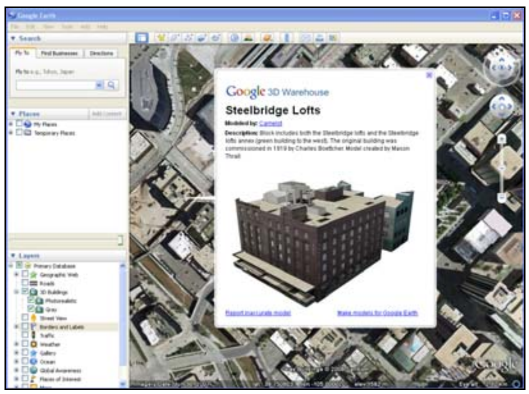

Figure 3-1 Google Earth 3D building

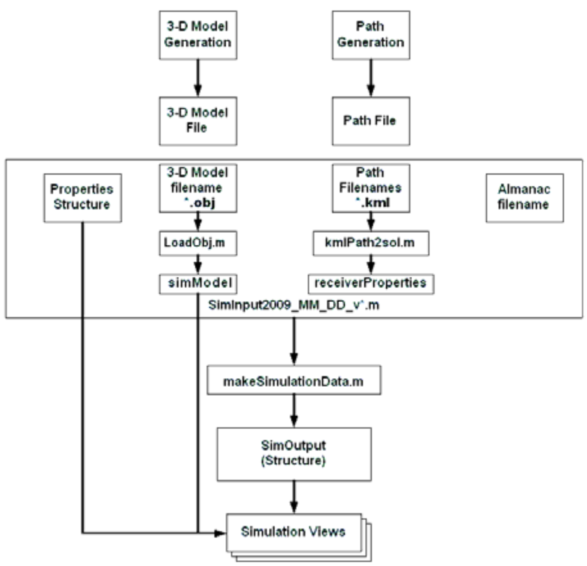

Figure 3-2 Simulation Steps

The makeSimulationData function generates the following data for each time step of the simulation:

- GPS Time
- Satellite positions (from GPS almanac file)
- User positions (entered in as a KML file)
- Ranges from receivers to visible GPS satellites (calculated using ray-tracing)
- Receiver-to-receiver ranges (calculated using ray-tracing)
- Length of obstructions in lines-of-sight between receivers (used to estimate signal propagation loss and received signal strength)
- Geometry of GPS and RF signal observations that can be received at each user location.

An example of a GPS satellite visibility view across a complete urban model, which can also be generated by the simulation tool, is shown in Figure 3-3.

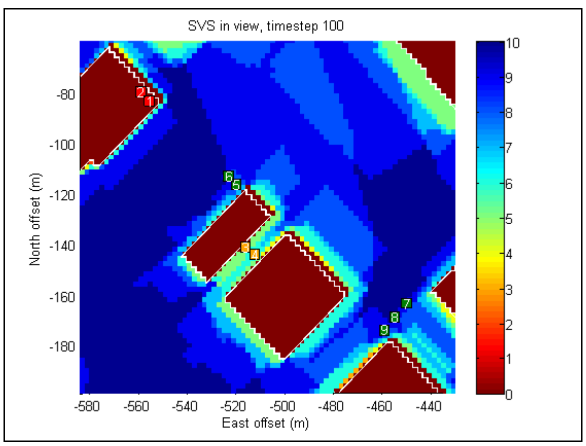

Figure 3-3 Example Satellite Visibility View

The simulation defines a propagation loss model in terms of attenuation per linear meter of an obstruction that the line of sight passes through. This parameter is calculated in the simulation by determining the intersections of the line of sight with model geometry and taking the sum of the length of each segment of the line of sight that lies within a building. The typical loss/meter as a function of frequency based on previous test data is shown in Table 3-1. The GPS or TOA signals are assumed to be in view when the signal-to-noise ratio (SNR) calculated based on the free-space propagation model and the simulated propagation loss based on the path through a building is above a specified signal detection keyword value. The 1-sigma noise on the TOA observation is also calculated using this predicted SNR for use in calculating the expected navigation accuracy.

Table 3-1 Urban Propagation Loss Model

Model Frequency	Residential	High Rise	Propagation Loss Model L_{UiUj} dB/m
912 MHz	7.5–12.5 dB	17-27 dB	.65 dB/m
1920 MHz	12-21 dB	18-32 dB	.94 dB/m
5990 MHz	16-26 dB	24-36 dB	1.21 dB/m
Dimension	8 – 17 meters	30 – 70 meters	

4 GDAP NAVIGATION

The GDAP navigation solution is calculated by estimating the N*m states for each of the N network participants. The m states for each of the individual participants include their 3-D position errors and the time offsets associated with each type of measurement set, for example, GPS, TOA from RF ranging or TDOA from SOA observations. Combining these observations into the following WLS measurement update solves for the N*m states for each of the position and clock offsets at the network nodes.

$$\underline{Z} = \begin{bmatrix} \underline{Z}_{PR} \\ \underline{Z}_{TOA} \\ \underline{Z}_{H} \end{bmatrix} \quad H = \begin{bmatrix} H_{PR} & H_{TOA} & H_{H} \end{bmatrix}$$

$$R = \begin{bmatrix} R_{PR} & 0 & 0 \\ 0 & R_{TOA} & 0 \\ 0 & 0 & R_{H} \end{bmatrix}$$

$$P = \left(H^T R^{-1} H\right)^{-1} \qquad \text{GDAP Covariance}$$

$$\underline{\hat{x}}^{+} = \underline{\hat{x}}^{-} + PH^T R^{-1} \underline{Z} \qquad \text{GDAP State Update}$$

5 NEW YORK SIMULATION

A simulation was performed for a scenario in Lower Manhattan, New York, over the area covered by the view in Figure 5-1 using the 3-D urban model downloaded from Google Earth shown in Figure 5-2. The number of GPS satellites in view at a typical time step are shown in Figure 5-3.

Figure 5-1 Aerial view of New York scenario location in Google Earth

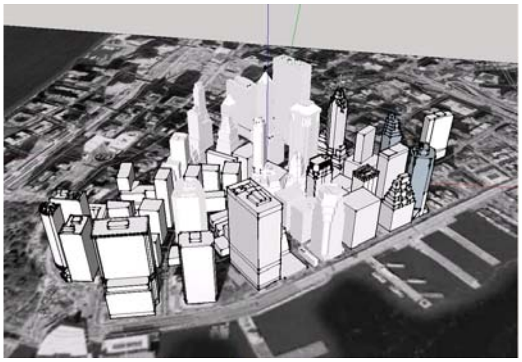

Figure 5-2 NY 3-D Model

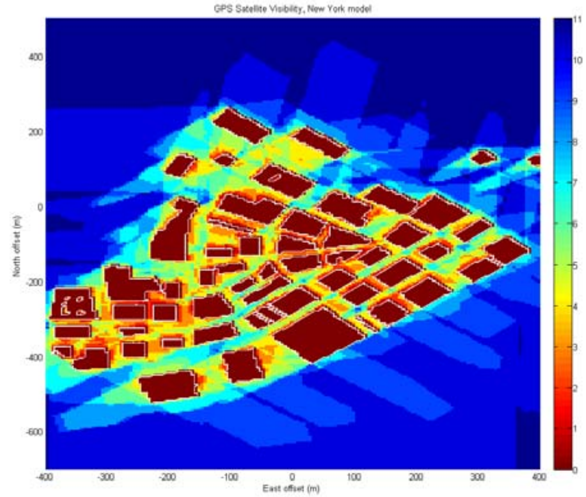

Figure 5-3 New York Satellite Visibility

The simulated paths for 20 user network participants were entered using KML files as shown in Figure 5-4. The simulation results for the networked locations at one timestep is shown in Figure 5-5. In this figure the ray paths available between the network participants are shown based on the simulated ray tracing. There are three integers in each bracket, separated by commas. The first number indicates the number of GPS satellites (satellite vehicles - SV's) signals that can be received at that location, the second indicates the number of TOA ranges that can be received and the third indicates the number of TOA ranges that are used in the GDAP navigation solution.

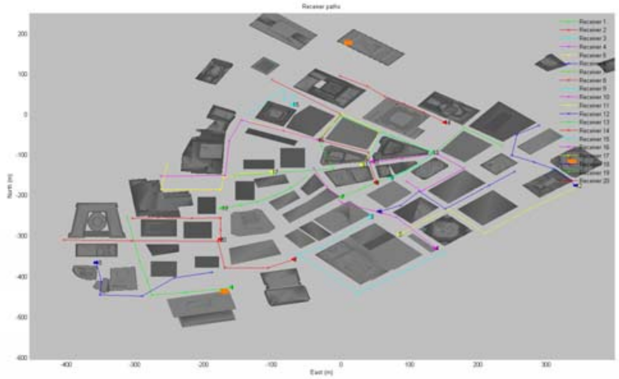

Figure 5-4 NY Receiver Paths

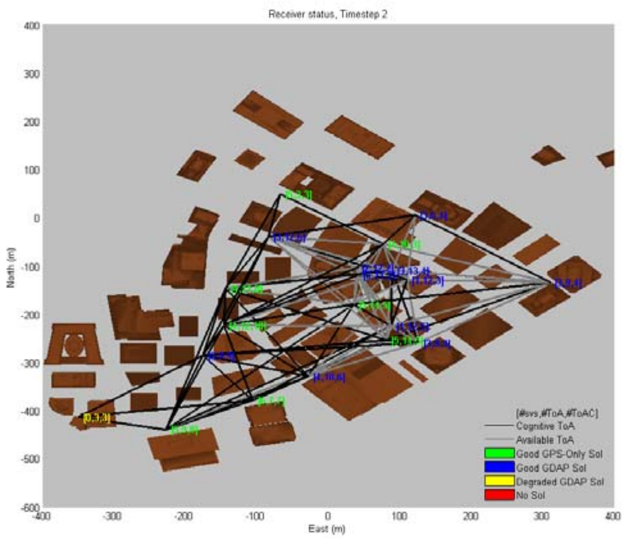

Figure 5-5 NY GDAP Simulation

Figure 5-6 summarizes the results of the simulation at different timesteps. The bar on the right for each time step shows the number of participants who were able to have a good GPS navigation solution (green), the number who could navigate but with poor GPS geometry (yellow) and the number who had insufficient satellites in view to achieve a navigation solution. The bar on the left indicates the number of participants who were able to achieve a GDAP-aided navigation solution (blue). In all cases, the GDAP collaborative navigation solution was able to provide the location for each network participant.

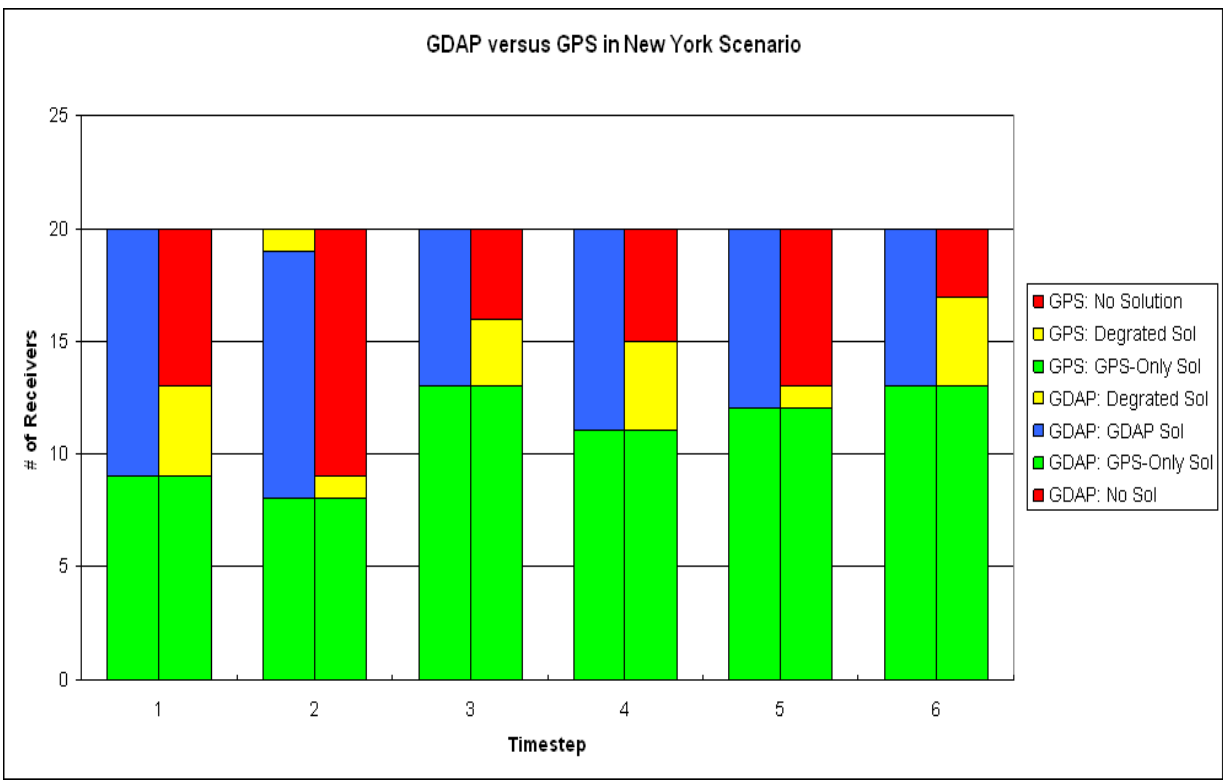

Figure 5-6 NY Performance

6 CONCLUSION

In this paper we have described a collaborative GPS Distributed Aperture Positioning (GDAP) system architecture which has the following qualities:

- Robust collaborative positioning in an urban environment where GPS satellite visibility is occluded
- Network assistance to allow positioning of users in an environment where GPS is completely obstructed or denied

The paper also describes a sophisticated simulation tool that can be used to generate simulated scenarios in a complicated urban environment.

NAVSYS is implementing the GDAP system architecture on a network of Software Defined Radios and is continuing its GDAP development effort in collaboration with Dr. Michael Buehrer and Virginia Tech's Mobile and Portable Radio Research Group.

7 REFERENCES

[1] Brown, Alison, and Ben Mathews, "Indoor Navigation Using A Software Defined Radio," Proceedings of the SDR '08 Technical Conference, Washington, DC, October 2008