Technical Note

EGNOS Performances in Urban Areas Using the ESA SISNeT Technology: Advanced Modelling of User Masking Effects

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TABLE OF CONTENTS

1. INTRODUCTION 1

1.1 PURPOSE OF THE DOCUMENT 1
1.2 OUTLINE OF THE DOCUMENT 1
1.3 REFERENCES 2
1.4 LIST OF ACRONYMS 4

2. BACKGROUND 5

2.1 OVERVIEW 5
2.2 THE ESA SISNeT TECHNOLOGY 5
2.3 THE ESA ESPADA SIMULATION SOFTWARE 6
2.4 ADVANCED MASK ANGLE MODELLING TOOL 7

3. SIMULATION PROCEDURE 11

3.1 OVERVIEW 11
3.2 TECHNICAL BASELINE FOR SIMULATIONS 11
3.3 SIMULATION PROCEDURE 12
3.4 RESULTS FORMAT 13

4. SIMULATED SCENARIOS 13

4.1 OVERVIEW 13
4.2 SCENARIO DESCRIPTION FORMAT 13
4.3 LIST OF SIMULATED SCENARIOS 14

5. OBTAINED RESULTS 14

5.1 OVERVIEW 14
5.2 RESULTS LISTING FORMAT 15
5.3 LIST OF RESULTS 16
5.4 SUMMARY OF RESULTS 16

6. CONCLUSIONS 20

6.1 CONCLUSIONS FOR SCENARIOS 0 TO 15 20
6.2 GENERAL CONCLUSIONS 21

APENDIX A: SIMULATION ASSUMPTIONS FOR THE GPS-ONLY SCENARIO 22

APENDIX B: SIMULATION ASSUMPTIONS FOR THE GPS + SISNET SCENARIO 23

APENDIX C: LIST OF SIMULATION SCENARIOS 24

APENDIX D: LIST OF SIMULATION RESULTS 40

LIST OF FIGURES

Figure 1: The ESPADA Main GUI. 7
Figure 2: The AMA tool is launched from the ESPADA main GUI through a menu option 8
Figure 3: The AMA tool main GUI..8
Figure 4: Local co-ordinate system employed by ESPADA and the AMA tool 9
Figure 5: 3D representation of the mask designed in Figure 3...10
Figure 6: A potential scenario corresponding to the model shown in Figure 5.................................11
Figure 7: GPS/EGNOS comparative bar plot for a mask angle of 25 degrees..................................12

LIST OF TABLES

Table 1: Summary of results (scenarios 0 to 6)..17
Table 2: Summary of results (scenarios 7 to 11)..18
Table 3: Summary of results (scenarios 12 to 15)..19
Table 4: Simulation assumptions for the GPS-only scenario...22
Table 5: Simulation assumptions for the GPS + SISNeT scenario 23

1. INTRODUCTION

1.1 Purpose of the Document

This Document aims at complementing the study performed in [1] with more advanced results. In [1], a comparison between GPS and EGNOS systems in terms of availability of accuracy was performed, for several satellite visibility conditions (always using constant mask angles). The main purpose was to assess if the EGNOS corrections have a positive impact in such extreme conditions, in which the GEO signals cannot be received, and the GPS satellites are obfuscated by obstacles (buildings and other objects easy to find in any urban area). The results shown that the EGNOS corrections are quite useful under those situations. Moreover, they play a more important role, with respect to the full visibility scenario. Hence, the interest of a broadcast method complementary to GEO satellites has been justified, i.e. the utility of the ESA SISNeT technology [2-8] has been preliminarily demonstrated.

Although a scenario based on a constant mask angle is possible, other scenarios are even more typical, and must be considered. For instance, the existence of streets (allowing a better visibility in some directions) is not considered in [1]. Taking this into account, ESA has enhanced its ESPADA simulation tool [9-11] to make possible those advanced analyses. The principal purpose of this Document is to present the developed simulation tools and the obtained results, providing a more accurate justification of the SISNeT concept. A total of fifteen simulation results are presented, based on scenarios that are easy to find in any urban area. The results are quite encouraging showing a tremendous advantage of EGNOS performance (accuracy/availability) versus GPS-only solutions, for EGNOS-SISNET powered receivers in typical urban environments.

1.2 Outline of the Document

This Document is organised as follows:

Chapter 1 introduces this Document, showing its purpose and organisation. A list of references for further reading and a list of acronyms are also included.

Chapter 2 provides some background information, centred on the ESA SISNeT technology (the concept to justify), and the ESPADA and AMA tools. These tools have been used to obtain the results included in this Document.

Chapter 3 describes the assumptions and procedures used for simulations, as well as the format employed for presenting the results.

Chapter 4 introduces a compact and visual format for describing the simulation scenarios and points to Appendix C, where the detailed list of scenarios is presented.

Chapter 5 introduces a compact and visual format for describing the simulation results and points to Appendix D, where the detailed list of results is presented. A summary of results is included as well.

Chapter 6 ends this Document, providing the most relevant conclusions derived from the simulation results.

This Document includes the following Appendices:

Appendices A and B summarise the assumptions considered for simulation activities.

Appendix C lists the simulated scenarios.

Appendix D lists the simulation results.

1.3 References

Reference	Title
1	F. Torán and J. Ventura-Traveset, "*GPS / EGNOS Comparative under Several Visibility Conditions,*" ESA internal note, Ref. E-TN-PFM-E-0020-ESA, November 2001.
2	F. Toran, J. Ventura-Traveset and J.C. de Mateo, "The ESA SISNET Project: Real-Time Access to the EGNOS Services Across the Internet," *Seventh International Workshop on Digital Signal Processing Techniques for Space Communications*, Sesimbra (Portugal), October 2001. Available at http://www.esa.int/estb.
3	F. Toran, J. Ventura-Traveset and J.C. de Mateo, "Internet-based Satellite Navigation receivers using EGNOS: the ESA SISNET project," *ESA Workshop on Satellite Navigation User Equipment Technologies (NAVITEC)*, Noordwijk (The Netherlands), December 2001, in press. Available at http://www.esa.int/estb.
4	"SISNET: Making EGNOS Available Over the Internet," *ESTB News*, ESA Newsletter, Issue 2, page 4, September 2001. Available at http://www.esa.int/estb.
5	F. Toran, J. Ventura-Traveset and J.C. de Mateo. "The ESA SISNET Project: Real-Time EGNOS Services through the Internet," *ESA Journal Preparing for the Future.*
6	F. Toran and J. Ventura-Traveset. "The ESA SISNET Project: Real-Time Access to the EGNOS Services across the Internet," *2nd ESA ESTB Workshop*, Nice (France), November 2001. Available at http://www.esa.int/estb.
7	H. Secretan, J. Ventura-Traveset, F. Toran, G. Solari and S. Basker, "EGNOS System Test Bed Evolution and Utilisation," *ION GPS 2001*, Salt Lake City (USA), September 2001. Available at http://www.esa.int/estb.

8	H. Secretan, J. Ventura-Traveset, F. Toran, G. Solari and S. Basker, "EGNOS System Test Bed Evolution and Utilisation," *NAVITEC Conference*, Noordwijk (The Netherlands), December 2001. Available at http://www.esa.int/estb.
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10	A. García, C. Garriga, P. Michel and J. Ventura-Traveset, "EGNOS Simulation Tool for Performance Assessment and Design Analysis (ESPADA)," *ESA Journal preparing for the Future,* Vol. 7, No.4, December 1997.
11	F. Toran, "*Advanced Simulation Tool for Satellite Navigation: from Radio Frequency to Positioning Using Real Data*," Research Work Essay, Directed by Dr. Diego Ramirez (University of Valencia) and Dr. Javier Ventura-Traveset (ESA), July 2001.
12	ESA, *EGNOS System Test Bed Website*. http://www.esa.int/navigation/estb
13	RTCA, *"Minimum Operational Performance Standards for Global Positioning System / Wide Area Augmentation System Airborne Equipment,"* Ref. RTCA/DO-229B, October 6, 1999
14	US DoD, "*Standard Positioning Service GPS*," Washington, October 2001.
15	*Minimum Operational Performance Standards for Global Positioning System / Wide Area Augmentation System Airborne Equipment*. Ref. RTCA/DO-229 of January 16, 1996.
16	European Space Agency. *EGNOS AOC System Requirements Document*. Ref. E-RD-SYS-E-001 ESA, Issue 1, Rev. 2 of February 1998.
17	ESA/Thomson-CSF. *Interface Control Document for EGNOS System Simulations*. Ref. EGN-ICD-E-389-T4S Issue 1, Rev. D of November 1997.
18	ESA. *Service Volume Model Simulation Assumptions for SBAS Performances*. Ref. IWG/SVM/2.0, Issue 2, Rev. 0, June 2000.
19	ESA ITT AO/1-3750/NL/DS, "Integration of EGNOS and Terrestrial Regional Networks," *ASTE Work plan 2001*.
20	The Mathworks, "*MATLAB Official Web Site*," http://www.mathworks.com

1.4 List of Acronyms

AMA	Advanced Mask Angle modelling tool
ASTE	Advanced System Telecommunication Equipment
DOP	Dilution Of Precision
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
ESPADA	EGNOS Simulation tool for Performance Assessment and Design Analysis
ESTB	EGNOS System Test Bed
GEO	Geostationary Satellite
GIVE	Grid Ionospheric Vertical Error
GLONASS	GLObal NAvigation Satellite System
GPS	Global Positioning System
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HNSE	Horizontal Navigation System Error
LAN	Local Area Network
MOPS	Minimum Operational Performance Standards
NSE	Navigation System Error
PL	Protection Level
PO	Project Office
RAIM	Receiver Autonomous Integrity Monitoring
RIMS	Ranging and Integrity Monitoring Stations
SISNET	Signal In Space through the InterNET
SPR	Software Problem Reports
SPS	Standard Positioning Service
UDRE	User Differential Ranging Error
UERE	User Equivalent Ranging Error
URE	User Ranging Error
VDOP	Vertical Dilution of Precision
VPL	Vertical Protection Level
WWW	World Wide Web
XPL	Horizontal/Vertical Protection Level

2. Background

2.1 Overview

This Chapter introduces some background on the ESA SISNeT technology, the concept justified through [1] and this Document.

This Chapter also introduces two ESA Simulation tools, which have been used for obtaining the results presented in this Document:

- ?? The ESA ESPADA [9-11] Simulation tool, which current version is 4.2;
- ?? The Advanced Mask Angle Modelling Tool (AMA).

2.2 The ESA SISNeT Technology

Satellite broadcasting through GEOs is proved to be an efficient strategy for avionic applications and other modes of transport. For some applications, though, GEO broadcasting may provide some limitations (e.g. building obstacles in cities or rural canyons may difficult the GEO reception). Since the EGNOS message will still be very useful for those applications, a different transmission link may need to be considered to take the maximum advantage of the EGNOS potential. For this reason, ESA has recently launched specific contract activities (through the Advanced System Telecommunication Equipment programme –ASTE–) to assess and demonstrate architectures where the ESTB signal [7,8] is broadcast through non-GEO means (e.g. FM or GSM broadcasting) [19]. In this context, ESA has also launched an internal project to provide access to the EGNOS test bed messages through the Internet. The product of this project is a new technology, called ***SISNeT*** (Signal in Space through the Internet). This Document (together with [1]) demonstrates the utility of the EGNOS message under low-visibility scenarios, hence, justifying the need of the SISNeT technology.

A first prototype of the SISNET concept was set-up by the ***ESA GNSS-1 Project Office*** in August 2001. This first prototype uses a PC computer to implement the user equipment software, and the connection to the Internet is achieved using a LAN environment (via a proxy server). A generic GPS receiver is connected to the computer through a serial port. The user software implements three SISNET-based applications:

- ?? Real-time analysis of the ESTB messages (ESTB laboratory application);
- ?? Real-time monitoring of the ESTB performance;
- ?? Real-time monitoring of the ESTB performance through the World Wide Web (WWW).

The SISNET project can grant important advantages to the GPS land-user community. A user equipped with a GPS receiver and a GSM (or GPRS) modem can access the SISNET services, thus being able to benefit from the EGNOS augmentation signals, even under situations of GEO blocking.

2.3 The ESA ESPADA Simulation Software

The objective of the EGNOS Simulation tool for Performance Assessment and Design Analysis (ESPADA) is to support the GNSS-1 Project Team simulation needs. These are basically two:

?? Availability of the accuracy given by the system;
?? Availability of its integrity over specified service volumes.

Also, ESPADA implements functions to compute accuracy (DOP, NSE) and integrity (RAIM, PL). Precise definitions of the requirements for those algorithms can be found in [15-18].

ESPADA uses the space and ground segments specified in the frame of the EGNOS program, which includes GPS, GLONASS and GEO constellations and the RIMS deployment. The orbital parameters of those constellations can be found in [15,16]. The locations of the RIMS sites can be found in [16,18].

ESPADA is user-friendly Windows-based PC software capable of performing EGNOS system-level simulations. The software has been developed using MATLAB? [20] programming language without applying a compilation process. That means the application must run under the MATLAB? environment (version 5.2 and above).

ESPADA is highly adaptable to changes in algorithm definitions, and portable to different host platforms with a reasonable low impact in its code. Since these requirements correspond to some characteristics of the MATLAB? programming language, it is easy to assure the software is portable and easy-to-maintain. The last version of ESPADA is 4.2, including the following features:

?? Professional installation procedure;
?? Esthetical changes in the main window (colours, alignment, etc.);
?? Load and save simulation scenarios;
?? Output in PowerPoint format;
?? Differential availability maps plotting capability;
?? RIMS location maps;
?? XPL inspector tool;
?? More than 30 Software Problem Reports (SPR) have been fixed;
?? Simulations with ESTB real data (ESTB Wizard);
?? AMA tool;
?? Real-time monitoring of the ESTB performances using the ESA SISNeT technology.

Figure 1 shows the ESPADA main GUI. For further reading on the ESPADA tool, the reading of [9-11] is strongly recommended.

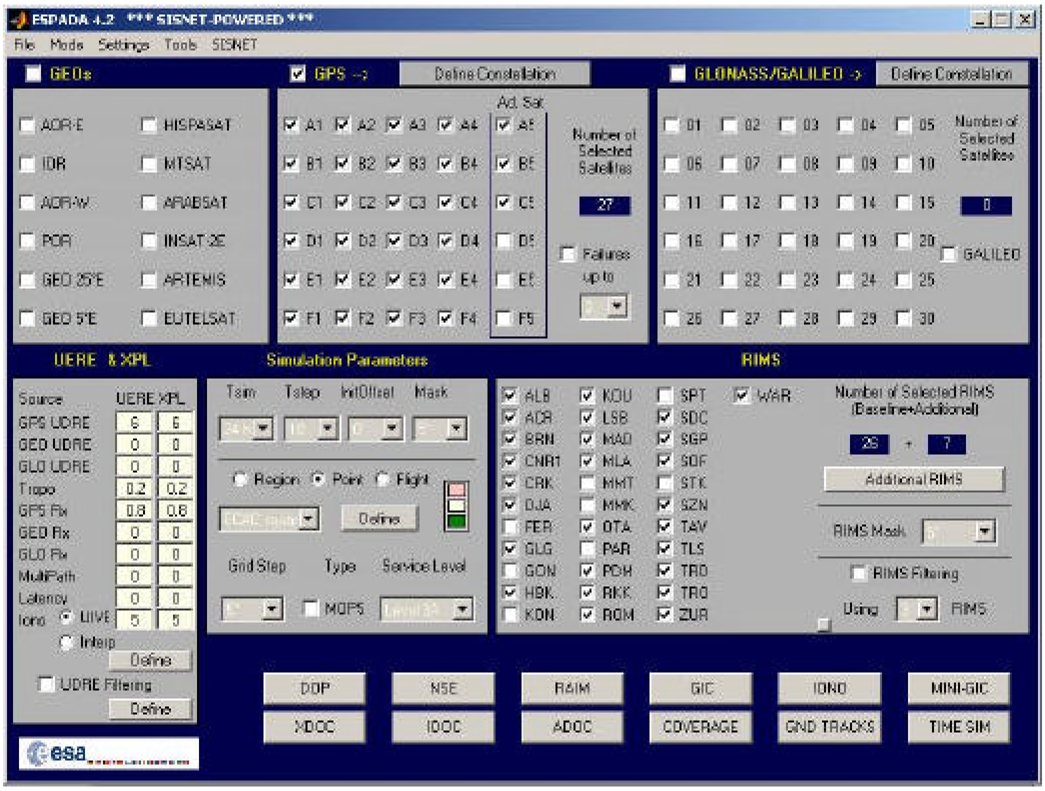


Figure 1: The ESPADA Main GUI.

2.4 Advanced Mask Angle Modelling Tool

The AMA tool complements the ESPADA software, allowing performing simulations for complex user masking conditions. In other words, AMA removes the limitation of using constant user mask angles in the simulations (i.e. the typical assumption, which is not usually in line with the real scenarios). Instead, AMA allows modelling the existence of obstacles in any disposition (e.g. buildings at each side of a street).

Since AMA needs to use the ESPADA simulation engine, it has been integrated both into the ESPADA simulation engine and GUI (see Figure 2). Therefore, the AMA tool must be understood as a part of the ESPADA software, and not as an independent tool.

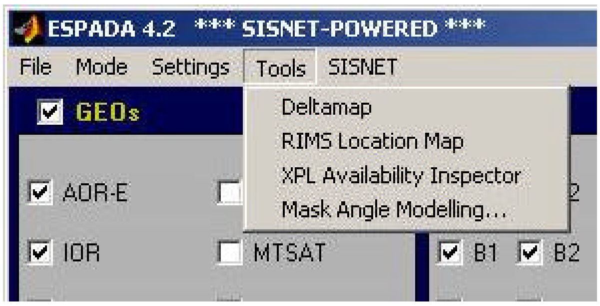


Figure 2: The AMA tool is launched from the ESPADA main GUI through a menu option

After pressing the "Mask Angle Modelling…" menu option, the AMA GUI is shown on screen (Figure 3). The window contains the necessary controls to create a table, representing an elevation versus azimuth relationship (both variables are expressed in radians). The elevation column must be understood as the mask angle to apply to a specific range of azimuths.

For each simulation step, ESPADA centres a local co-ordinate system on the user's location (the orientation of each axis is illustrated in Figure 4). The table introduced through the AMA tool is referred to the same co-ordinate system. For each satellite, ESPADA calculates the corresponding azimuth and elevation (? and f , via conversion to spherical co-ordinates), with respect to the local co-ordinate system. In addition, ESPADA uses the table to obtain the mask angle corresponding to the satellite's azimuth. If the elevation of the satellite is lower than the mask angle, that satellite is considered not visible.

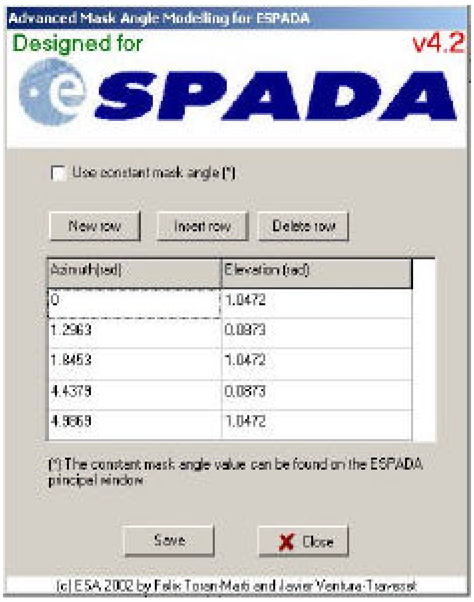


Figure 3: The AMA tool main GUI

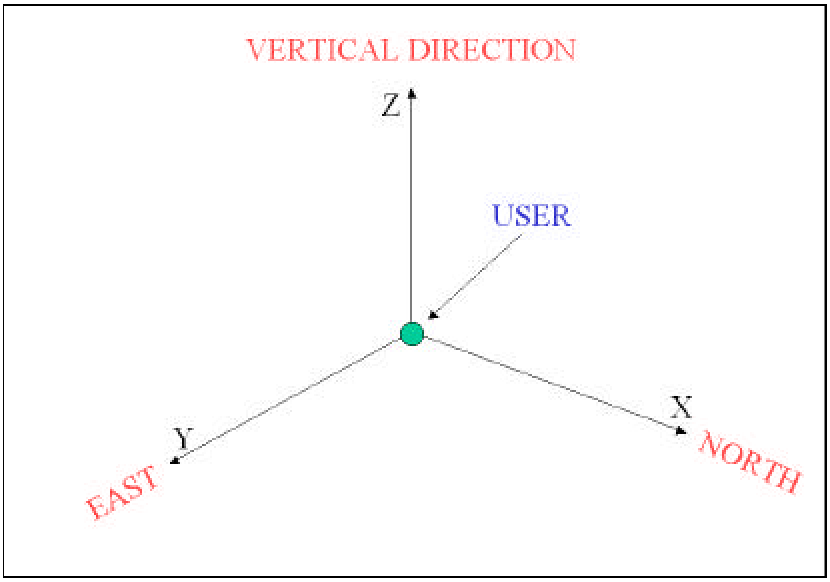


Figure 4: Local co-ordinate system employed by ESPADA and the AMA tool

The table must be interpreted as follows. If a pair of consecutive rows presents the following contents:

	Azimuth	Elevation
Row n	? (n)	f (n)
Row n+1	? (n+1)	f (n+1)

That means ESPADA will apply a mask angle of f (n) radians for azimuths ranging from ? (n) to ? (n+1). The mask angle corresponding to the last row is extended up to 2p radians. For the table shown in Figure 3, a mask angle of 1.0472 rad is considered for azimuths in [4.9869, 2p] rad.

The checkbox in the main GUI indicates ESPADA to use a constant mask angle, which is introduced through the ESPADA GUI.

Together with the AMA GUI, a second window is shown on screen, containing a 3D representation of the designed mask. Again, this graph uses the co-ordinate system depicted in Figure 4. Figure 5 shows the representation of the mask corresponding to Figure 3.

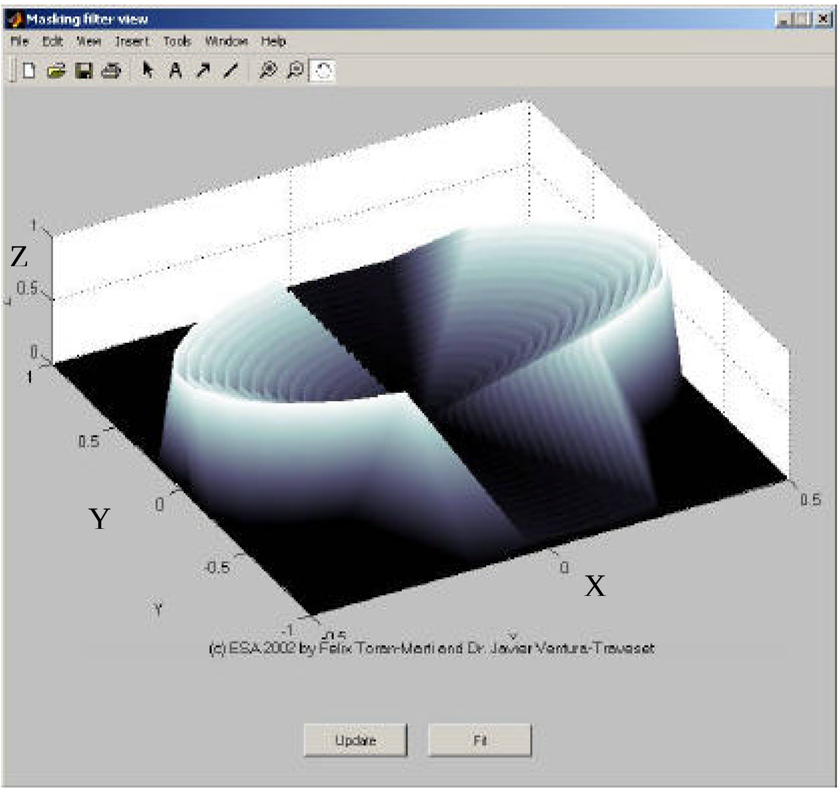


Figure 5: 3D representation of the mask designed in Figure 3.

The objective of the 3D representation is only giving an intuitive idea of the masking effect modelled through the azimuth-elevation table. It presents a revolution volume based on a unit cone, which vertex corresponds to the user location (the central point of the XY plane, i.e. x=0.5 m, y=0.5m, z=0 m). The cone is theoretically generated using an infinite radius, but the one shown on screen is cut-off by a 1m x 1m x 1m cube. To have a practical idea of the masking effect, the 3D volume must be understood as an opaque material. If that material avoids the user to see a satellite, that satellite is not visible. Otherwise, the satellite is considered visible. The example shown in Figure 5 shows a constant mask angle of 60 degrees, which becomes 5 degrees fort two small azimuth intervals. This situation may correspond to a long avenue with buildings on each side (see Figure 6). The mask angle of 5 degrees represents the effect of far buildings.

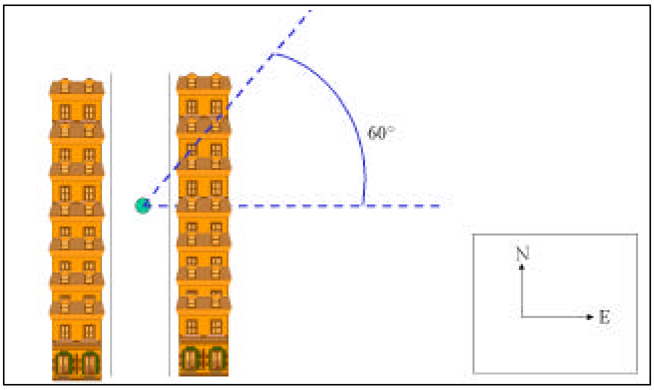


Figure 6: A potential scenario corresponding to the model shown in Figure 5

3. Simulation Procedure

3.1 Overview

This Chapter describes:

?? The technical baseline employed for the simulations presented in this Document (i.e. the simulation assumptions);
?? The simulation process;
?? The results format.

3.2 Technical Baseline for Simulations

Since the objective of this study is to compare GPS-only versus SISNeT in terms of availability of accuracy, the following two User Equivalent Range Error (UERE) budgets have been defined:

?? GPS-only: described in Appendix A of this Document;
?? GPS + SISNeT: described in Appendix B of this Document.

The differences between those budgets reside in the contribution of the User Range Error (URE) and the ionosphere. Note the assumptions are conservative, based on both GPS URE specified value as per recently released GPS SPS document [14] and EGNOS specified residual error statistics after corrections.

3.3 Simulation Procedure

The simulation process involved in this study has been based in the following procedure:

1. Select several scenarios characterised by different user masking conditions, applicable to real and common situations.

2. For each scenario:
   a. Analyse the availability of accuracy for GPS-only.
   b. Analyse the availability of accuracy for GPS + SISNeT.
   c. Produce a GPS/SISNeT comparative bar plot.

Steps 2-a and 2-b involve several simulations, which have been automated through two MATLAB [20] functions. A third MATLAB function automates the production of the output plot. The source code of those routines can be found in [1].

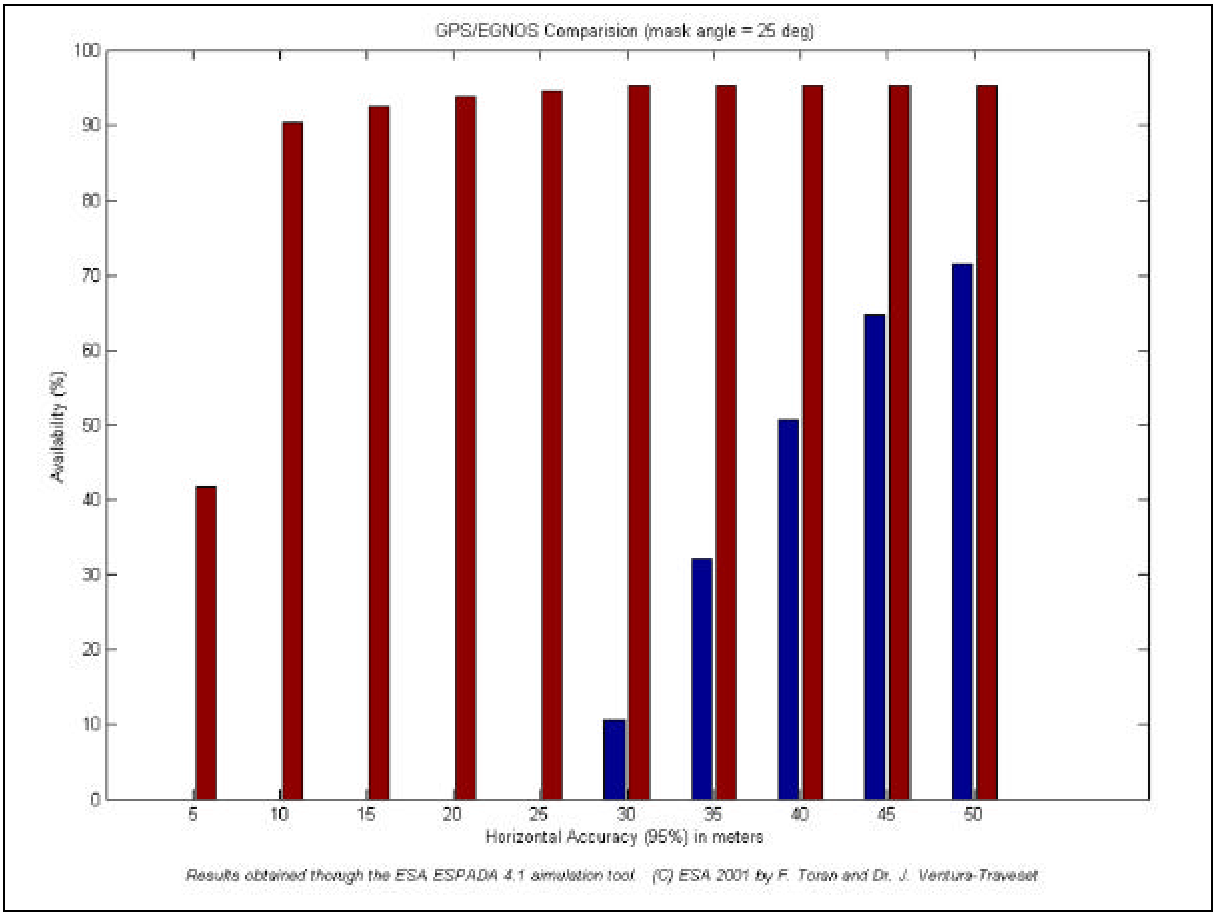


Figure 7: GPS/EGNOS comparative bar plot for a mask angle of 25 degrees

3.4 Results format

As explained in previous Section, the output of the study is a set of comparative bar plots (one per scenario). Figure 7 shows an example of that kind of output, corresponding to a constant user mask angle of 25 degrees. The comparative bar plots allows easy comparing GPS and SISNeT performances in the accuracy domain, under specific visibility conditions.

The red bars correspond to the GPS + SISNeT scenario, while the blue bars correspond to the GPS -only scenario. The horizontal axis shows some accuracy requirements. The vertical axis shows the associated availabilities of accuracy.

4. Simulated Scenarios

4.1 Overview

This Chapter lists all the scenarios simulated in this study. Firstly, a compact, comprehensive and visual format for describing the scenarios is introduced. Finally, this Chapter links to Appendix C, where that format is used for listing a total of fifteen simulated scenarios.

4.2 Scenario Description Format

The different scenarios simulated in this study are presented in the form of "cards", using the format shown bellow.

The explanation of each field is the following:

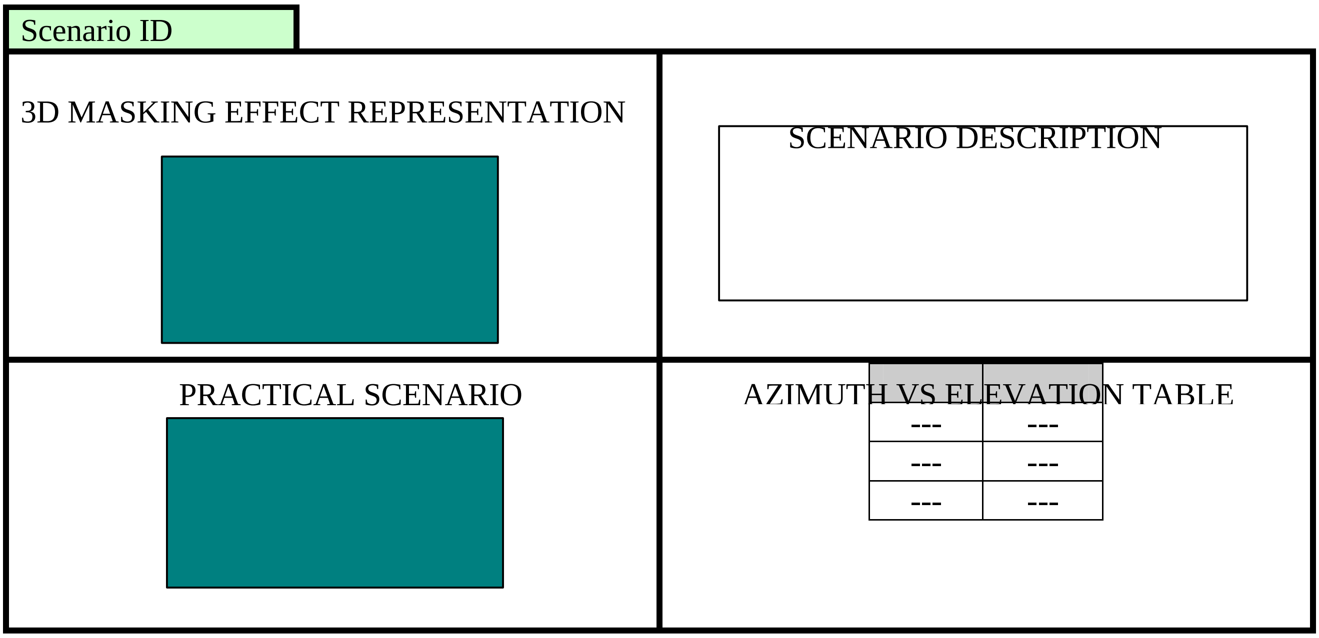
?? **Scenario ID**. A unique number identifying each scenario, for future reference.

?? **3D masking effect representation**. An image produced by the AMA tool, showing the 3D representation of the masking effect (see Section 2.4). The North (N) and East (E) axis are shown. The "holes" in the mask correspond to a mask angle of 5 degrees, but are not visible in most graphs due to lighting effects.

?? **Practical scenario**. A potential scenario in coherence with the 3D representation, which can be easily found in most urban areas. The images are not scaled, and must be considered as an intuitive tool for a quick understanding of each scenario. The far buildings (or closer small buildings) causing the mask angle of 5 degrees are not presented in all the graphs, but its existence must be assumed. A green circle, located at the origin of the co-ordinate system, designates the user. North and East axes are also included, corresponding to the N -

E axes shown in the 3D representation (note the axes of the practical scenario are rotated with respect to the axes of the 3D representation).

- **Scenario description**. Short fragment of text describing the scenario;
- **Azimuth versus elevation table**. The table introduced in the AMA tool GUI, from which the 3D representation is derived.



4.3 List of Simulated Scenarios

The complete list of simulated scenarios (formatted as explained in the previous Section) can be found in Appendix C of this Document.

5. Obtained Results

5.1 Overview

This Section presents the simulation results, corresponding to the fifteen scenarios proposed in the previous Chapter. Firstly, a visual and compact format for presenting the results is introduced. Then, this Chapter links to Appendix D, where the complete listing of results can be found (using the proposed format).

Finally, a visual summary of results is shown through three Tables, allowing quickly finding the advantage of SISNeT over GPS-only for each scenario.

5.2 Results Listing Format

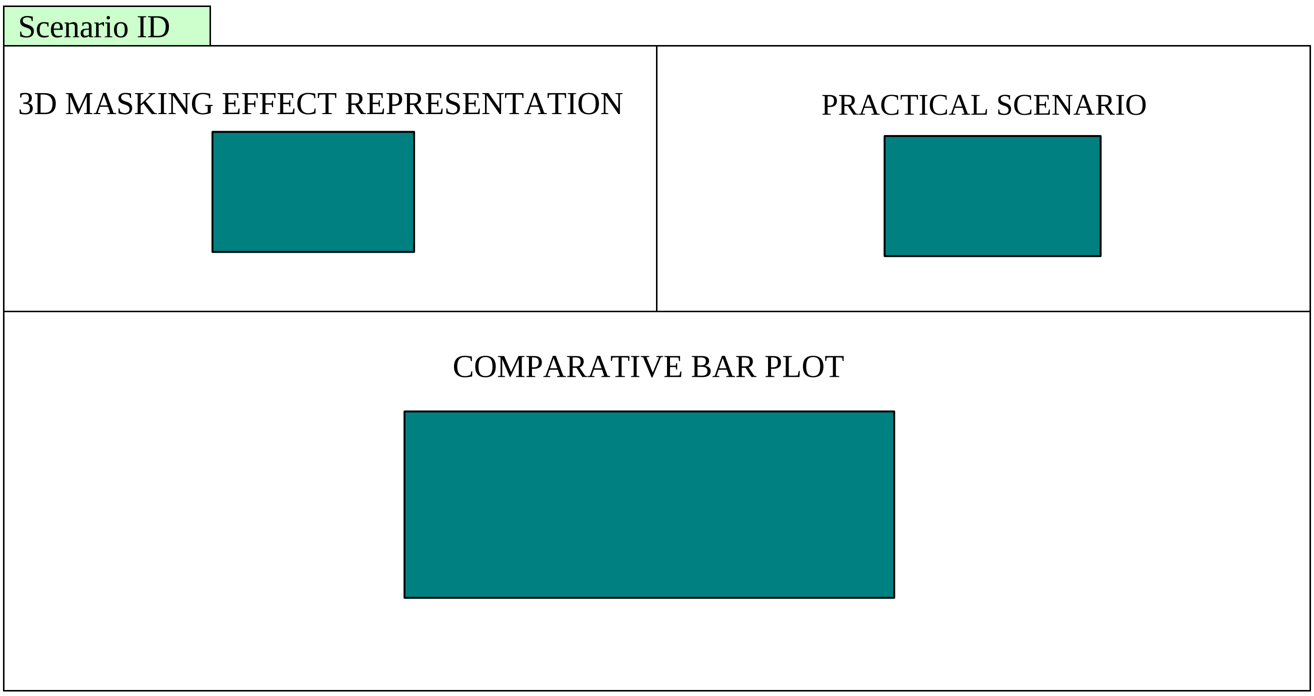
The simulation results corresponding to the scenarios listed in Appendix C are presented in the form of "cards", using the format shown in the next page. The explanation of each field is the following:

- **Scenario ID**. Scenario identification numbers, defined in Appendix C.

- **3D masking effect representation**. 3D representation of the masking effect (see Section 2.4), taken from the associated scenario description (Appendix C) for the reader's advantage.

- **Practical scenario**. A potential scenario in coherence with the 3D representation, which can be easily found in most urban areas. Taken from the associated scenario description (Appendix C) for the reader's advantage.

- **Comparative bar plot**. Main result of each simulation, comparing the performance of GPS-only vis-à-vis SISNeT in terms of availability of accuracy (see Section 3.4 for a description of this kind of plot).



5.3 List of Results

The complete list of simulation results — formatted as explained in the previous Section and in coherence with Appendix C — can be found in Appendix D of this Document.

5.4 Summary of Results

A visual summary of the simulation results can be found in Table 1 (scenarios 0 to 6), Table 2 (Scenarios 7 to 11) and Table 3 (scenarios 12 to 15). The following information is shown in those Tables as columns:

?? **Scenario ID**. Scenario identification number (assigned in Appendix C).
?? **3D representation**. See Section 2.4.
?? **Practical scenario**. See Section 5.2 and Appendix C.
?? **SISNeT advantage**. Advantage of the SISNeT scenario with respect to the GPS-only scenario, in terms of availability of accuracy (i.e. SISNeT_availability - GPS_ availability). The advantage is shown for five representative accuracies: 10, 20, 30, 40 and 50 meters.

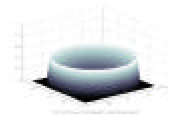
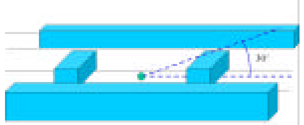
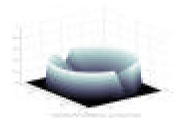
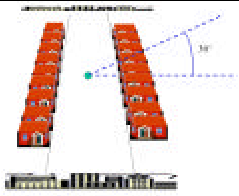
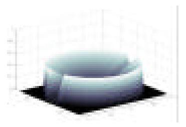
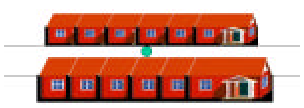
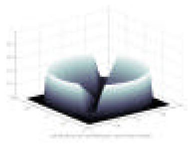
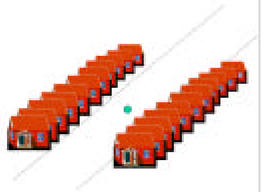
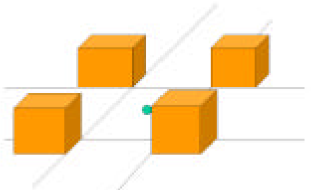
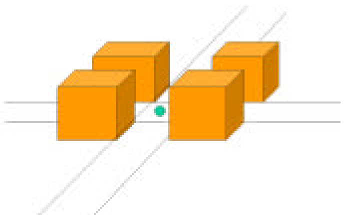
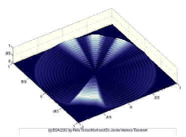
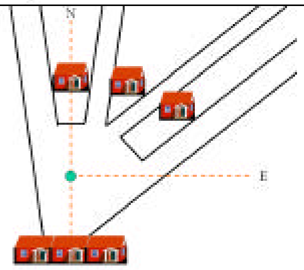
Scenario ID	3D Representation	Practical Scenario	SISNeT Advantage				
			10 m	20 m	30 m	40 m	50 m
0			74%	79%	80%	56%	37%
1			82%	88%	86%	58%	34%
2			79%	86%	84%	58%	38%
3			87%	90%	64%	46%	24%
4			98%	99%	79%	25%	10%
5			92%	95%	91%	44%	23%
6			100%	100%	49%	5%	2%

Table 1: Summary of results (scenarios 0 to 6)

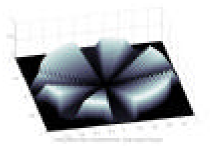
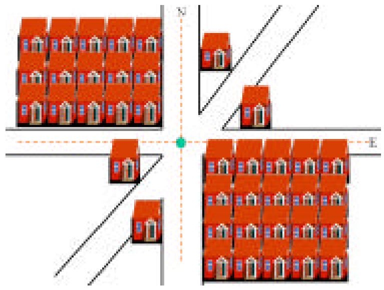
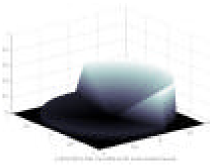
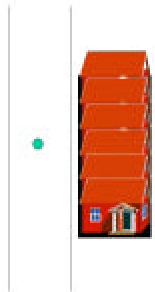
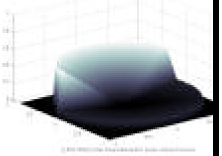
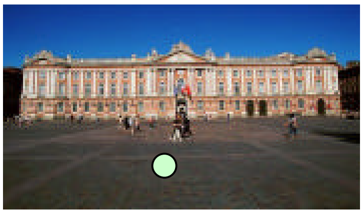
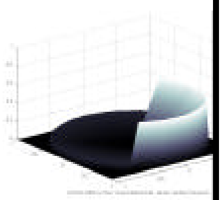
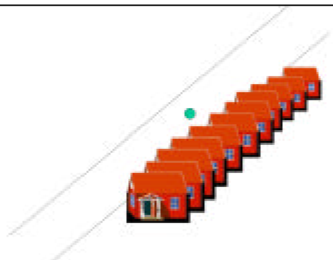
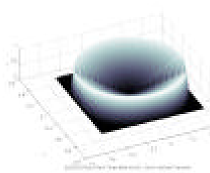
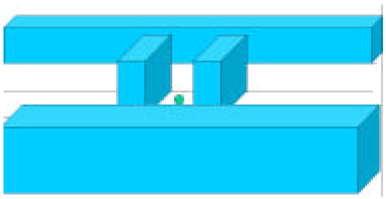
Scenario ID	3D Representation	Practical Scenario	SISNeT Advantage				
			10 m	20 m	30 m	40 m	50 m
7			96%	98%	84%	41%	16%
8			100%	100%	83%	27%	16%
9			97%	100%	77%	21%	10%
10			100%	100%	72%	10%	1%
11			0%	0%	0%	0%	0%

Table 2: Summary of results (scenarios 7 to 11)

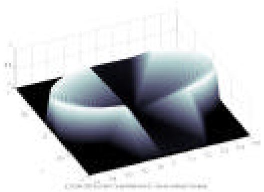
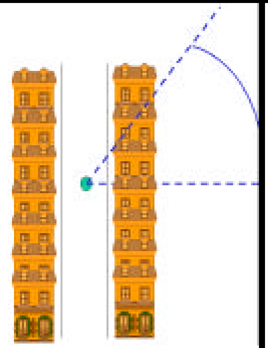
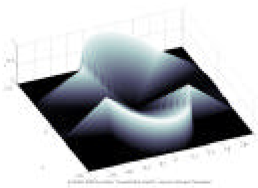
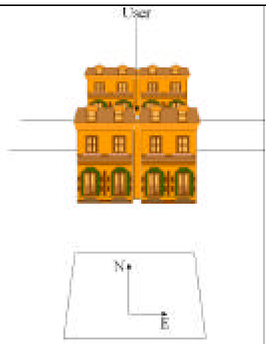
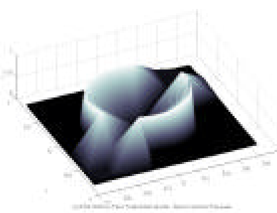
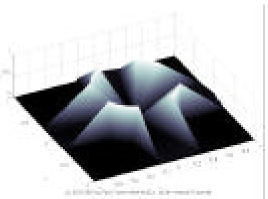
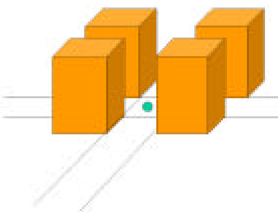
Scenario ID	3D Representation	Practical Scenario	SISNeT Advantage				
			10 m	20 m	30 m	40 m	50 m
12			7%	22%	26%	28%	29%
13			0.7%	4.2%	4.2%	4.2%	4.2%
14			9%	18%	26%	29%	23%
15			42%	54%	55%	47%	26%

Table 3: Summary of results (scenarios 12 to 15)

6. Conclusions

This Section indicates the main Conclusions of this study. For the sake of clarity this Section is organised in two parts:

1) First, we comment in some detail on the individual results obtained for scenarios 0 to 15
2) Second, an overall assessment of the analysis is presented.

6.1 Conclusions for scenarios 0 to 15

1. The availability obtained through SISNeT is always better than that obtained using GPS-only.

2. For the whole set of simulated scenarios, and for all the accuracies from 10 to 50 meters, SISNeT offers an important improvement of availability. In most of the cases, the improvement is also important for 5 meters of accuracy.

3. Comparing with the case of constant mask angle (scenario 0), an aperture in the mask (i.e. a street, see scenarios 1 to 3) increases the availability offered by SISNeT, while the availability for GPS-only does not change significantly. That means the study performed in [1] was conservative and, hence, the performances of SISNeT are better than initially expected.

4. Wider apertures on scenario 0 (see scenarios 4 and 5) cause an increase of availability for GPS-only. Anyway, the availability obtained through SISNeT is extremely better, showing again the interest of this technology.

5. Scenario 6 presents a big percentage of plain terrain. The GPS availability of accuracy is only close to the SISNeT one for accuracies of the order of 40 m. For lower accuracies (10 - 20 m), the impact of SISNeT is impressive, obtaining 100% availability versus 0% offered by GPS. In other words, in those masking conditions, these accuracies could only be obtained if SISNET technology is incorporated to a GPS-only receiver.

6. For scenarios 8 to 10 (presenting just one block of buildings), SISNeT offers a large increase of availability, being 100% especially for the lower accuracies (10 -20 m).

7. The scenarios including higher mask angles (up to 60 degrees) are more stringent (Scenarios 11 to 15). Obviously, in those scenarios the differences of availabilities are lower than the obtained in scenarios 0 to 10. Nevertheless, SISNeT stills improving the availability of accuracy, with an especially important impact for scenario 15 (crossroads, which is a typical city environment). Note that in these limiting scenarios, a small increase of the availability has a lot of interest.

6.2 General Conclusions

An EGNOS-SISNeT powered receiver provides much better availability of accuracy than a GPS-only receiver for typical urban environments. While in all in view situations, typical EGNOS accuracy (95%) performances will be of the order of 1-2 meters (vs. 10-20m of GPS-only), the impact of EGNOS-SISNeT becomes more apparent when typical urban environment situations are assumed. Indeed, while EGNOS achieved availability performances are quite resistant to user masking effects, the geometrical degradation linked to poor masking angles has a major degradation effect on GPS-only achievable availability. For instance, in several representative urban scenarios, while an EGNOS-SISNeT powered receiver could provide 100% availability for 10m accuracies (95%), GPS-only availability was 0%.

These results, linked to the minimum extra complexity of a GPS-SISNeT powered receiver versus a GPS-only receiver, justifies the interest of providing EGNOS corrections through complementary means to GEO broadcasting. Land mobile is a typical community, which may largely benefit from SISNeT. The simulation results presented here will be complemented with test campaign results using the ESTB (EGNOS mock-up) and several GPS-SISNeT powered receivers developed by ESA.

Finally, it is the Author opinion that the EGNOS (or ESTB) SISNET combination provides an excellent testing vehicle to assess Galileo-like future applications for land mobile. Indeed, in a first approach, it could be assumed that GPS satellites corrected by SISNET (i.e. GPS satellites do always benefit from clock/ephemeris/iono corrections irrespectively of the user masking angle) may well represent future GALILEO performances where non-GEOs are needed to obtain final user performances.

APENDIX A: SIMULATION ASSUMPTIONS FOR THE GPS-ONLY SCENARIO

Table 4 summarises the simulation parameters used for the GPS-only simulations.

Parameter	Value	Comments
GEO constellation	Disabled	
GPS constellation	Enabled	- 27 satellites - No failures - Reference constellation: 01/07/1999 [18]
GLONASS/GALILEO Constellations	Disabled	Not used
GPS URE [14]	6 m	
GEO UDRE	N/A	Not used
GLONASS UDRE	N/A	Not used
Troposphere	0.25 m	
GPS receiver noise	0.8 m	
GEO receiver noise	N/A	Not used
GLONASS receiver noise	N/A	Not used
Multipath	0 m	
Latency	0 m	
Ionosphere	5 m	
Duration of the simulation	24 h	
Time step	10 min	
Simulation target	Point	
Co-ordinates	43.4 N 1.4 E	Toulouse (France)
User grid step	5 deg	
MOPS [13]?	No	
RIMS baseline	June 2001	
RIMS mask angle	5 deg	

Table 4: Simulation assumptions for the GPS-only scenario

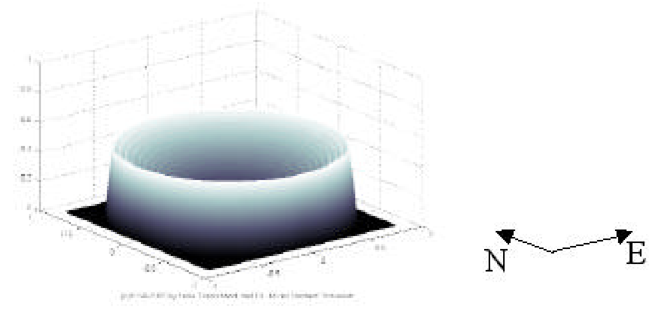
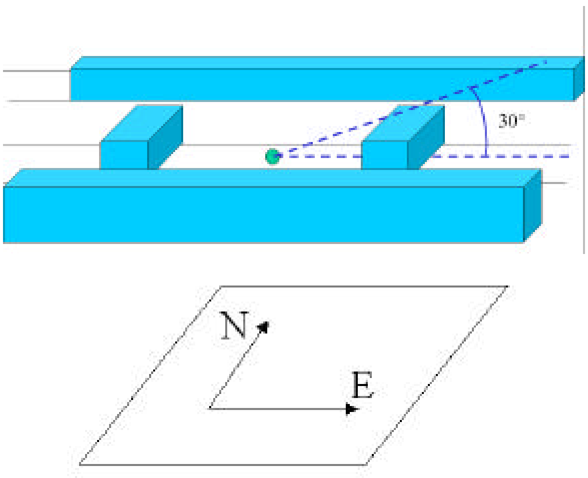
APENDIX B: SIMULATION ASSUMPTIONS FOR THE GPS + SISNeT SCENARIO

Table 5 summarises the simulation parameters used for the GPS + SISNeT simulations.

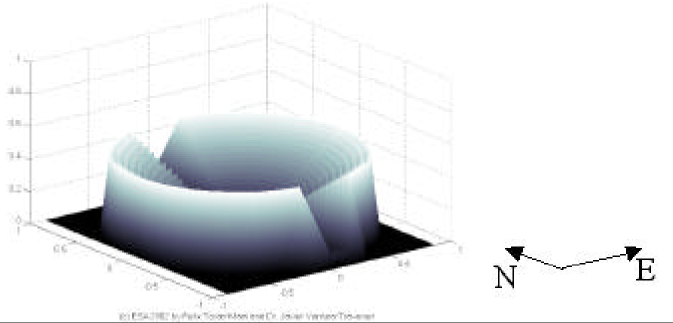
Parameter	Value	Comments
GEO constellation	Disabled	
GPS constellation	Enabled	✍ 27 satellites ✍ No failures ✍ Reference constellation: 01/07/1999 [18]
GLONASS/GALILEO Constellations	Disabled	
GPS UDRE	0.5 m	
GEO UDRE	N/A	Not used
GLONASS UDRE	N/A	Not used
Troposphere	0.25 m	
GPS receiver noise	0.8 m	
GEO receiver noise	N/A	Not used
GLONASS receiver noise	N/A	Not used
Multipath	0 m	
Latency	0 m	
Ionosphere	0.5 m	
Duration of the simulation	24 h	
Time step	10 min	
Simulation target	Point	
Co-ordinates	43.4 N 1.4 E	Toulouse (France)
User grid step	5 deg	
MOPS [13]?	No	
RIMS baseline	June 2001	
RIMS mask angle	5 deg	

Table 5: Simulation assumptions for the GPS + SISNeT scenario

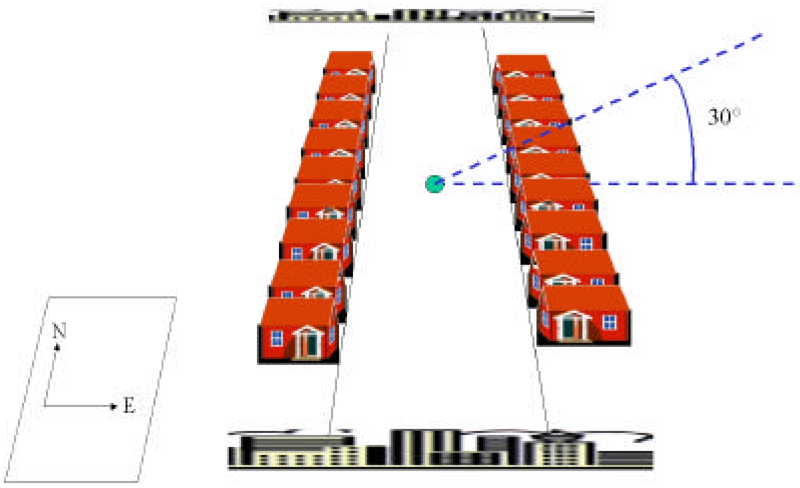
APENDIX C: LIST OF SIMULATION SCENARIOS

0	
	This scenario corresponds to a constant mask angle of 30 degrees. That angle is set through the ESPADA main GUI. A possible scenario corresponds to a user between two flats, inducing a mask angle of 30 degrees for a couple of azimuth intervals. In addition, two wide blocks of buildings avoid seeing satellites bellow 30 degrees for the rest of azimuths.
	**No table needed (constant mask angle of 30° set through the ESPADA main GUI)**

1

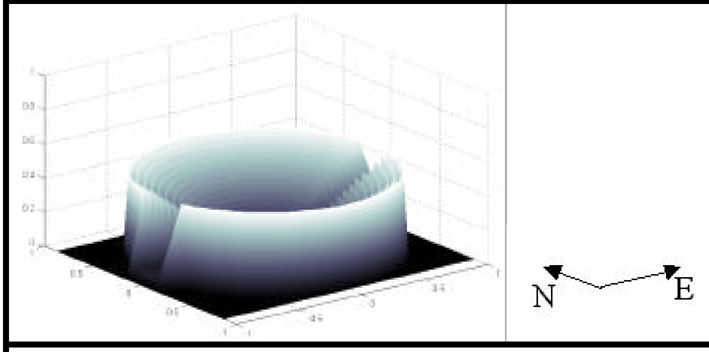


A street along the N-S direction, with a block of houses at each side.

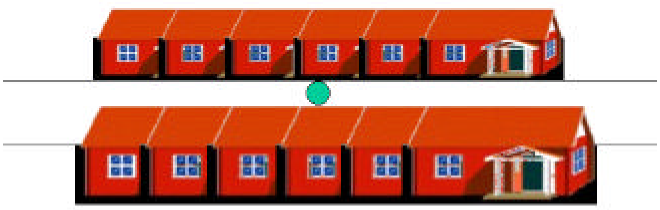


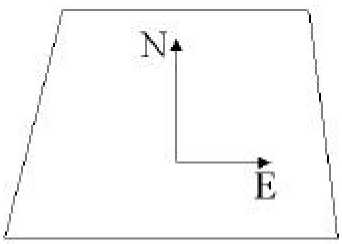
Azimuth (rad)	Elevation (rad)
0	0.5236
1.3963	0.0873
1.7453	0.5236
4.5379	0.0873
4.8869	0.5236

2



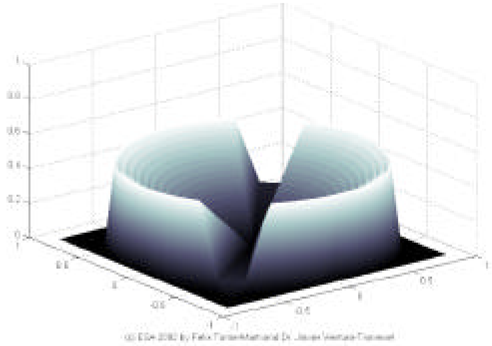
A street along the W-E direction, with a block of houses at each side.



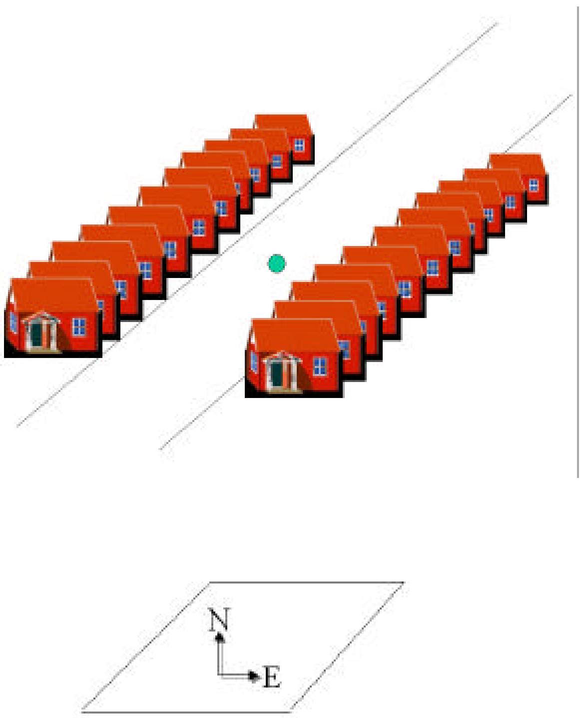


Azimuth (rad)	Elevation (rad)
0	0.0873
0.1745	0.5236
2.9671	0.0873
3.3161	0.5236
6.109	0.0873

3

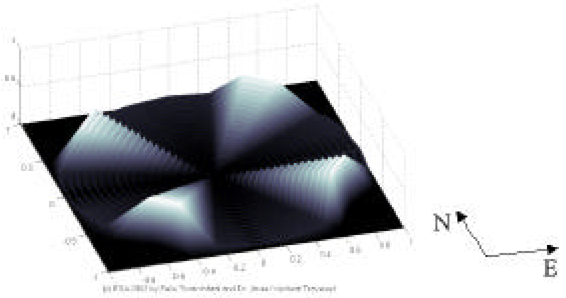


An oblique street, with a block of houses at each side.

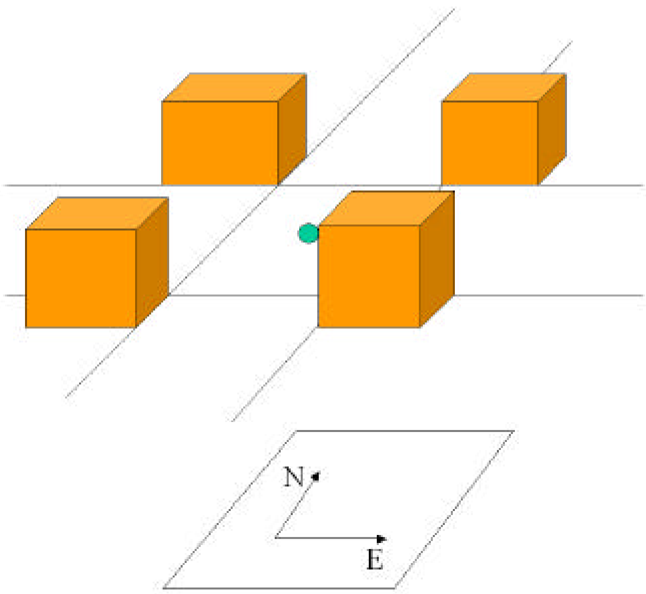


Azimuth (rad)	Elevation (rad)
0	0.5236
0.6109	0.0873
0.9599	0.5236
3.7525	0.0873
4.1015	0.5236

4

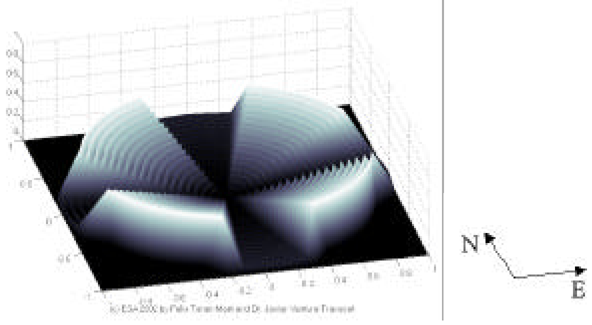


Two perpendicular streets forming a crossroads, with the user in the centre of the intersection. The buildings have a moderated width.

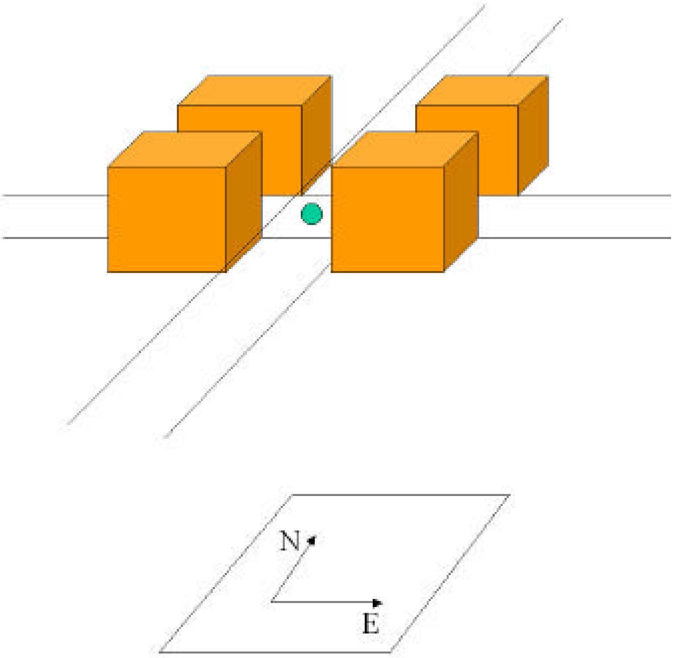


Azimuth (rad)	Elevation (rad)
0	0.0873
0.5236	0.5236
1.0472	0.0873
2.0944	0.5236
2.61799	0.0873
3.6652	0.5236
4.1888	0.0873
5.23598	0.5236
5.7596	0.0873

5

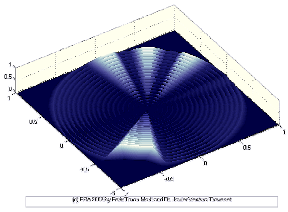


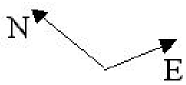
Another crossroads. This time, the buildings are wider and the streets are thinner.



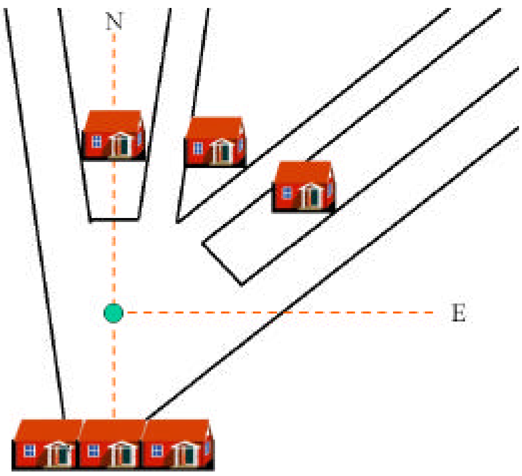
Azimuth (rad)	Elevation (rad)
0	0.0873
0.2618	0.5236
1.3089	0.0873
1.8326	0.5236
2.8798	0.0873
3.4034	0.5236
4.4506	0.0873
4.9742	0.5236
6.0214	0.0873

6



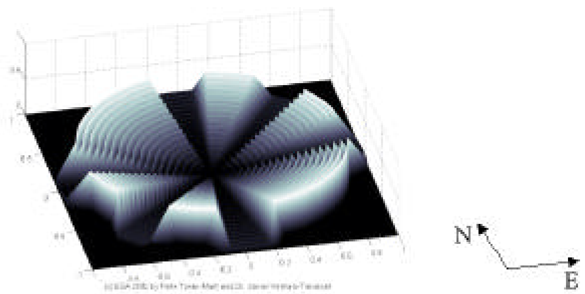


A more complex scenario. Three streets (with houses between them) converge to a square, with one block of buildings in front. The user is located in the centre of the square.

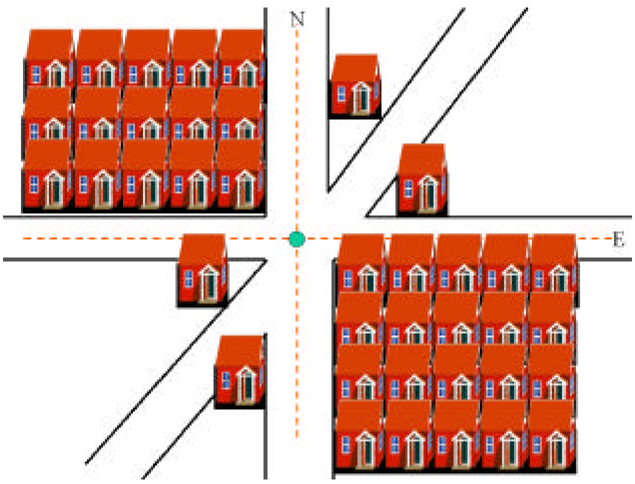


Azimuth (rad)	Elevation (rad)
0	0.0873
0.2618	0.5236
0.5236	0.0873
0.7854	0.5236
1.0472	0.0873
1.309	0.5236
1.5708	0.0873
3.6652	0.5236
4.1888	0.0873

7

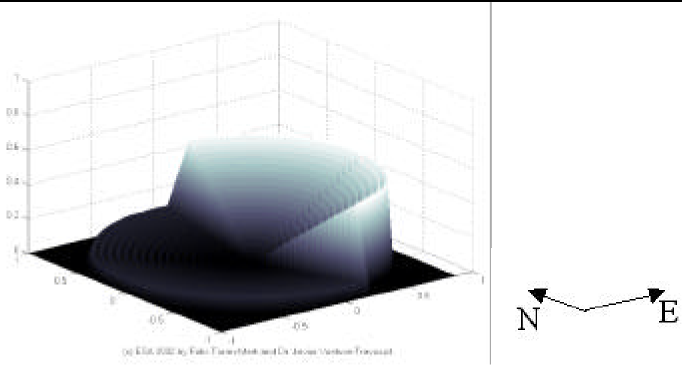


A crossroads (more complex than scenarios 4 and 5) composed of three streets intersecting at the user location. Two diametrically opposed blocks of buildings cause the mask effect corresponding to the bigger intervals of azimuths. This scenario corresponds to the combination of scenarios 1,2 and 3.

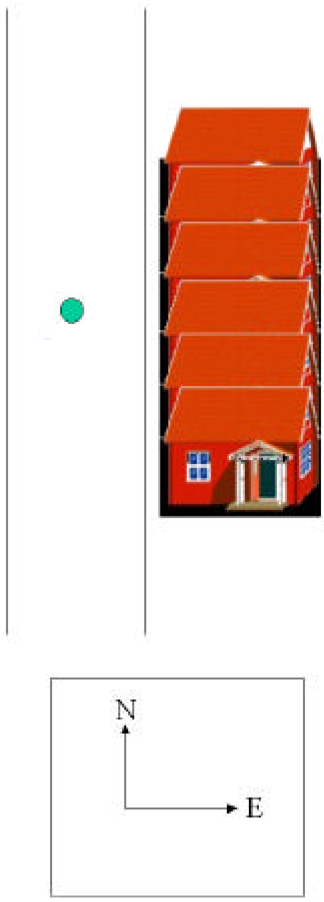


Azimuth (rad)	Elevation (rad)
0	0.0873
0.1745	0.5236
0.6109	0.0873
0.9599	0.5236
1.3963	0.0873
1.7453	0.5236
2.9671	0.0873
3.3161	0.5236
3.7525	0.0873
4.1015	0.5236
4.5379	0.0873
4.8869	0.5236
6.109	0.0873

8

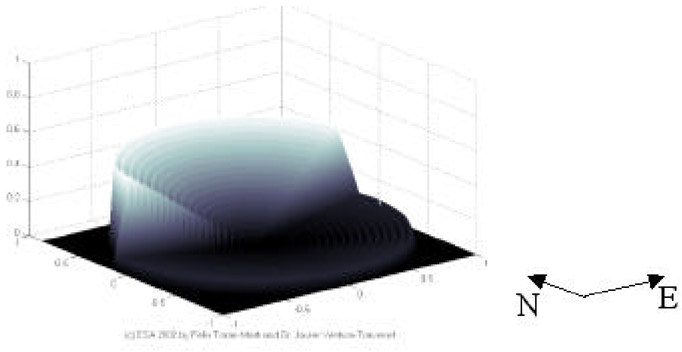


A street with a block of houses at the East side.

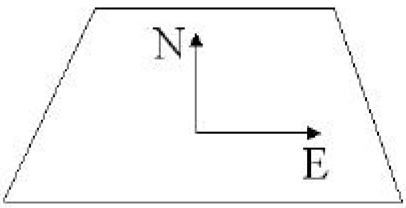


Azimuth (rad)	Elevation (rad)
0	0.5236
1.3963	0.0873
4.8869	0.5236
6.1	0.5236

9

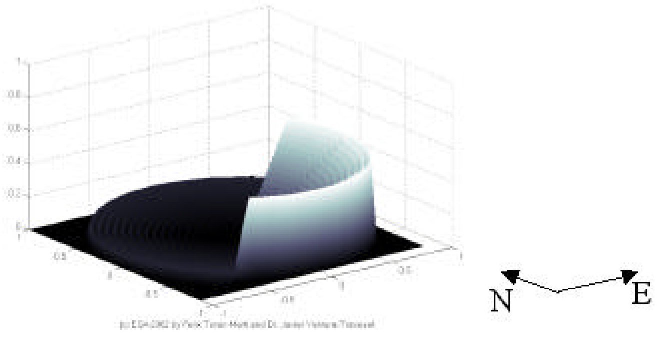


A street with a wide building at the North side.

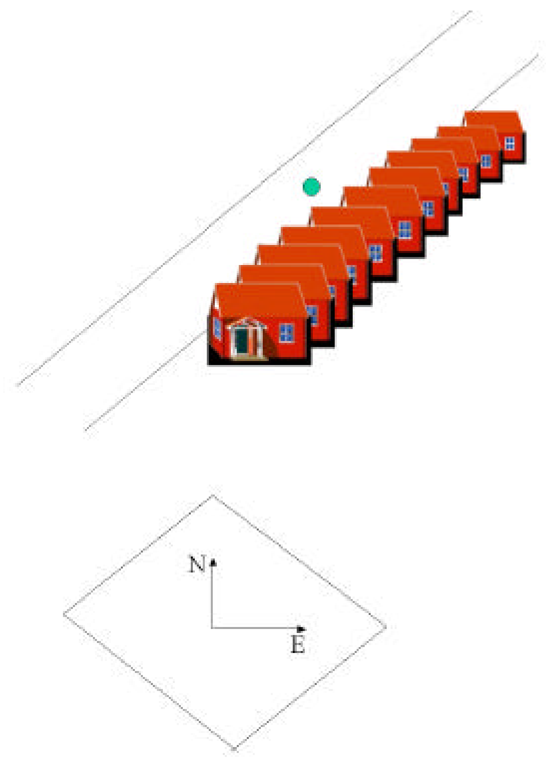


Azimuth (rad)	Elevation (rad)
0	0.0873
0.1745	0.5236
2.9671	0.0873
6.109	0.0873

10

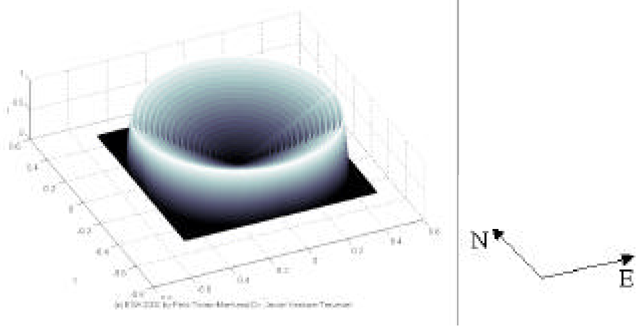
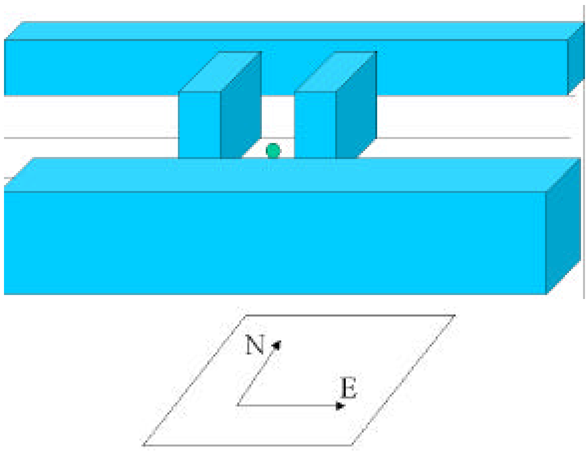


An oblique street with a block of houses at the Southeast side.

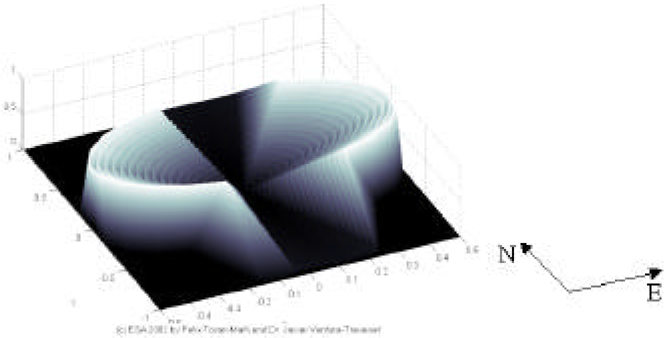


Azimuth (rad)	Elevation (rad)
0	0.5236
0.6109	0.0873
4.1015	0.5236
6.1	0.5236

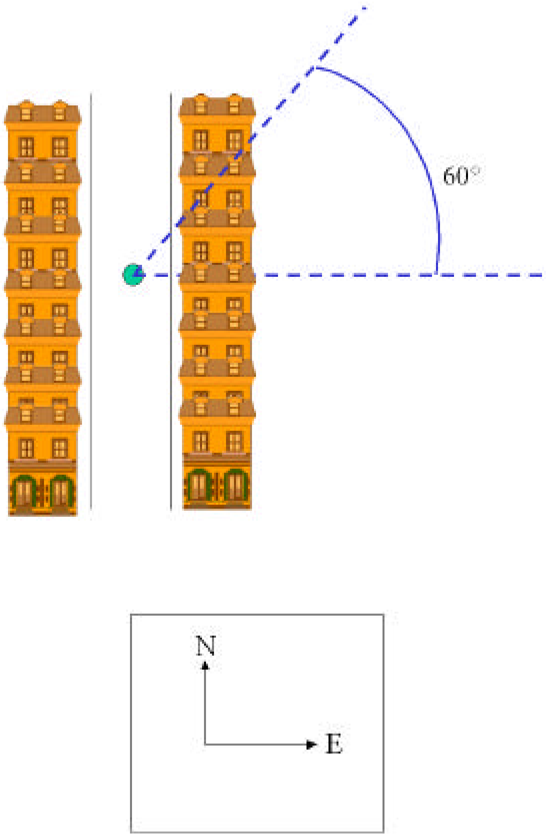
11

	This scenario corresponds to a constant mask angle of 60 degrees. That angle is set through the ESPADA main GUI. A possible scenario corresponds to a user between two flats, inducing a mask angle of 60 degrees for a couple of azimuth intervals. In addition, two wide blocks of buildings avoid seeing satellites bellow 60 degrees for the rest of azimuths.
	**N/A (constant mask angle of 60º set through the ESPADA main GUI)**

12

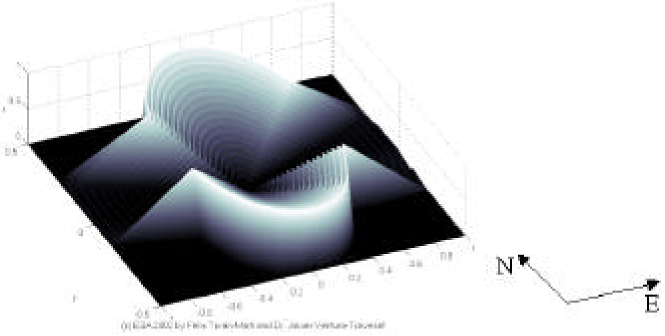


A street along the N-S direction, with a block of buildings at each side. This scenario is quite similar to scenario 1 (the only difference is the height of the buildings, higher in this case).

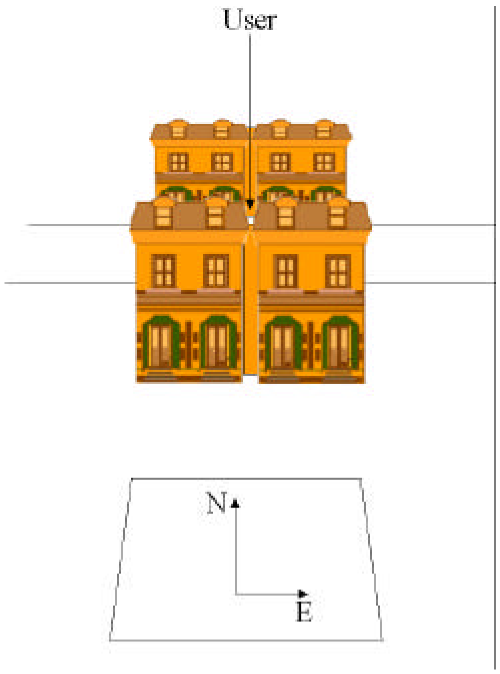


Azimuth (rad)	Elevation (rad)
0	1.0472
1.2963	0.0873
1.8453	1.0472
4.4379	0.0873
4.9869	1.0472

13

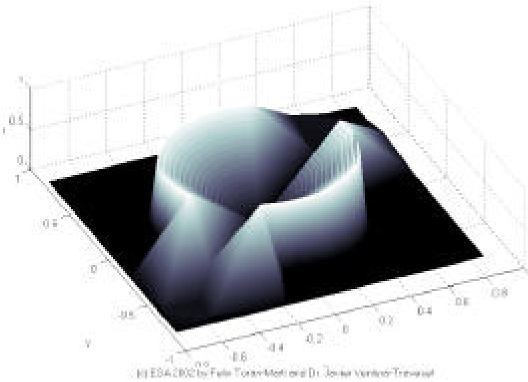


A street along the W-E direction, with a block of buildings at each side. This scenario is quite similar to scenario 2 (the only difference is the height of the buildings, higher in this case).

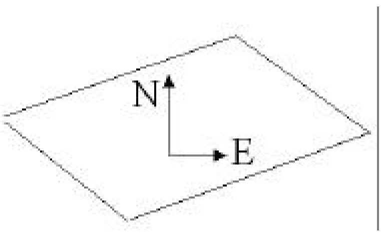


Azimuth (rad)	Elevation (rad)
0	0.0873
0.2745	1.0472
2.8671	0.0873
3.4161	1.0472
6.009	0.0873

14

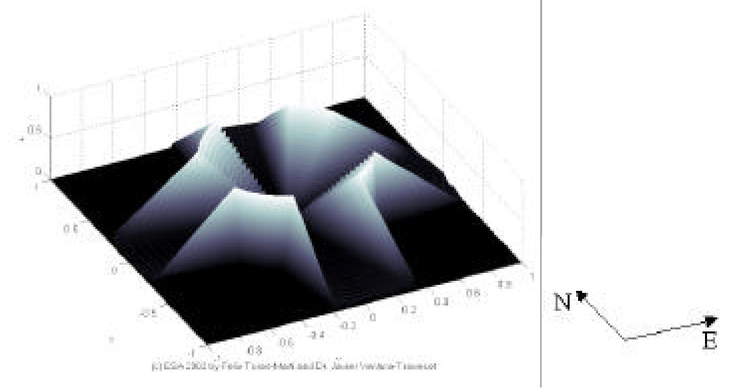


An oblique street, with a block of houses at each side. This scenario is quite similar to scenario 3 (the only difference is the height of the buildings, higher in this case).

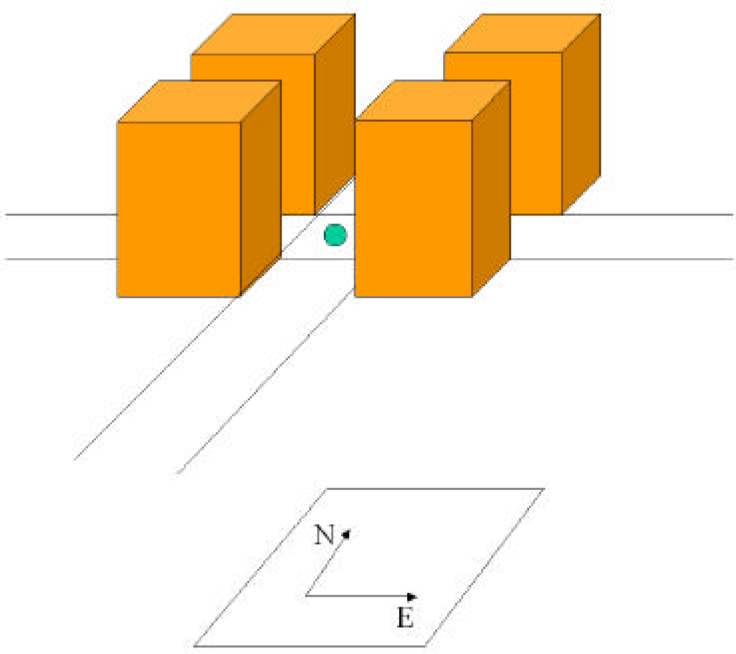


Azimuth (rad)	Elevation (rad)
0	1.0472
0.5109	0.0873
1.0599	1.0472
3.6525	0.0873
4.2015	1.0472

15



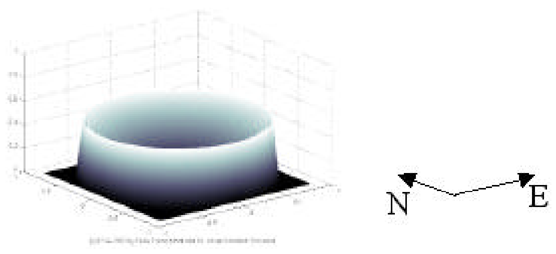
Two perpendicular streets forming a crossroads, with the user located at the centre of the intersection. This scenario is quite similar to scenario 4 (the only difference is the height of the buildings, higher in this case).

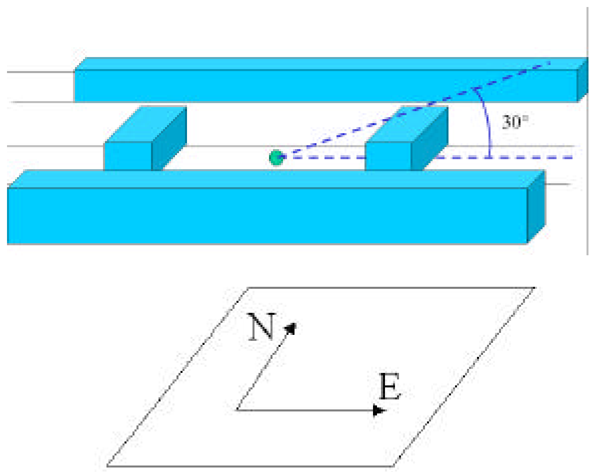


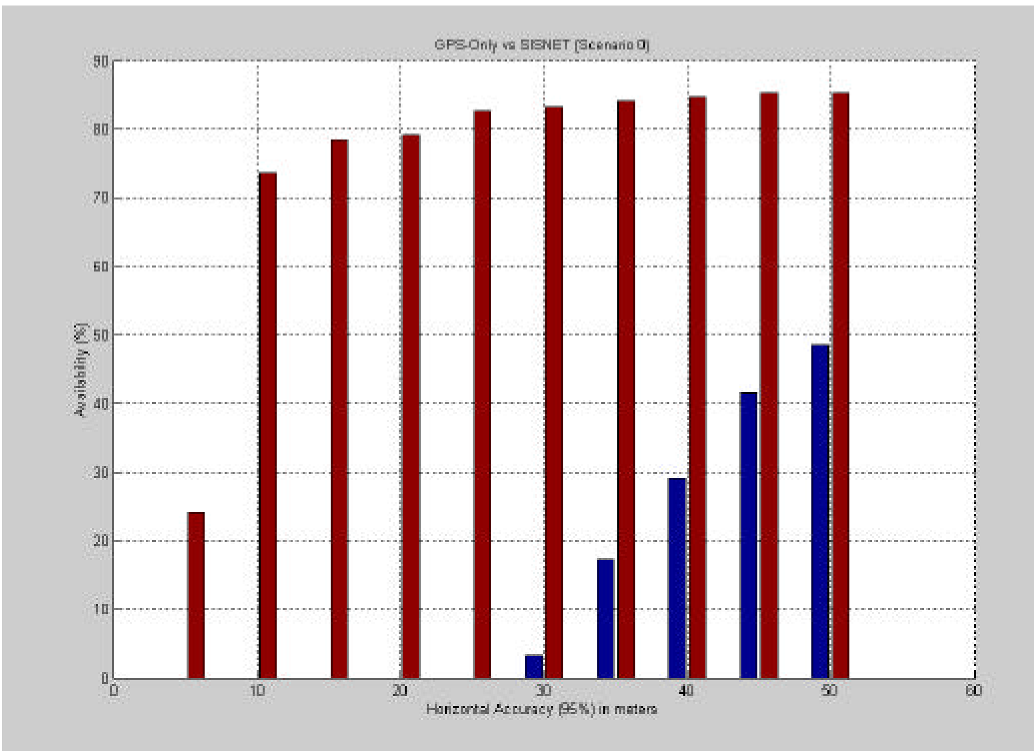
Azimuth (rad)	**Elevation (rad)**
0	0.0873
0.3618	1.0472
1.2089	0.0873
1.9326	1.0472
2.7798	0.0873
3.5034	1.0472
4.3506	0.0873
5.0742	1.0472
5.9214	0.0873

APENDIX D: LIST OF SIMULATION RESULTS

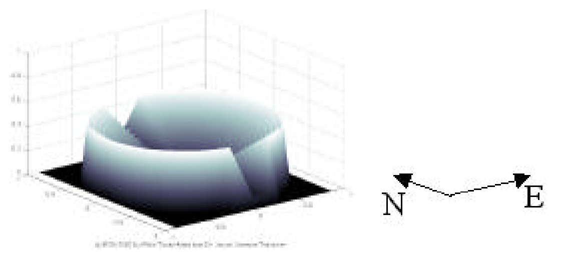
0

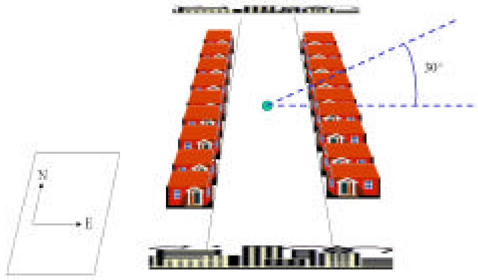


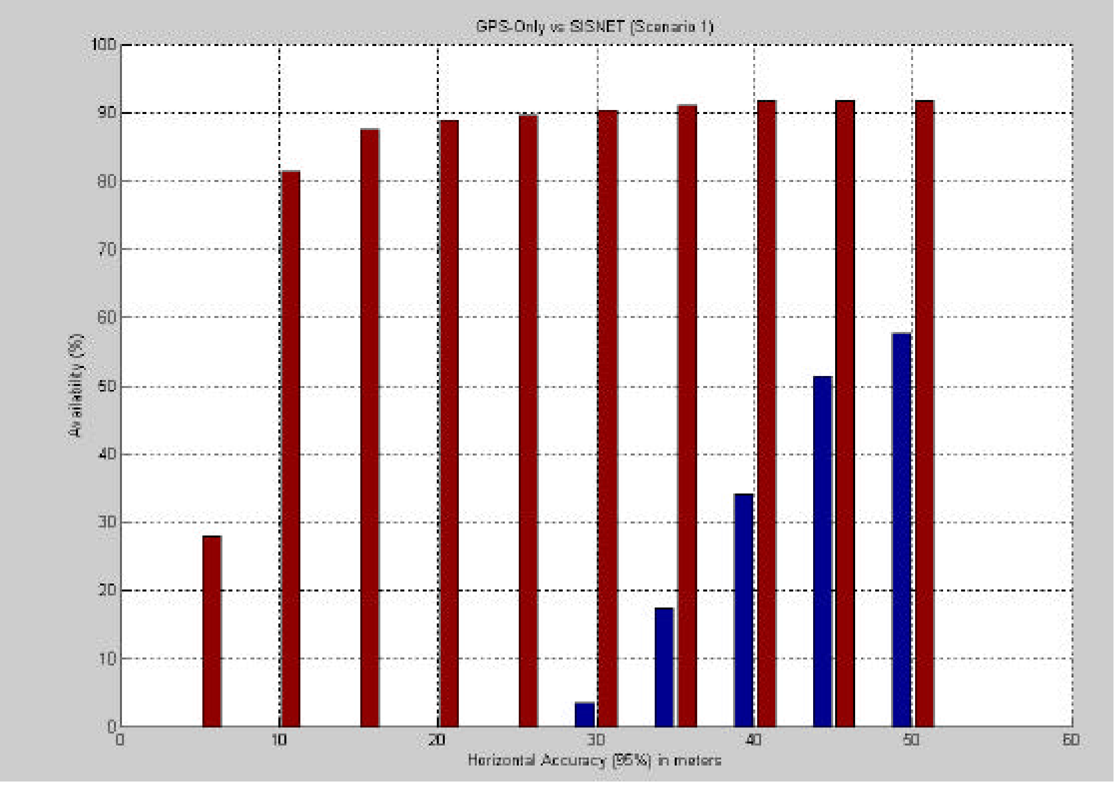




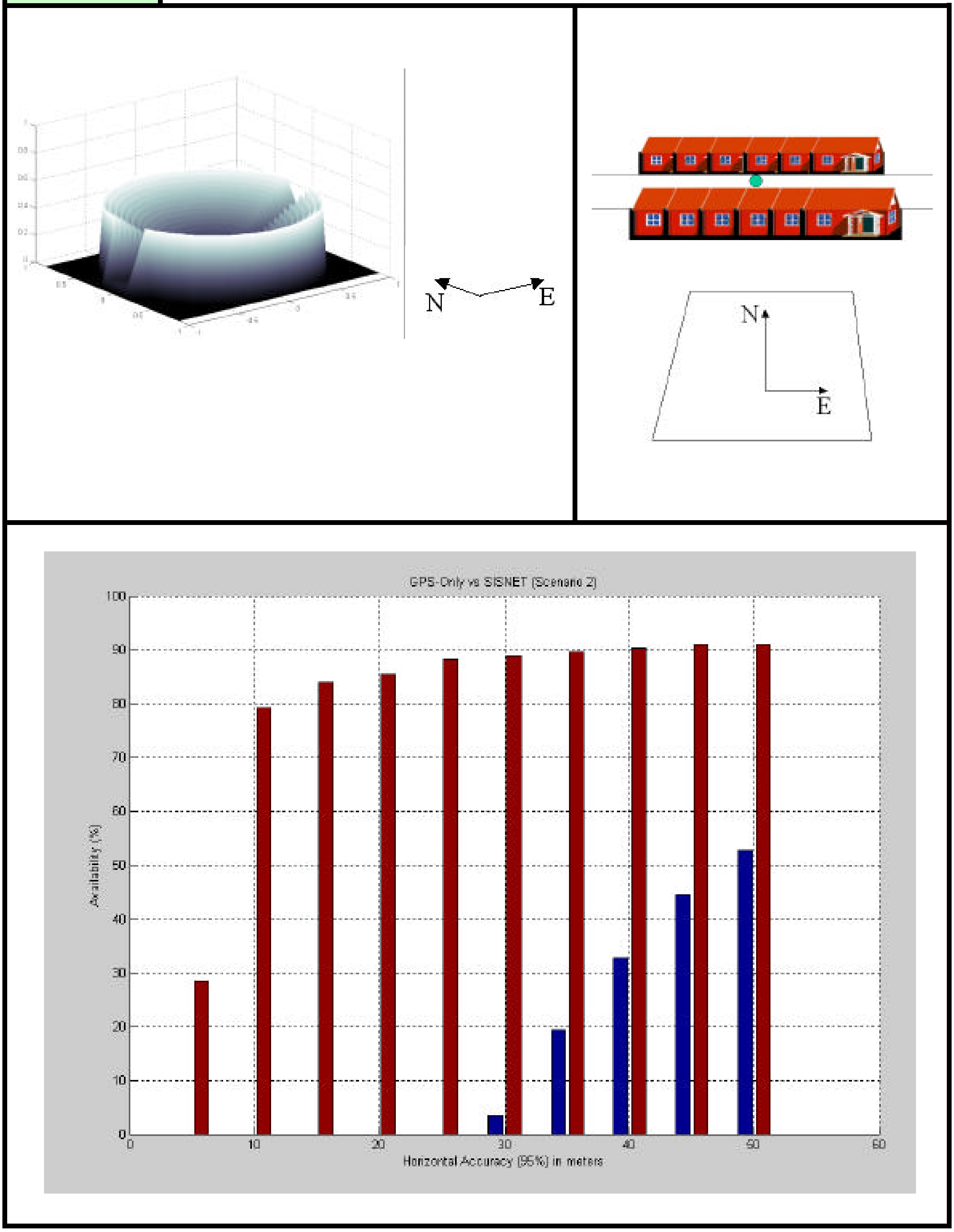
1


N
E

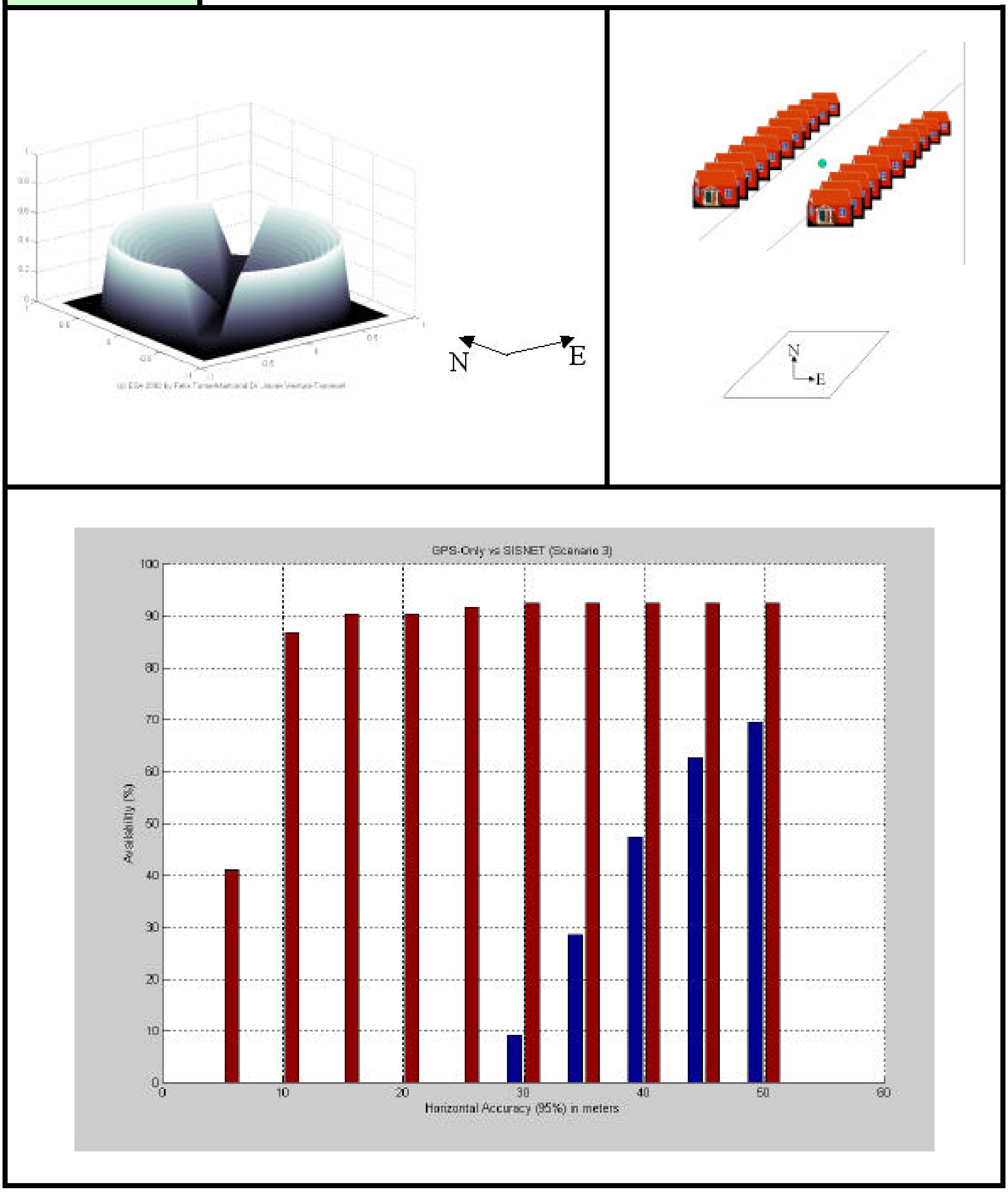

N
E


GPS-Only vs SISNET (Scenario 1)
Availability (%)
Horizontal Accuracy (95%) in meters
0
10
20
30
40
50
60
70
80
90
100

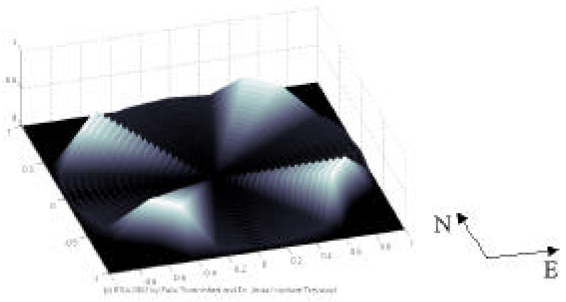
2

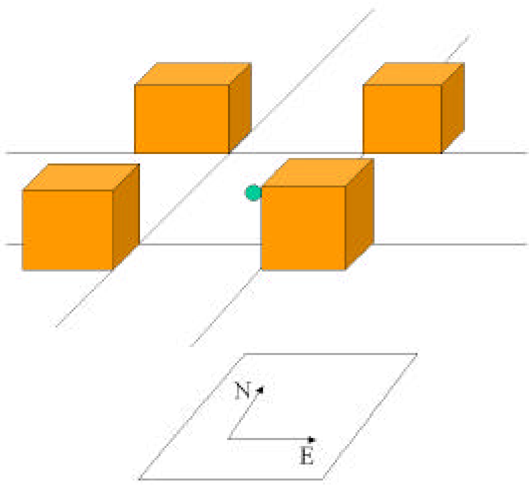

N
E
N
E
GPS-Only vs SISNET (Scenario 2)
Availability (%)
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
Horizontal Accuracy (95%) in meters

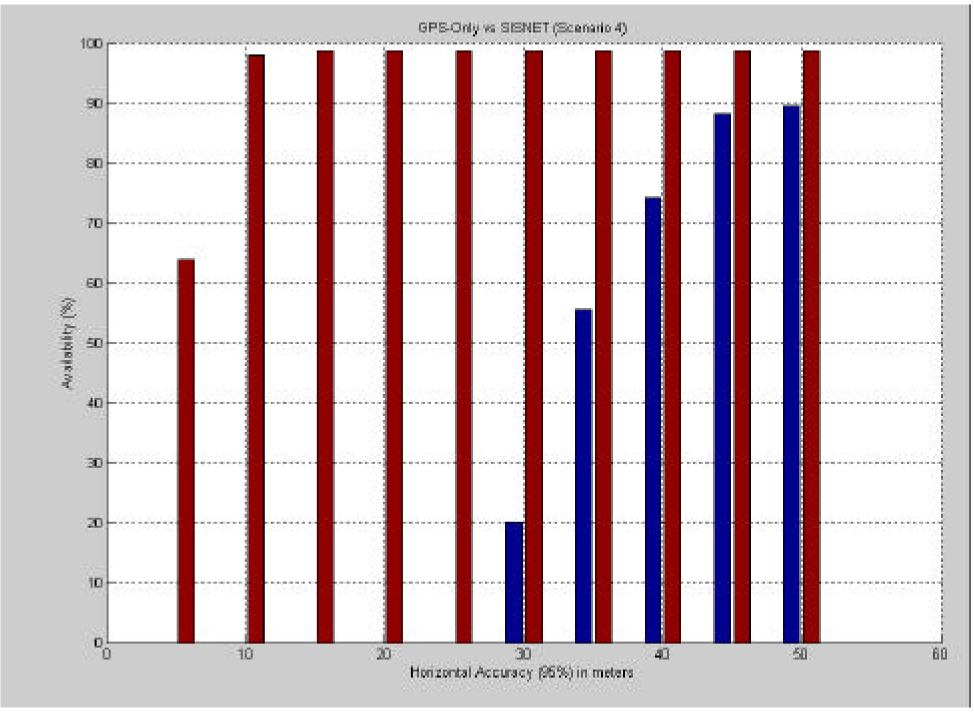
3


N
E
N
E
GPS-Only vs SISNET (Scenario 3)
Availability (%)
Horizontal Accuracy (95%) in meters
0
10
20
30
40
50
60
70
80
90
100

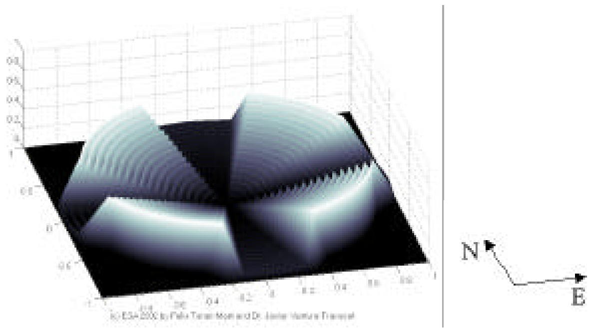
4

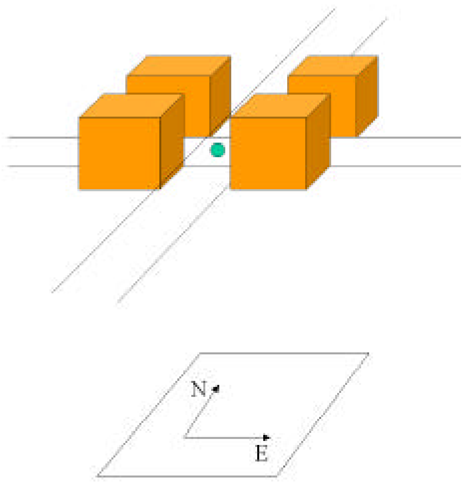

N
E

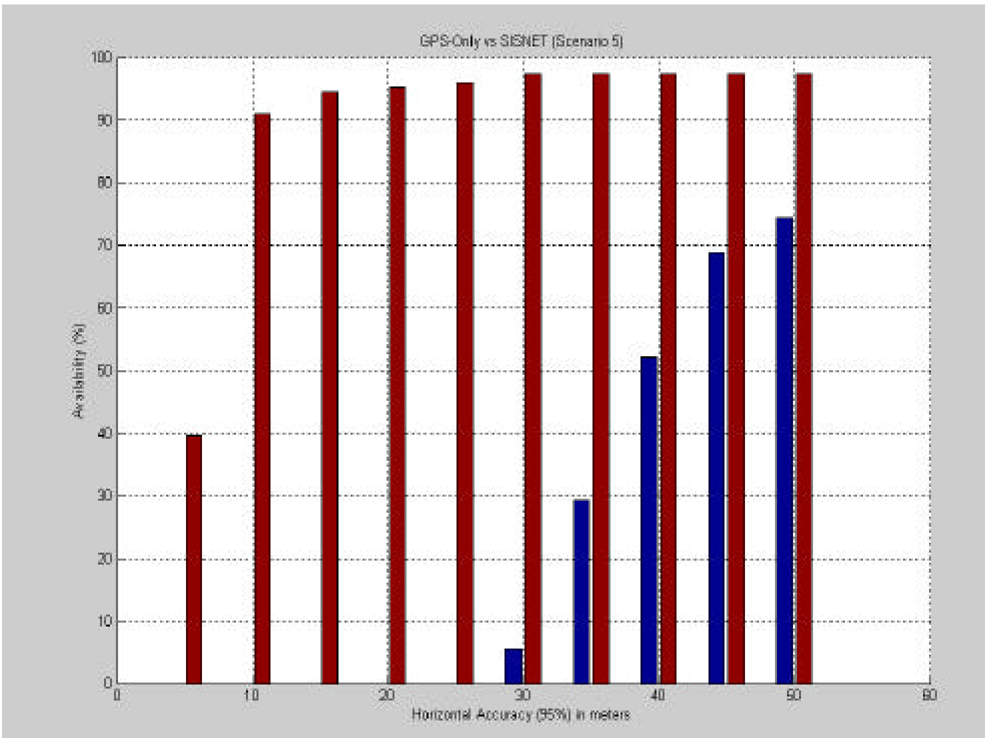

N
E


GPS-Only vs SISNET (Scenario 4)
Availability (%)
Horizontal Accuracy (95%) in meters
0
10
20
30
40
50
60
70
80
90
100

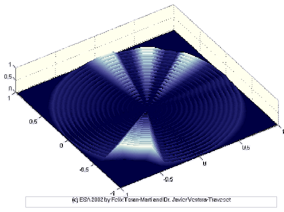
5

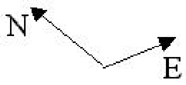

N
E

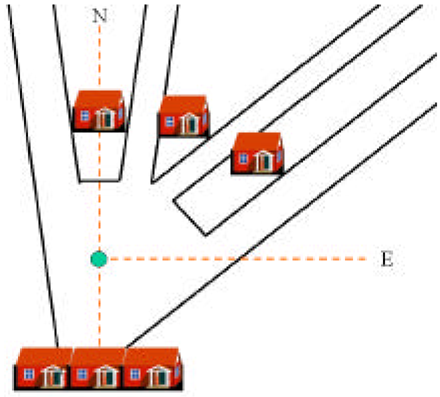

N
E

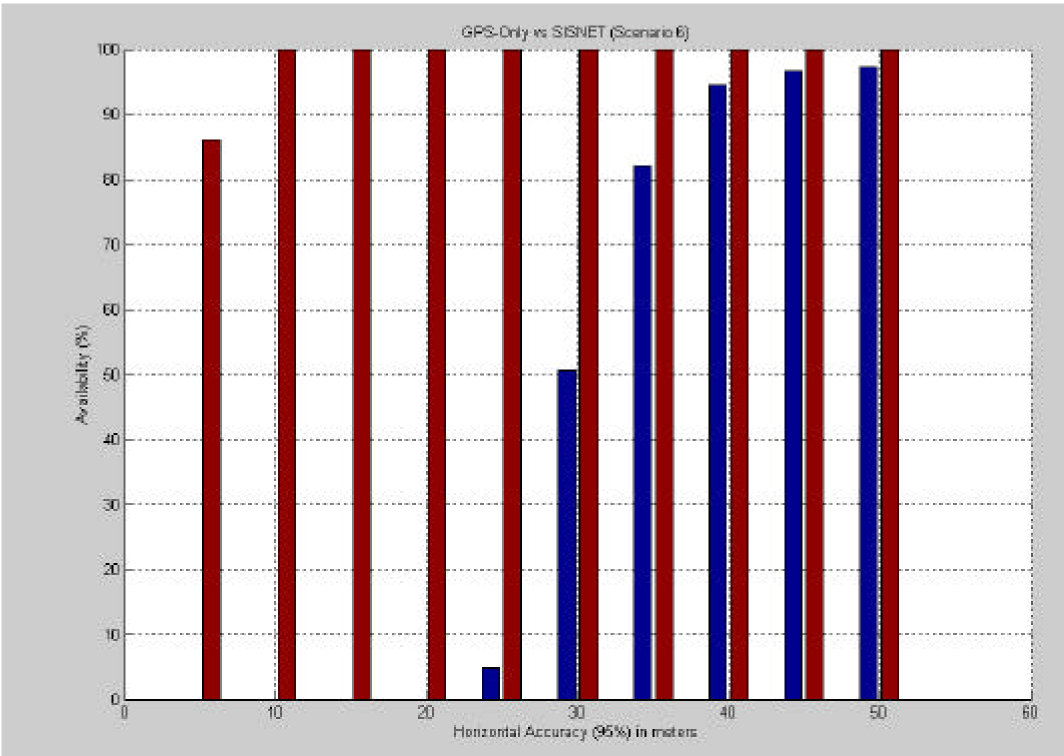

GPS-Only vs SISNET (Scenario 5)
Availability (%)
Horizontal Accuracy (95%) in meters

6

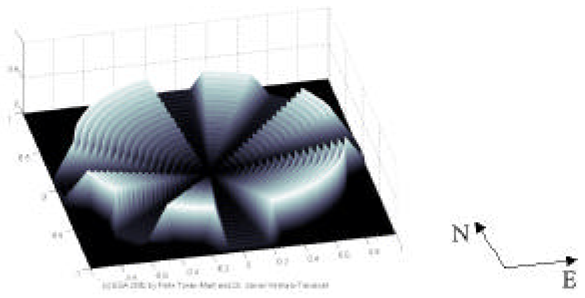


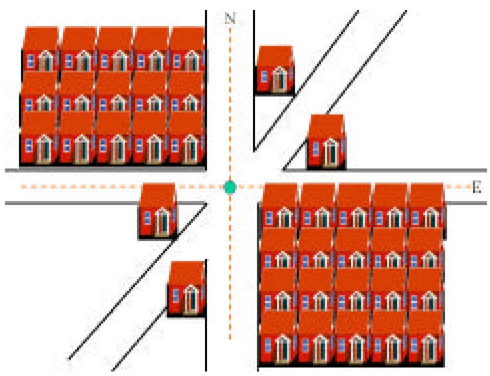

N
E

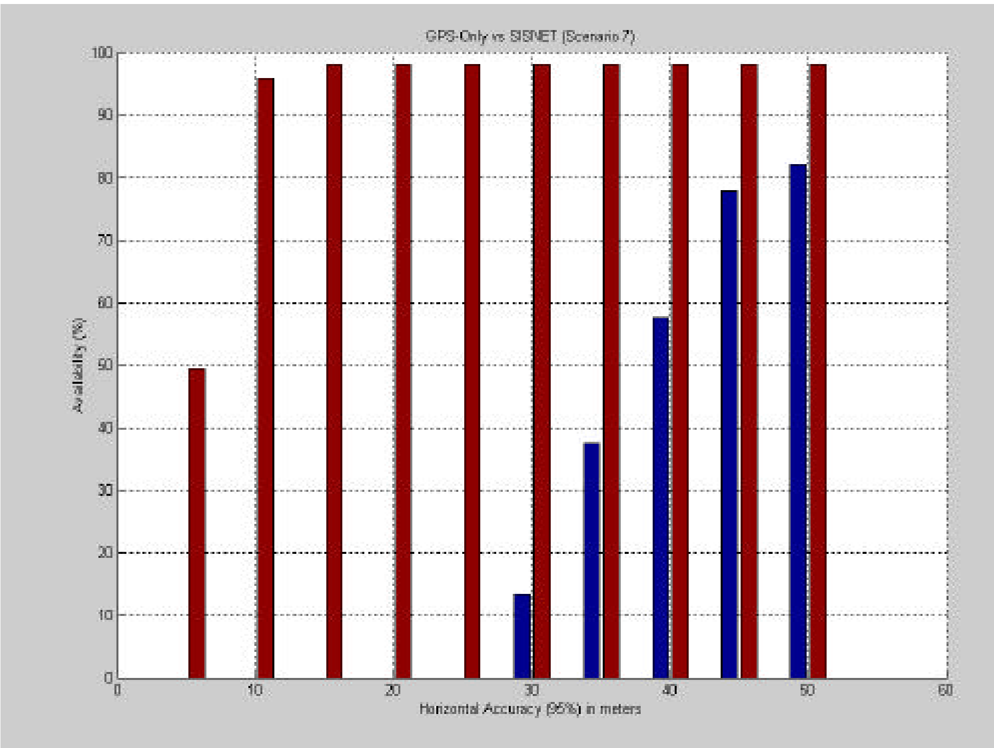

N
E


GPS-Only vs SISNET (Scenario 6)
Availability (%)
Horizontal Accuracy (95%) in meters

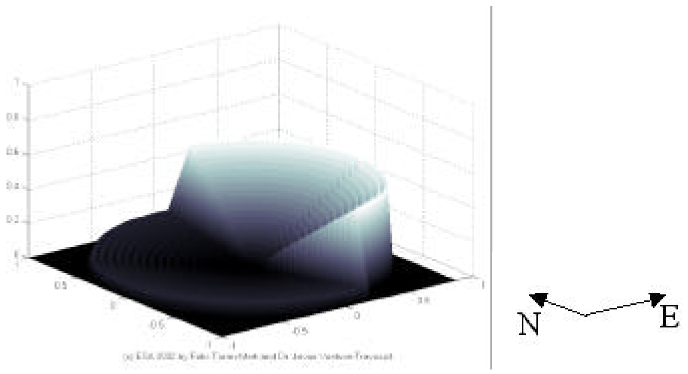
7

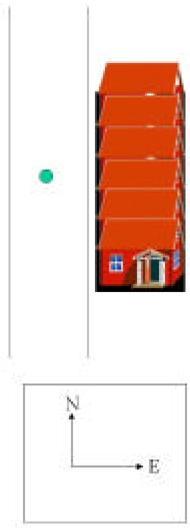

N
E

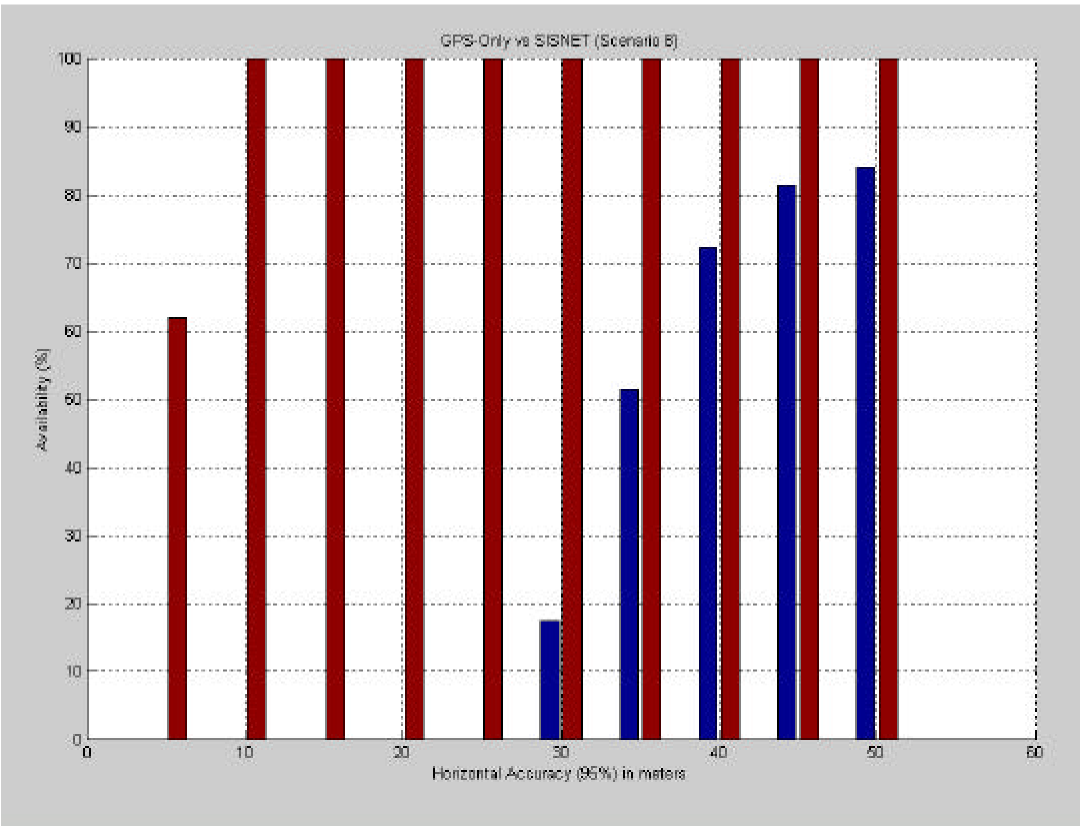

N
E


GPS-Only vs SISNET (Scenario 7)
Availability (%)
Horizontal Accuracy (95%) in meters
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60

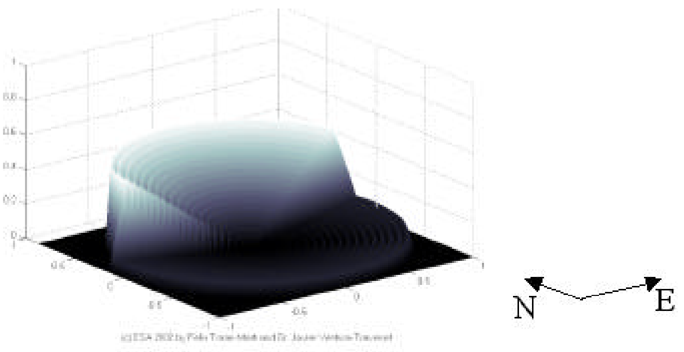
8

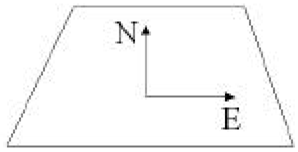

N
E

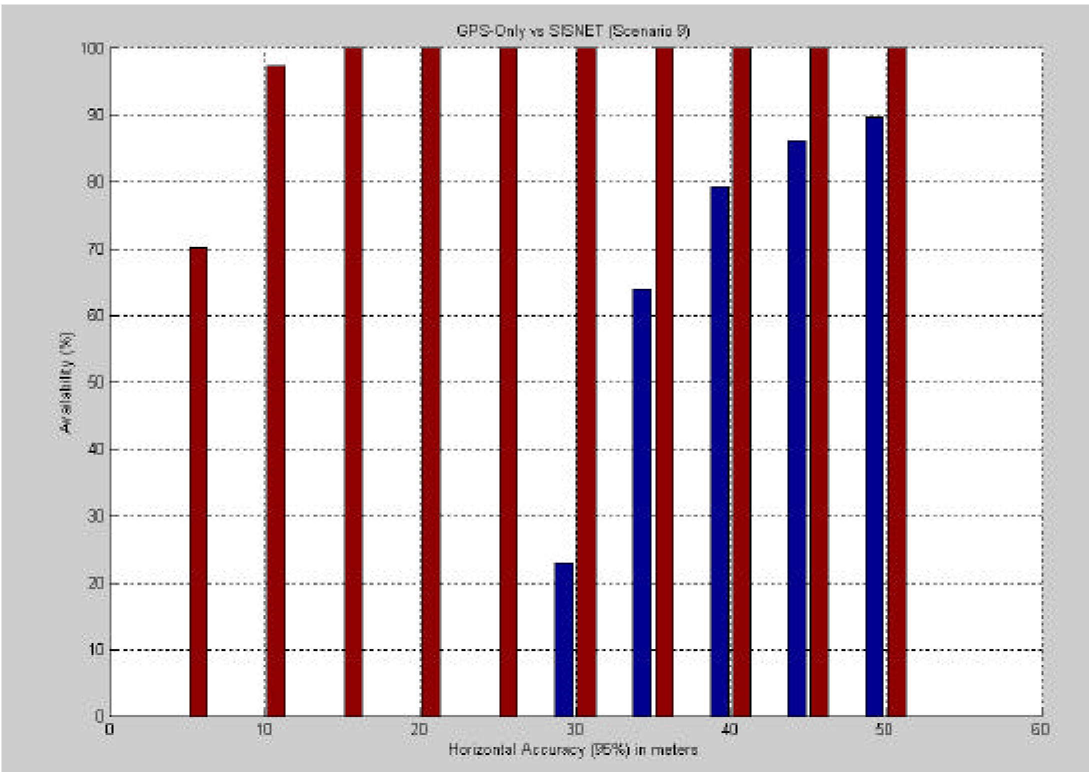

N
E


GPS-Only vs SISNET (Scenario 8)
Availability (%)
Horizontal Accuracy (95%) in meters
0
10
20
30
40
50
60
70
80
90
100

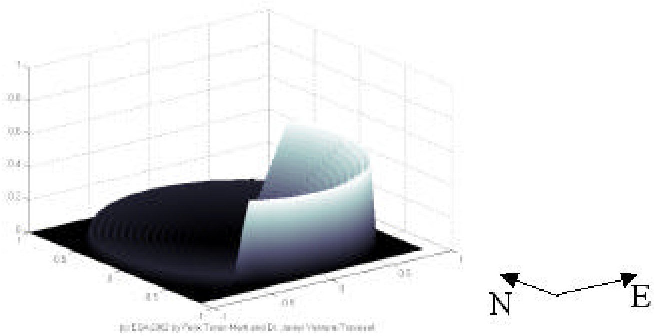
9

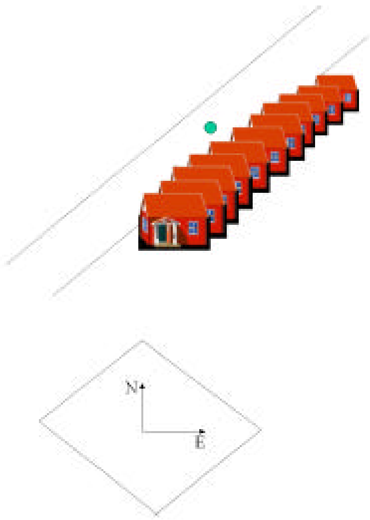

N
E

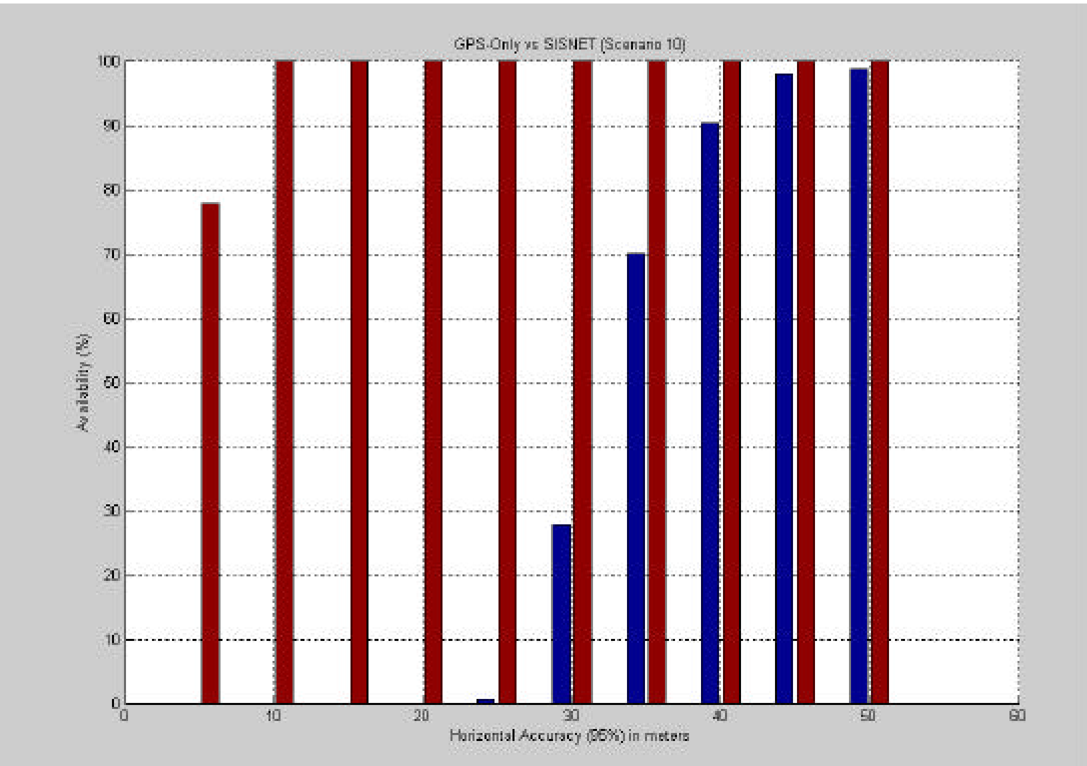

N
E


GPS-Only vs SISNET (Scenario 9)
Availability (%)
Horizontal Accuracy (95%) in meters

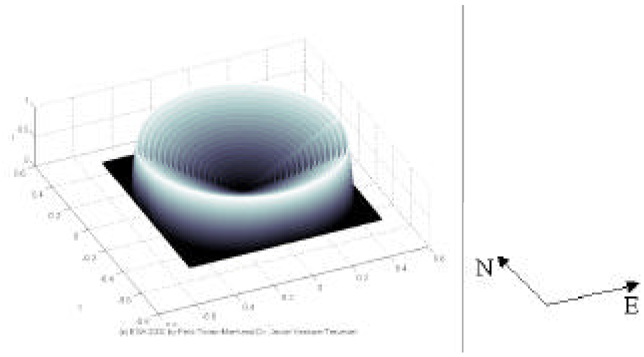
10

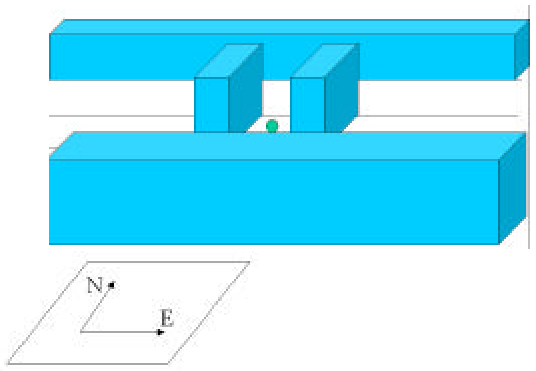

N
E


N
E


GPS-Only vs SISNET (Scenario 10)
Availability (%)
Horizontal Accuracy (95%) in meters

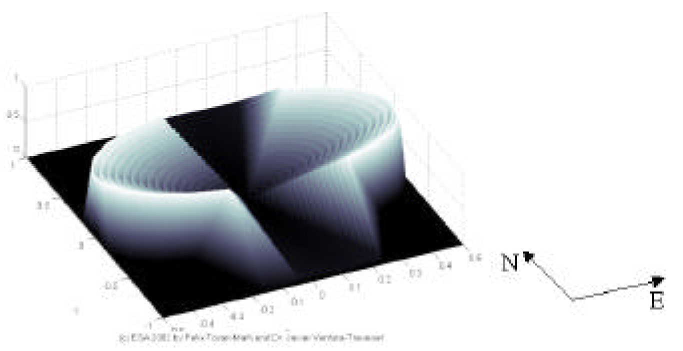
11

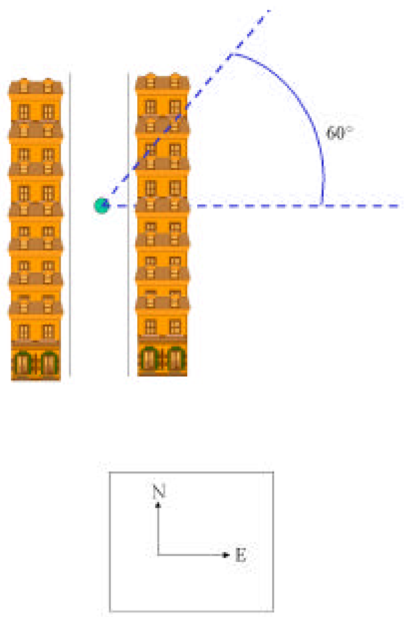


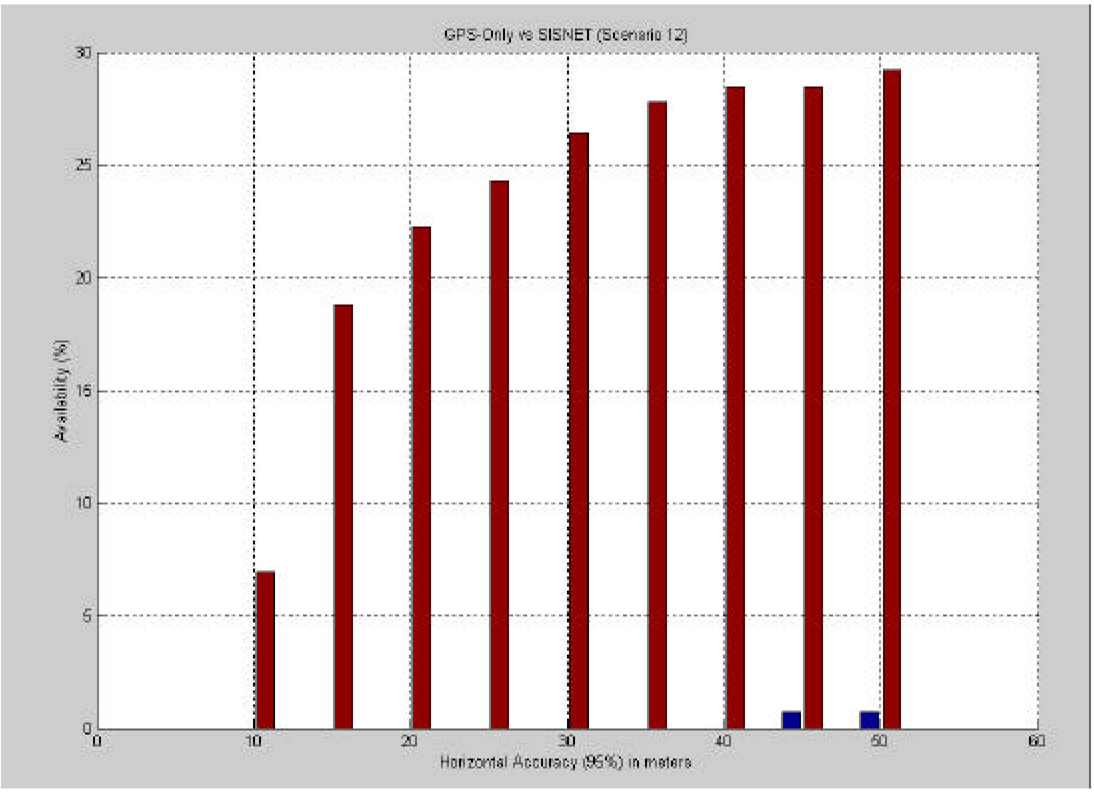


This scenario causes an availability of 0% for all the simulated accuracies, for both GPS-only and SISNeT scenarios. This is due to the visibility of less than four satellites for all the simulation instants.

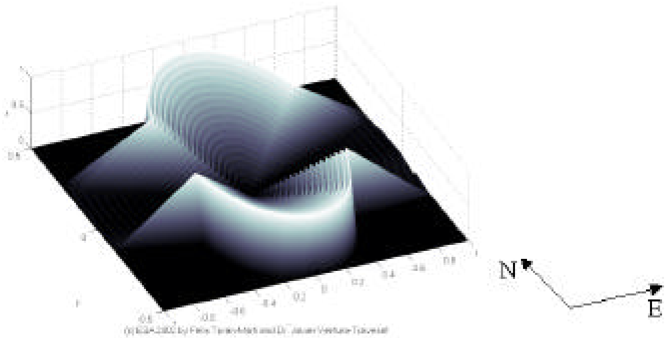
12

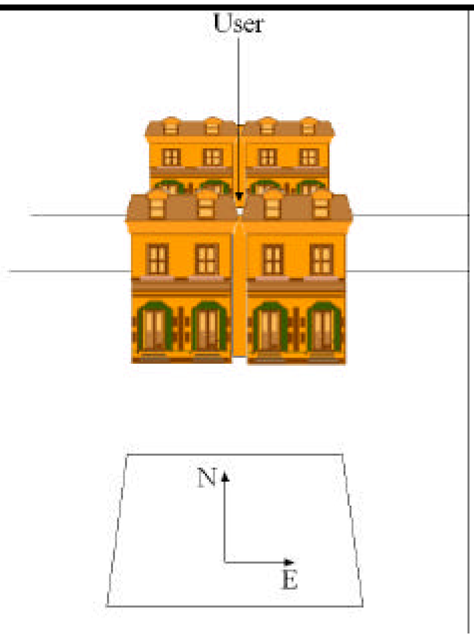

N
E

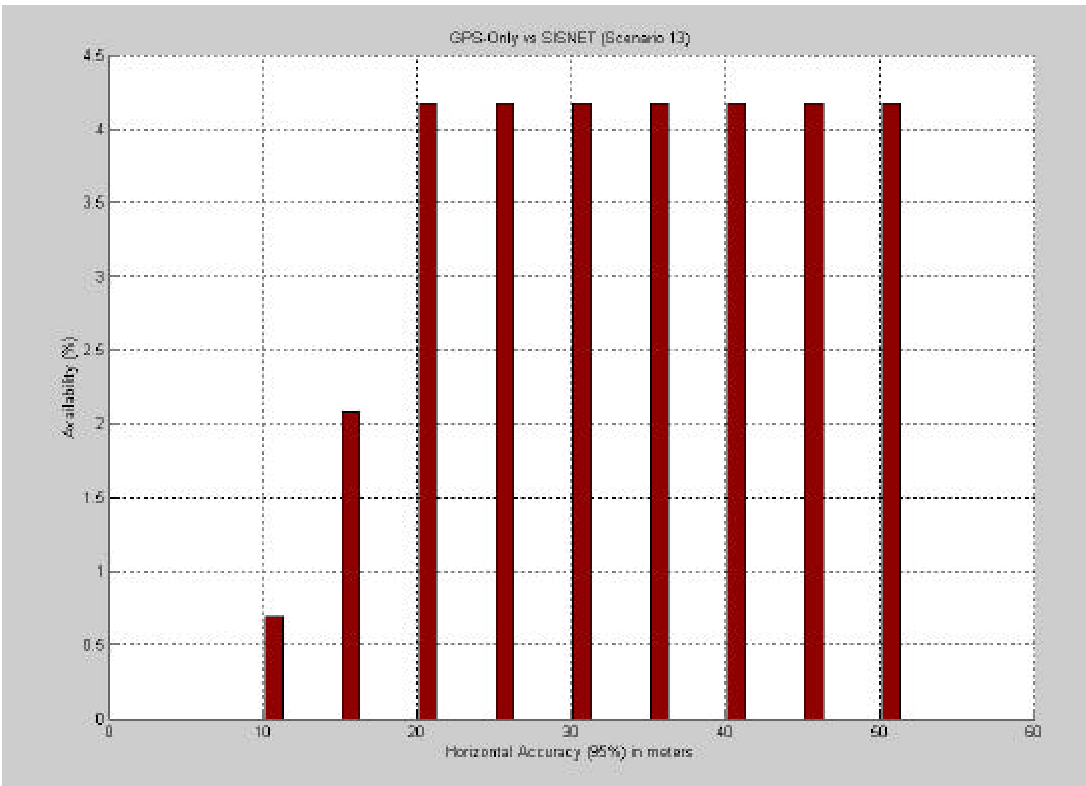

60°
N
E


GPS-Only vs SISNET (Scenario 12)
Availability (%)
Horizontal Accuracy (95%) in meters
0
5
10
15
20
25
30
0
10
20
30
40
50
60

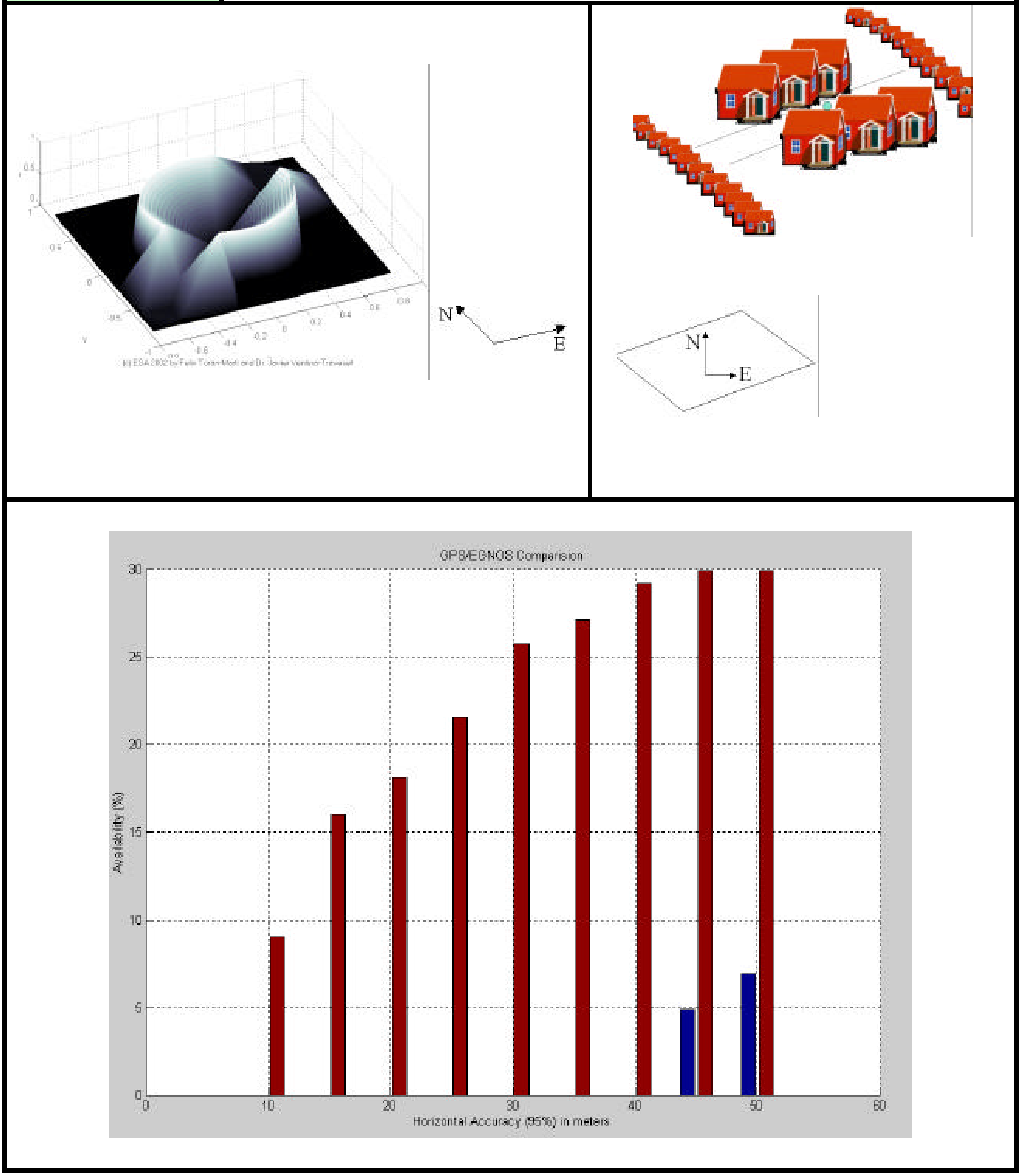
13


N
E

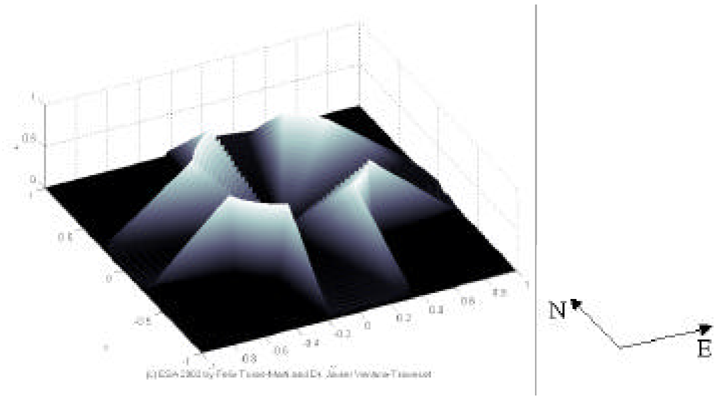

User
N
E

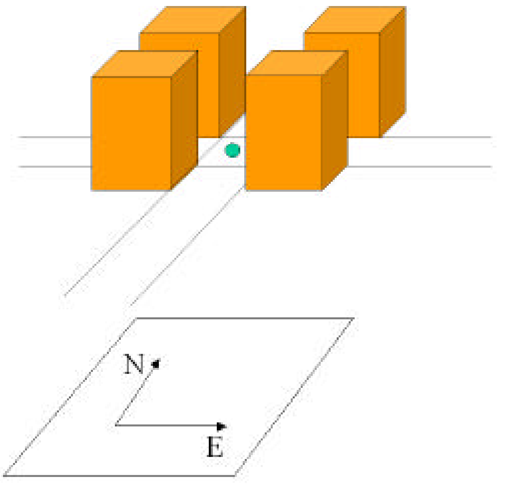

GPS-Only vs SISNET (Scenario 13)
Availability (%)
Horizontal Accuracy (95%) in meters
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
10
20
30
40
50
60

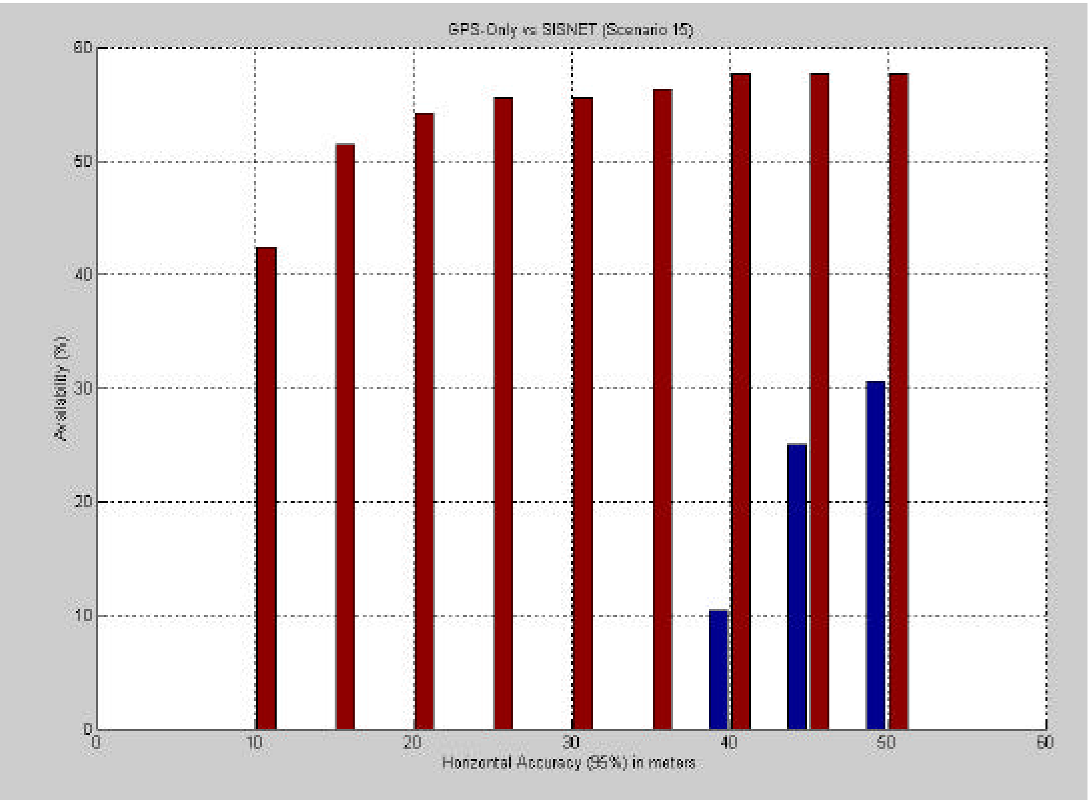
14


N
E
N
E
GPS/EGNOS Comparision
Availability (%)
Horizontal Accuracy (95%) in meters

15


N
E


N
E


GPS-Only vs SISNET (Scenario 15)
Availability (%)
Horizontal Accuracy (95%) in meters

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