Augmentation satellites constellations, a simulation on EGNOS and QZSS for Europe coverage

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BIOGRAPHY

Antonio Angrisano has obtained a degree in Navigation Sciences (radio-navigation area) from Faculty of Sciences and Technologies of Naples "Parthenope" University, Naples, Italy in 2006. He has a collaboration with Department of Applied Sciences of "Parthenope" University in 2007 about "Design of new constellations for positioning systems". Actually he is PhD student in Geodetic and Topographic Sciences, branch of Satellite Navigation.

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Mario Vultaggio is Full Professor of Navigation at the Naples "Parthenope" University, Naples, Italy. His fields of research were mainly in Navigation, Cartography, VTS (Vessel Traffic Services), Space and Astronomical Navigation. Nowadays his research subjects are mainly in radio and satellite navigation field, integrated navigation systems. He has been member of European Project on Safety of Navigation COST301. Now he is member of EUGIN (European Union Group Institute of Navigation) and IAIN (International Associations of Institute of Navigation) Committee and IEC WG10.
During his scientific activity he has written more than one hundred papers. Since 1994 he is Leader of navigation positioning for marine vehicles of Italian Antarctic Research; moreover he has planned and setup integrated systems for marine navigation (NET-NAV and nn2000). He is one of Key Persons and Vice-President of Italian Institute of Navigation.

ABSTRACT

The current GPS civil service provides suitable performance only in situations of good electromagnetic visibility; the positioning becomes difficult in severely signal degraded environments, e.g. mountainous or urban areas, where a lot of GPS signals are blocked by buildings or natural obstacles. In these situations GPS could supply only inaccurate positioning or even could be not able to provide position, owing to bad geometry or lack of minimum number of visible SV. In this study simulation software has been developed in MATLAB® environment in order to study the integration of existent and feasible constellations. Detailed coverage analysis of a super-constellation made up of GPS-EGNOS-QZSS will be presented based on existent GPS-EGNOS satellites and hypothetical Shifted-QZSS constellation over Europe. Good results were noticed by integration of all the considered constellations for a wide service area, even for middle values of mask angles.

1. INTRODUCTION

The GPS gaps can be partially solved employing space-based augmentations systems; in this paper we consider the European EGNOS and the Japanese QZSS ideally relocated on Europe. Both systems, in different way, improve the main parameters that quantify the performance of a navigation satellite system, i.e. availability, accuracy, continuity and integrity, but their own constellations have different features and different potential uses. The aim of this study is the analysis of GPS coverage with or without the considered space-based augmentations for various visibility conditions in Europe. It's also considered the coverage performance of a super-constellation composed by GPS satellites, geostationary EGNOS SV and geosynchronous QZSS SV shifted on Europe. The used indicators, to compare the various satellites configurations, are the visibility VSN (Visible Satellites Number) and GDOP (Geometric Dilution Of Precision), which represent the quality of positioning; VSN and GDOP are computed for a great number of worldwide observers, particularly in Europe. A statistical analysis is also introduced in order to obtain meaningful results. Moreover we will define and show a Service Area.

2. AUGMENTATION SYSTEMS ARCHITECTURE AND INTEGRATION

2.1 EGNOS

EGNOS is the European SBAS (Satellite Based Augmentation systems), it has been developed by the European Space Agency (ESA) in co-operation with the European Commission and Eurocontrol. The system is made up of 3 segments (Fig. 1):

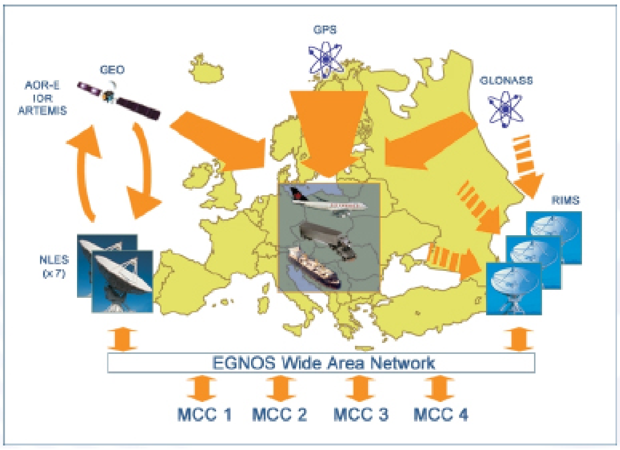

Fig. 1: EGNOS Architecture

- Space segment: the already existing GPS constellation and 3 geostationary satellites broadcasting WAD (Wide Area Differential) corrections and integrity informations. Geostationary satellites also broadcast GPS-like signal that should improve the satellites geometry;
- Ground segment: 34 stations RIMS (Ranging and Integrity Monitoring Stations) monitoring all satellites in view. 4 MCC (Mission Control Centre) generating the WAD (Wide Area Differential) corrections and integrity messages. EWAN (EGNOS Wide Area Network) it is the network that allows the connection of the ground segment elements. 4 NLES (Navigation Land Earth Station) that upload the SBAS messages on GEO satellites.
- Support segment: the EGNOS Support Facilities are composed of the Performance Assessment Check out Facility (PACF) and the Application Specific Qualification Facility (ASQF). The PACF is a centralized facility that provides Operations support, Engineering support and some Maintenance and Logistics support capabilities for the EGNOS Operations system. The ASQF is a centralized facility that provides the technical interface to EGNOS users and will provide technical analysis of EGNOS performances versus agreed service levels.
- User segment: users of aeronautic, maritime and ground transport equipped with SBAS receivers used to adapt the data provided by the service to the different applications. Using the same L1 frequency, the GEO satellites broadcast signals very similar to the GPS ones. EGNOS is under final phase of testing and will be declare operative (as system) during 2008.

2.2 QZSS

The Quasi – Zenith Satellite System (QZSS) is a space-based positioning system, designed to be a GPS augmentation for East Asia and Oceania. The QZSS is a joint program of the Japan Aerospace Exploration Agency and a consortium of Japanese industries; the first QZSS satellite will be launched in 2009, so probably the system should be operative in 2010. The system is planned to improve GPS performance above all on urban and mountainous areas of Japan, thanks to the orbital configuration of its constellation.

QZSS is composed by a Space Segment (SS), a Ground Segment (GS) and a user segment. The Space Segment consists of three geosynchronous satellites (i.e. with an orbital period of 24 sideral hours) that move on three identical Higly-inclined Elliptical Orbits (HEO); the satellites have right ascensions of ascending nodes and reciprocal differences of arguments of latitude so that they produce coincident ground tracks. The orbital ground tracks are 8-shaped and centred on 135°E meridian. A table, which resumes the main parameters of QZSS constellation, is shown in Fig. 2 and a representation of the tracks is shown in Fig. 3.

Number of Satellites	**3**
Number of Orbits	**3**
Inclination	**43° ± 4°**
Eccentricity	**0.075 ± 0.015**
Major Semiaxis	**42164 Km** (average)
Orbital Period	**1 Sideral Day** (average)
Perigee Distance	**39002 Km** (average)
Apogee Distance	**45326 Km** (average)
RAAN	**To Be Defined**
Argument of Perigee	**270° ± 2°**
Central Long. Ground Trace	**135° ± 5°**

Fig. 2: QZSS orbital parameter

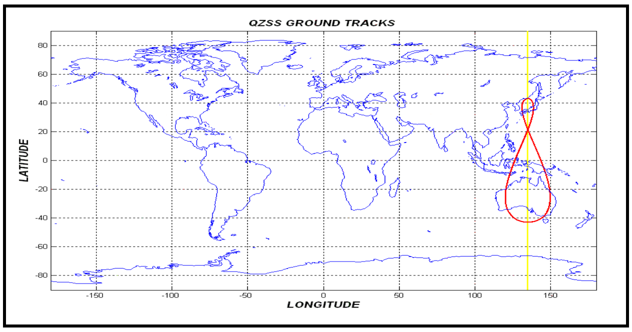

Fig. 3: QZSS ground tracks

QZSS constellation is planned to have always at least one satellite positioned near zenith over Japan, so that users can receive positioning signals without obstructions in urban and mountainous areas. QZSS is really useful to enhance GPS performance in areas highly urbanized, characterized by the so called "urban canyon", where a lot of GPS signals are blocked by buildings with bad satellite geometries, producing no precise or even impossible positioning. Considering an observer located at Tokyo (φ=35°41'N, λ=139°46'E) we can see (Fig. 4) that at least one QZSS satellite is always visible at elevation angle more than 78° and for some hours a day two satellites are visibile at elevation angles more than 70°; space vehicles at elevation angles of 70°-80° are usually visible for observers placed in urban canyons.

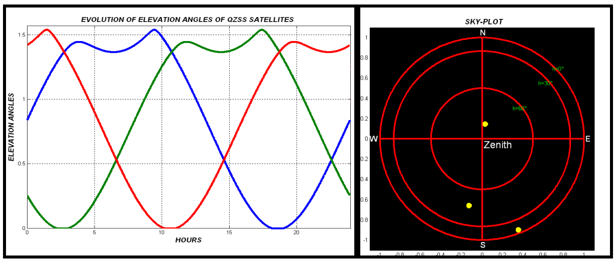

Fig. 4: Evolution of elevation angle in 24 hours and sky-plot for a fixed epoch (observer at Tokyo)

QZSS enhances GPS (and in general GNSS) service in two ways: improving availability and improving accuracy and reliability.

The availability enhancement is obtained putting GPS-like payload on QZSS satellites and broadcasting GPS-like signals; in Japan at least one QZSS-SV is visible at high elevation angles, but observation geometry improvement are evident also in Oceania, Asia and Pacific Ocean.

The accuracy and reliability enhancement is obtained transmitting ranging correction data, monitoring system failure and broadcasting integrity data (ionospheric correction parameters should be used only by Japan users).

QZSS signals are developed to maximize the interoperability with GPS and to assure compatibility with all GNSS systems.

Ground Segment consists of a Master Control Station, Monitoring Stations, Tracking Control Stations and a Time Management Station.

Monitoring Stations receive signals transmitted by QZSS satellites; Master Control Station collects monitoring data and estimates and predicts SV orbits e timing. Moreover, the Master Control Station creates navigation message with collected data and uplink it to QZSS SV by Tracking Control Stations.

2.3 SHIFTED-QZSS AND INTEGRATION AIM

In this work we want to carry out a deep study on the european coverage supplied by GPS, GEO and HEO constellations at various latitudes and with various maskings to simulate the conditions of an urban positioning. Waiting European Galileo system, such constellations could be used as gap-filler or in future as backup system or as Galileo ERIS (External Region Integrity Systems) support.

In order to do such simulation we use a constellation obtained by ideally shifting the QZSS constellation on Europe, leaving all orbital parameters unchanged but changing central longitude of ground trace (15°E). In this paper we call the simulated and translated constellation "Shifted-QZSS" or S-QZSS to distinguish it from the original one. With respect to the original constellation, S-QZSS coverage performances don't change because GPS constellation is quasi-symmetric. A table that resumes the main parameters of Shifted-QZSS constellation is shown in Fig. 5 and a representation of the tracks is shown in Fig. 6.

Number of Satellites	3
Number of Orbits	3
Inclination	43°
Eccentricity	0.075
Major Semiaxis	42164 Km
Orbital Period	1 Sideral Day
Perigee Distance	39002 Km
Apogee Distance	45326 Km
RAAN	To Be Defined
Argument of Perigee	270°
Central Long. Ground Trace	15°

Fig. 5: Shifted-QZSS orbital parameter

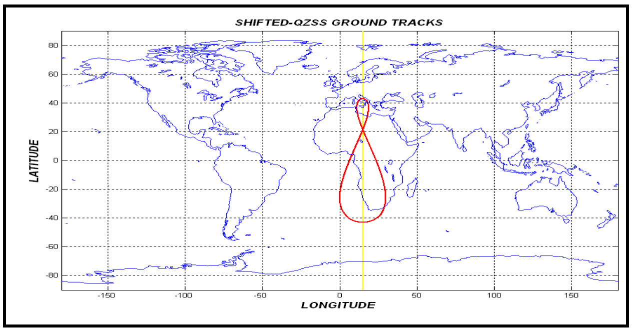

Fig. 6: Shifted-QZSS ground tracks

3. COVERAGE ANALYSIS

In order to examine the worldwide coverage and particularly the European one provided by GPS stand-alone constellation and by GPS constellation augmented with EGNOS and/or Shifted-QZSS constellation, we have developed a simulation software in MATLAB® environment, resumed in the block diagram in Fig. 7.

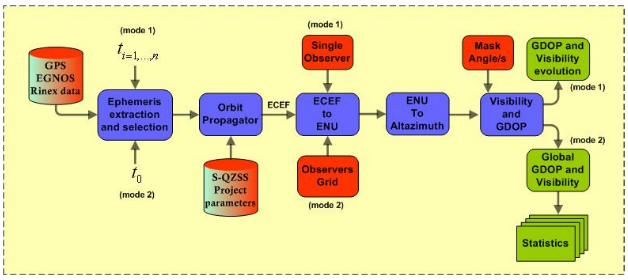

Fig. 7: Software block diagram

3.1 SOFTWARE DESCRIPTION

In the developed software we have considered as inputs: GPS and EGNOS Rinex navigation message files, which contain the daily broadcast ephemerides. Rinex data were stored by a Septentrio PolaRx2 receiver placed in a location near Naples, at:

φ: 40°57'.59272 N;
λ: 14°35'.91161 E;
h: 254.95 m (WGS84);
data are related to 16 February 2008.

The first block of algorithm deals with the extraction of GPS and EGNOS satellites ephemerides from Rinex files and the selection of the ones nearest to the observation epoch. The selected ephemerides and the theoretic orbital parameters of Shifted-QZSS constellation are the inputs of an orbit propagator, which updates the ephemerides at observation epoch. The SV ECEF (Earth- Centered, Earth-Fixed) coordinates, outputs of orbital propagator, are transformed in the local system ENU (East North Up) and then in elevation and azimuth coordinates, relative to the fixed observer. In the last block of the software, number of visible satellites and GDOP are computed for a given mask angle.

The software can work in two ways:

- Considering a single observer for a lot of epochs with a constant mask angle, or a masking changing versus azimuth in order to simulate a real environment.
- Considering a grid of observers evenly distributed on Earth or on a part of it for a fixed epoch with an average mask angle.

In the first mode VSN and GDOP evolutions versus time are plotted; in the second one VSN and GDOP maps are obtained for a certain area at a fixed epoch, which can be statistically processed considering more epochs to obtain more significant coverage indicators. In order to obtain more significant plots, global and regional grids of GDOP and VSN values are generated every 15 min for 24h, producing a 3D matrix of data (Fig. 8).

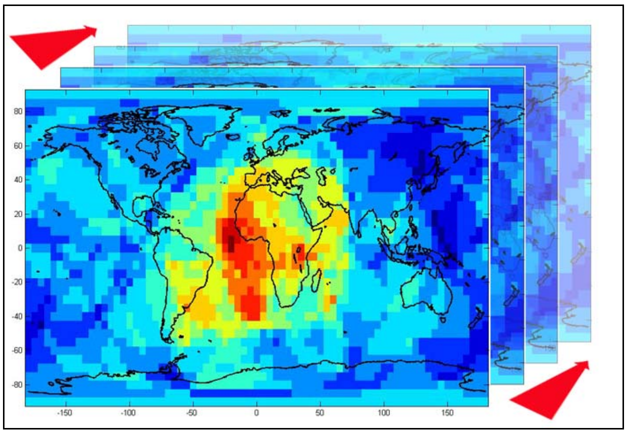

Fig. 8: Plot of 3D grid

For every grid observer a certain VSN and GDOP probabilities are computed.

3.2 GLOBAL AND EUROPEAN COVERAGE

To analyse the global coverage of GPS, GPS+EGNOS, GPS+S-QZSS and GPS+EGNOS+S-QZSS, we consider a grid of observers placed evenly on Earth surface, distant each other 5° in latitude and longitude; VSN and GDOP are computed with regard to every observer at observation epoch. Mask angle values of 15°, 30° or 40° are adopted to represent different visibility conditions. To obtain a complete scenario for a fixed mask angle, probability of VSN>6 and GDOP<4.5 are estimated using an observation step of 15 min for 24 hours.

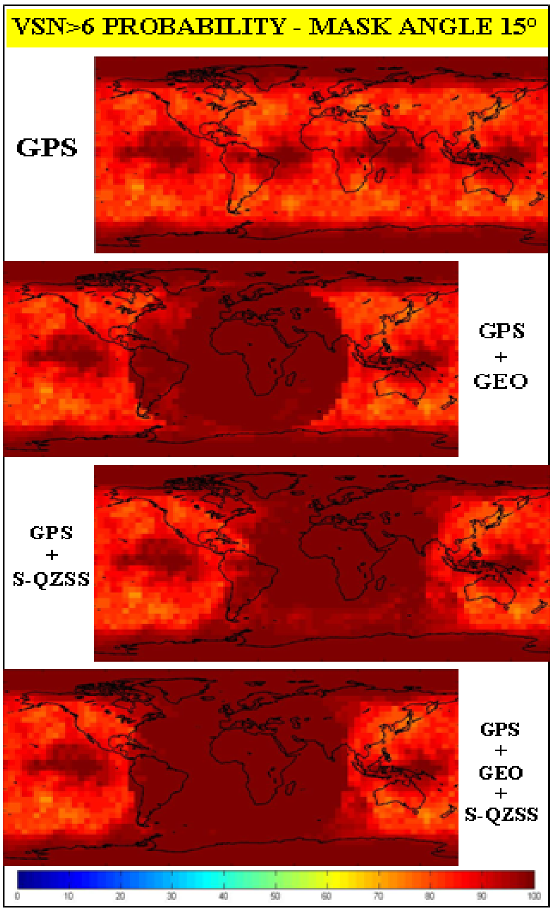

Fig. 9: VSN>6 Probability with mask angle 15°

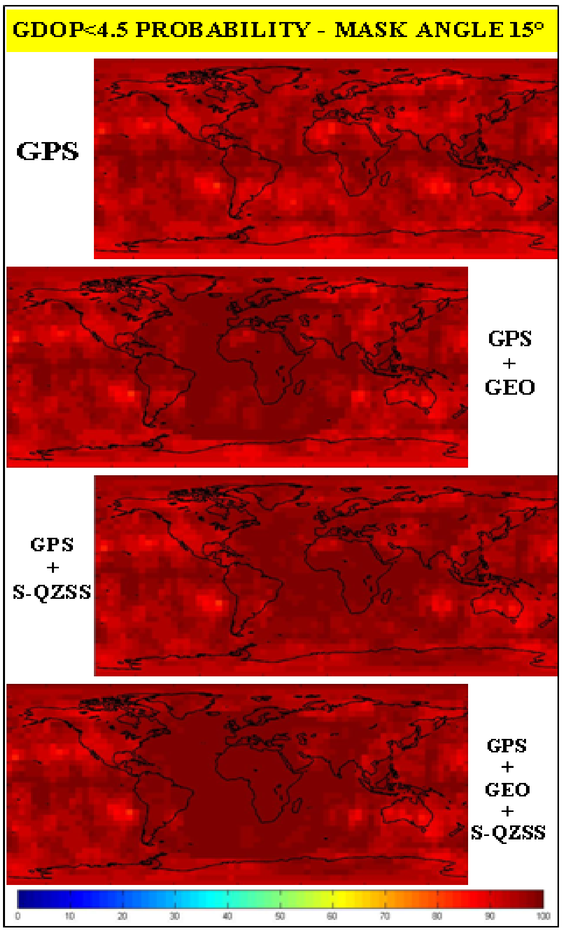

Fig. 10: GDOP<4.5 Probability with mask angle 15°

Thresholds VSN>6 and GDOP<4.5 are adopted as conservative conditions because 6 visible satellites guarantee redundancy on positioning (PVT) and 4.5 is GDOP limit for a good observation geometry. To investigate the coverage of the considered constellations on Europe, a grid of observers is placed between meridians 10W and 60E and parallels 30N and 80N, with a step of 1°; a coverage analysis similar to global one is carried out.
With a mask angle 15° the only GPS provides a probability to have a VSN>6 of about 100% at polar zones and 80-90 elsewhere (Fig. 9).
Geostationary and geosynchronous augmentations in this case improve the visibility in similar ways, raising to 100% the above-mentioned probability for great Earth areas (Europe, Africa, South America, Atlantic Ocean) and the super-constellation enhances further the situation (Fig. 9).
The stand-alone GPS provides a GDOP<4.5 probability near to 90% worldwide (Fig. 10), GPS+EGNOS and GPS+S-QZSS increase the value to 95 for the areas defined above, the super-constellation to almost 100%.

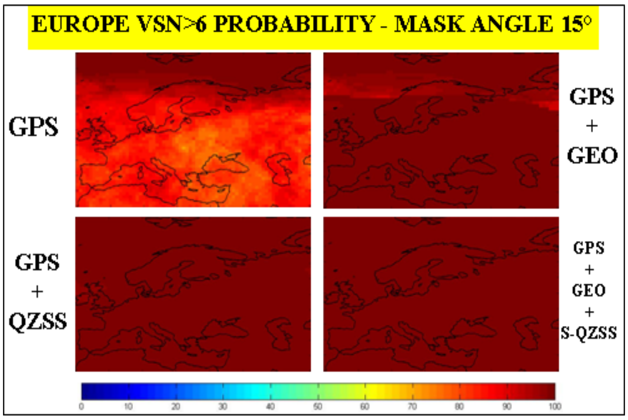

Fig. 11: VSN>6 Probability with mask angle 15°

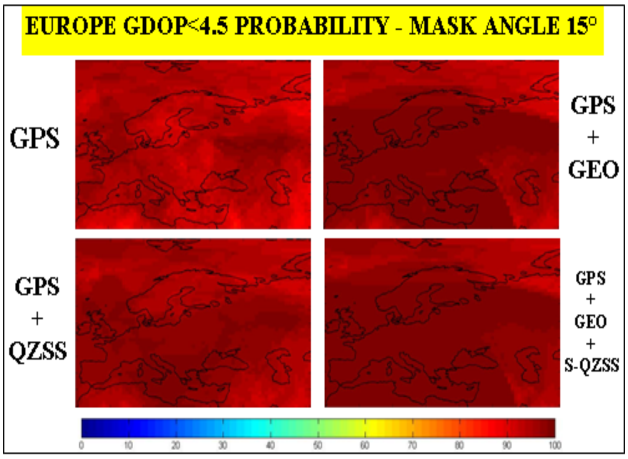

Fig. 12: GDOP<4.5 Probability with mask angle 15°

By the examination of charts in Fig. 10 and 11 VSN and GDOP performances on Europe are shown, we can see that the whole Europe is covered by 6 GPS satellites 80% of times with GDOP<4.5 probability near to 90%. The integration with 3 EGNOS satellites produces an improvement to 100% in visibility and near to 100% in GDOP; the integration with 3 S-QZSS satellites produces a similar improvement in visibility and a slightly lower one in GDOP compared with EGNOS satellites. The simultaneous use of EGNOS and S-QZSS satellites with GPS constellation provides of course the best results: VSN>6 probability 100% and GDOP<4.5 probabilities almost 100%.
At low mask angle (~15°) the stand-alone GPS is sufficient to guarantee good coverage performances with regard above all to availability and continuity; in this scenario, which certainly doesn't represents the worst case, EGNOS and S-QZSS could be useful for upgrade accuracy and integrity.

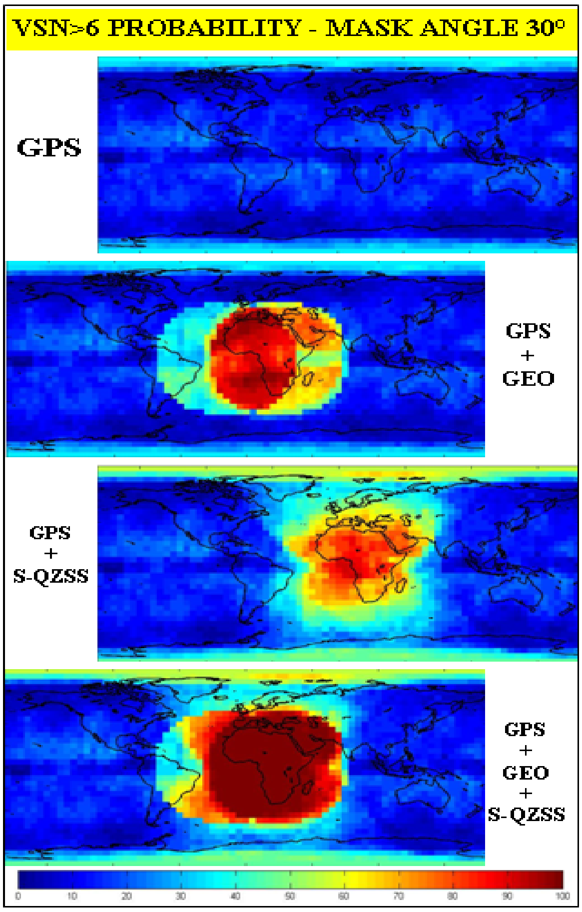

Fig. 13: VSN>6 Probability with mask angle 30°

A mask angle 30° is a good approximation of a quite adverse but not prohibitive environment for signal propagation and PVT solution. In these conditions the VSN of GPS constellation is rather poor, the probability to have a number of visible satellites greater than 6 is about 10-20% almost everywhere, while over polar zones is 35-40% (Fig. 13). The GPS coverage situation is quite critical, in fact the GDOP<4.5 probability is about 20-30% almost everywhere and near to 0% in polar zones where it's impossible a precise positioning (Fig. 14). The GPS+EGNOS constellation provides a considerable visibility improvement above all on the area defined by footprints intersection of 3 EGNOS GEO SV; this area includes Africa and Southern Europe and has a VSN>6 probability about 85-95%. In this area GDOP<4.5 probability is about 50-70%. Also by the sides of this area we note an increasing VSN, between 40% and 70% and a GDOP increase between 25% and 45%.

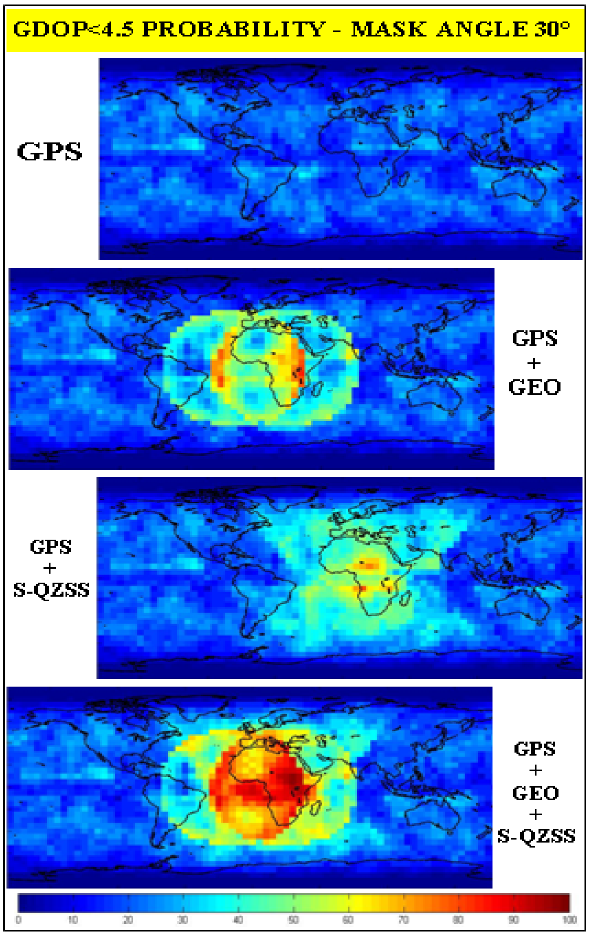

Fig. 14: GDOP<4.5 Probability with mask angle 30°

Comparing with previous case the GPS+S-QZSS constellation improves the visibility in different way; a wider area takes advantages, but with worse performances. VSN>6 probability is 70-80% in Africa, 60-70% in Europe and the benefits of S-QZSS augmentation are clear at higher latitudes too. A similar improvement is obtained for GDOP; GDOP<4.5 probability is 50-70% in Africa and 50-55% in Europe. The super-constellation improves the visibility in both ways: a wide area is well covered with good performances. In this case the VSN>6 probability is 100% in Africa and Southern Europe. Good GDOP coverage is also obtained; GDOP<4.5 probability is between 65% and 90% in Africa and between 60% and 70% over Europe.

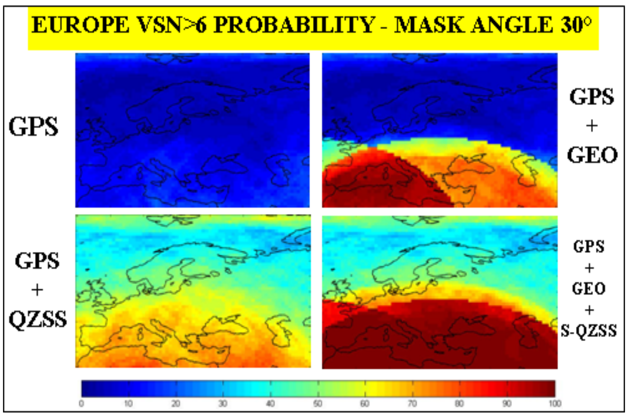

Fig. 15: VSN>6 Probability with mask angle 30°

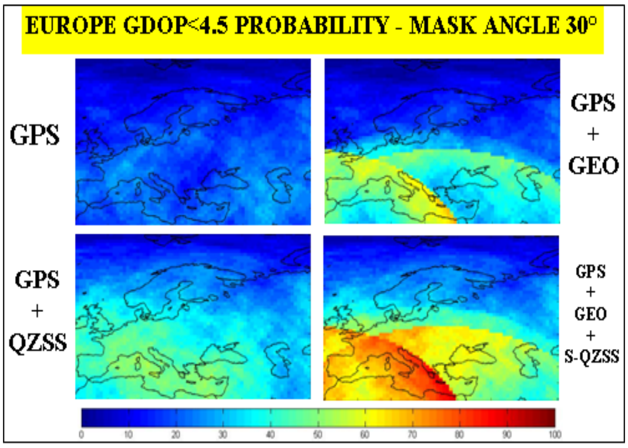

Fig. 16: GDOP<4.5 Probability with mask angle 30°

By the examination of Figures 15 and 16, which represent coverage performances over Europe with a constant mask angle 30°, we can see that in this condition GPS constellation is insufficient to provide precise positioning: VSN>6 probability is near 0% on whole Europe and GDOP<4.5 probability is low (20-30%). The integration of GEO SVs produces a coverage improvement only over Southern Europe (Italy, Spain, Southern France, Mediterranean Sea with VSN>6 probability 90% and GDOP<4.5 probability near to 60%); on the rest of the Europe the coverage remains insufficient, owing to geostationary satellites problems to cover high latitudes. S-QZSS integration produces a good improvement in visibility and GDOP (55-70% and 40-50% respectively), but no area in Europe is suitably covered. The GPS+EGNOS+S-QZSS constellation provides a full coverage on Middle and Southern Europe with a VSN>6 probability near to 100% and a GDOP<4.5 probability about 65-80%; Northern Europe is served by at least 6 SVs 60-70% of time, with a good observation geometry about 50% of time.

A common urban environment can be simply represented considering an average mask angle 30°; in this condition the super-constellation is suitable to offer good performances with reference to availability and continuity thanks to the visibility improvements. The coverage quality is enhanced thanks to GDOP improvement, which causes a more accurate positioning. If S-QZSS is able to broadcast EGNOS-like signals, accuracy will be further enhanced; it should give more probability to receive SBAS correction and integrity message also in urban environment.

GPS constellation with a mask angle 40°, is inadequate to provide a continuous and precise positioning; both VSN>6 and GDOP<4.5 probabilities are near to 0% (Fig. 17 and 18). Geostationary EGNOS satellites produce some benefit only on a few areas of Africa, whereas S-QZSS constellation is almost ineffective in this situation. The super-constellation allows a good visibility enhancement on Africa, but with a GDOP very poor. On Europe (Fig. 19, 20) such a masking makes impossible a continuous and accurate positioning service with GPS, GPS+EGNOS, GPS+S-QZSS constellations; the super-constellation provides a coverage improvement in some zones: VSN>6 probability is about 60% on the Iberian Peninsula, 70-80% on Mediterranean sea, Italy and Greece, but near to 0% elsewhere.

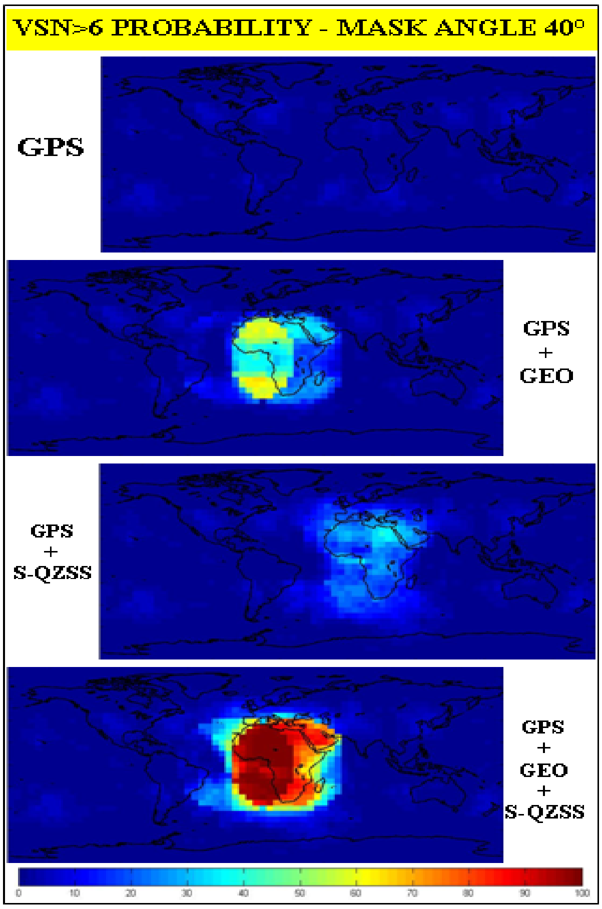

Fig. 17: VSN>6 Probability with mask angle 40°

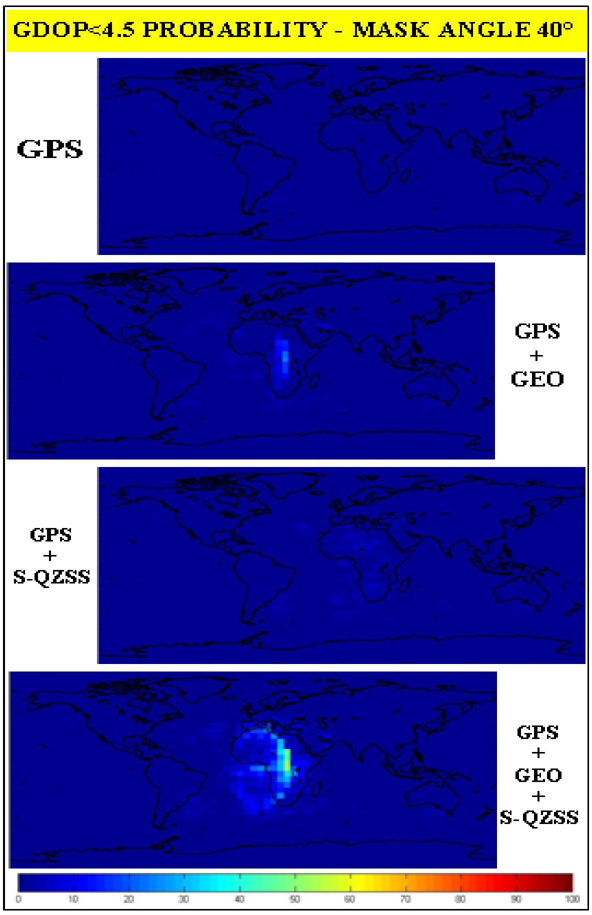

Fig. 18: GDOP<4.5 Probability with mask angle 40°

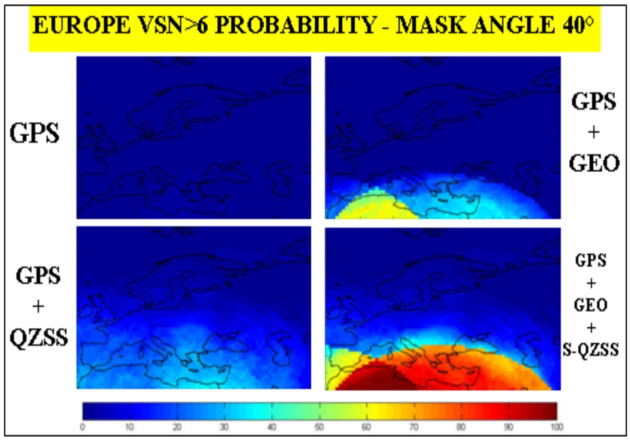

Fig. 19: VSN>6 Probability with mask angle 40°

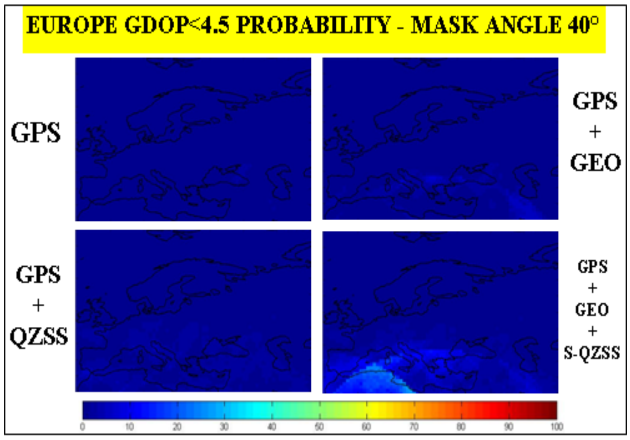

Fig. 20: GDOP<4.5 Probability with mask angle 40°

GDOP<4.5 probability is between 0 and 10% on whole Europe and so that a continuous and precise positioning is impossible.

3.3 SERVICE AREA DEFINITION

The obtained results encourage defining a “service area” (highlighted by ellipses in Fig. 21) where both considered parameters (VSN and GDOP) reach appropriate values to guarantee availability and continuity of good satellite geometry. The following parameters have been chosen to define the service area:

- Simulation interval: 24 h
- Time step: 15 min
- Observers grid step: 1deg x 1deg
- Mask angle: 30deg
- GDOP< 6: Probability > 70%
- VSN ≥ 5: Probability ≈ 100%

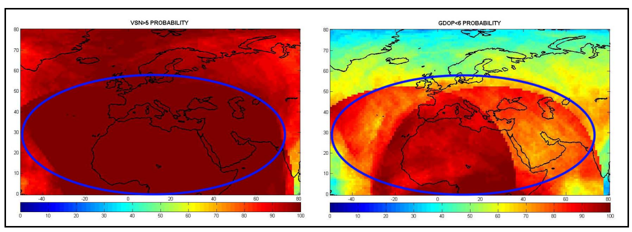

Fig. 21: A possible service area

3.4 URBAN CANYON SIMULATION

The developed software is able to analyse the coverage evolution for a certain period, considering a single observer; this application is useful to study in detail the behaviour of a navigation constellation over a not wide zone. Now we want to examine deeply the behaviour of GPS constellation and its augmentations over Europe; for this purpose we have selected Naples centre area to test the coverage evolutions of the considered constellations.

A first analysis is made considering mask angles 15°, 30°, 40° which represent masking conditions of growing difficulty; for a fixed observer VSN and GDOP were computed every 60 seconds in a whole day and a statistical analysis with VSN>5 and GDOP<6 probability is carry out. The observer is placed at Naples at coordinates (φ: 40°50' N; λ: 14°15' E).

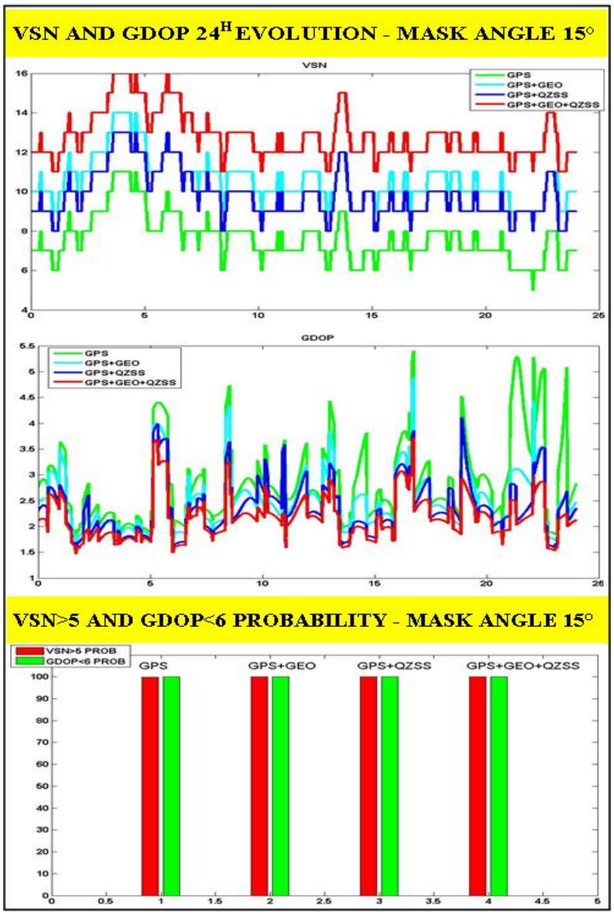

Fig. 22: Coverage evolution with mask angle 15°(Naples)

With a mask angle 15° GPS constellation provides good performances (Fig. 22): VSN>5 and GDOP<6 probabilities are 100%. GPS+EGNOS constellation has always 3 visible SV more than GPS, and 1 more than GPS+S-QZSS, which has however a lower mean GDOP. VSN of GPS+EGNOS+S-QZSS constellation is between 11 and 16 and the GDOP value is ever below 3.7.

With a mask angle 30° (Fig. 23) sometimes the only GPS has a VSN<4, so it's impossible the determination of 3D fix; VSN>5 probability is about 40% and GDOP<6 probability is about 45%. GPS+EGNOS constellation has a lightly better visibility than GPS+S-QZSS one and a similar GDOP evolution; for both constellations VSN>5 probability is 95-100% and GDOP<6 probability 70-80%. VSN of GPS+EGNOS+S-QZSS is between 7 and 13, and GDOP between 2.5 and 8; GDOP<6 probability is about 95%.

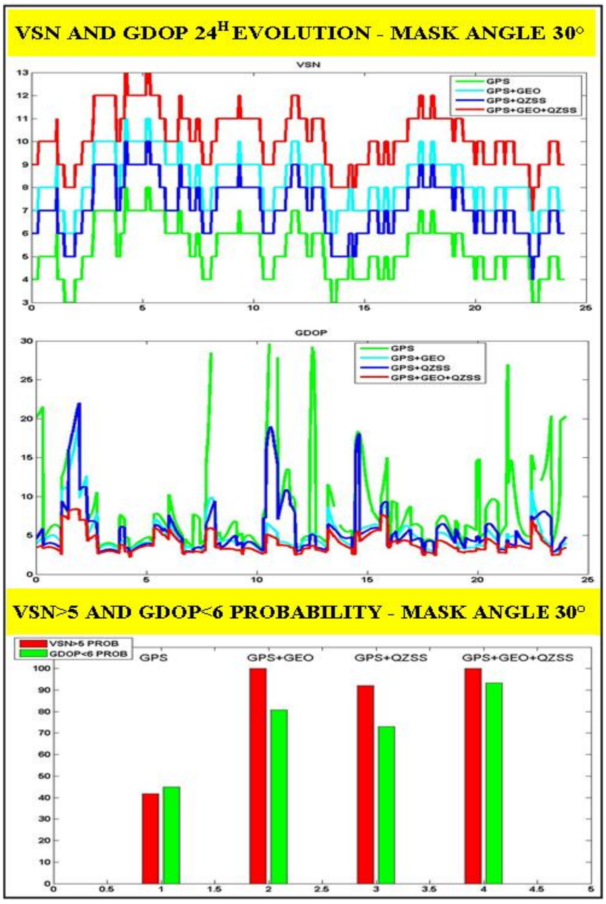

Fig. 23: Coverage evolution with mask angle 30°(Naples)

With a mask angle 40° (Fig. 24) GPS is inadequate to provide a continuous 3D positioning service, because very frequently there is a poor constellation coverage (VSN<4). The visibility of GPS+EGNOS and GPS+S-QZSS constellations is very similar, but GPS+S-QZSS supplies a better GDOP and a more continuous coverage. VSN of super-constellation are between 5 and 11, so a continuous positioning service is guaranteed; the accuracy is not too good, because GDOP<6 probability is near to 40%.

A further analysis is made considering a real environment rather than constant mask angle, building a 3D model of an urban area in AutoCAD (Fig. 25); a map of historic centre of Naples is considered and the third dimension was obtained extruding the buildings contours with rough height values. In the 3D model three different observers are considered and for each of these VSN and GDOP are computed every 60 seconds for 24 hours. The observers (marked by blue spots on Fig. 25) have different types of blocking situation; the first observer has a low masking angle (comparable to the blocking configuration with constant mask angle 15°), the second with a high masking and the third one with a very high masking angle. With a weak urban masking (observer 1 Fig. 25 and results showed Fig. 26) the GPS coverage is suitable to provide a good positioning service, the VSN is at least 5 and the GDOP value rarely exceeds 10.

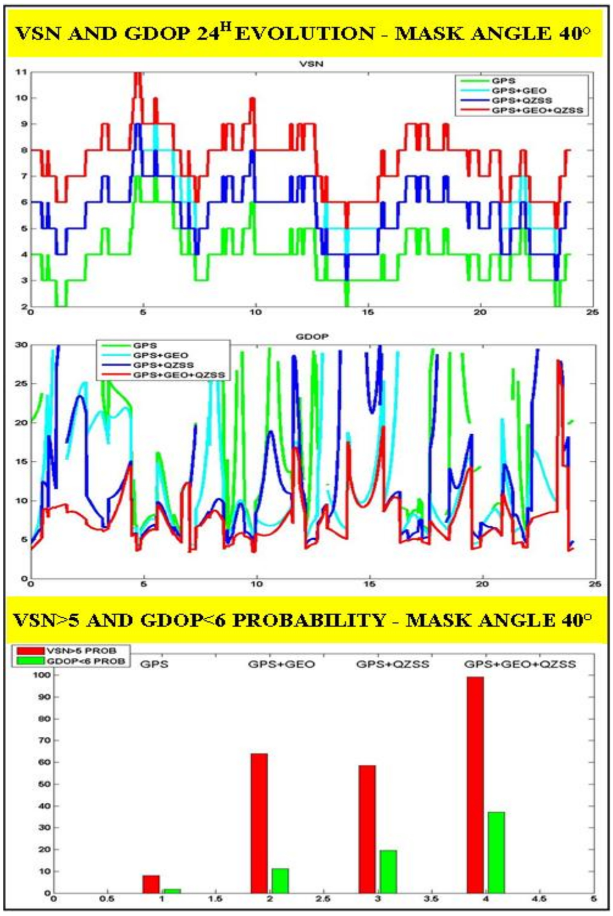

Fig. 24: Coverage evolution with mask angle 40° (Naples)

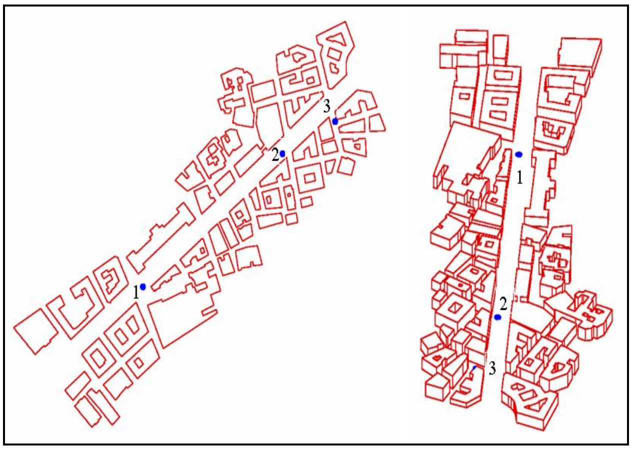

Fig. 25: A 3D model of a street of Naples

The augmentation constellations improve further the performances; the EGNOS integration works (Fig. 26) like S-QZSS one. The super-constellation works very well, the VSN is between 9 and 17 and the maximum GDOP value is about 5. The aforesaid urban masking, although not prohibitive, is slightly harder than the constant masking 15°.

With a high urban masking (observer 2 Fig. 25 and results showed in Fig. 27) the stand-alone GPS is not sufficient to provide good coverage performances; VSN>5 probability is near to 30% and positioning service is often cut off.

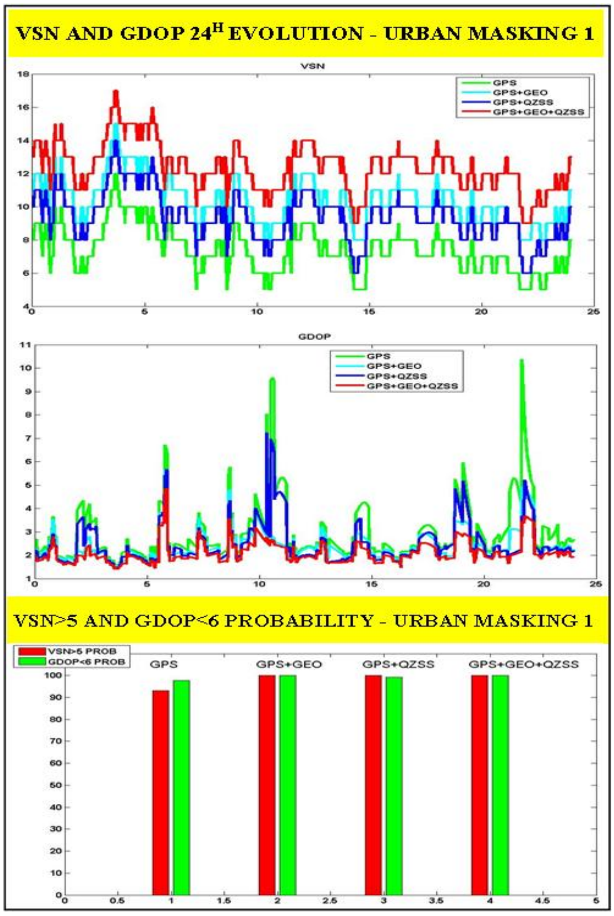

Fig. 26: Coverage evolution with weak masking (Naples)

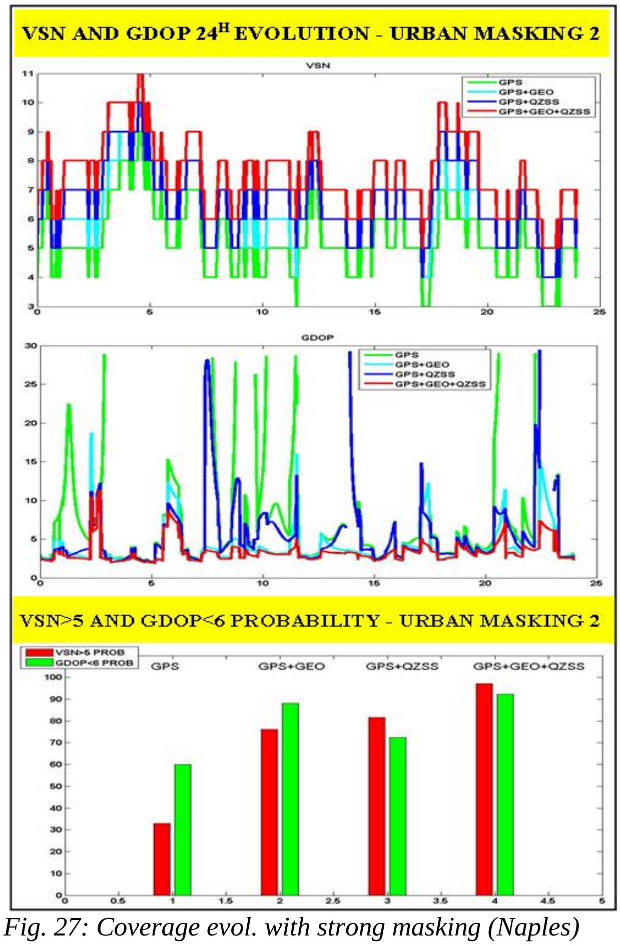

Fig. 27: Coverage evol. with strong masking (Naples)

In these masking conditions and with an observer at middle latitude, S-QZSS and EGNOS augmentations work differently; S-QZSS provides a better visibility, while GEO constellation supplies a better GDOP. The super-constellation combines and exalts the qualities of EGNOS and S-QZSS constellations, VSN>5 and GDOP<6 probability approach to 100% in these adverse conditions too. This second urban masking is clearly harder than the constant masking 30°.
With a very high urban masking (observer 3 Fig. 25 and results showed in Fig. 28) the coverage performances of GPS are very poor, so the 3D position solution is often impossible or uncertain. S-QZSS and EGNOS constellations, if considered separately, guarantee neither a continuous service nor a good accuracy. Moreover the EGNOS corrections aren't much useful in aforesaid masking conditions where the position is uncertain itself or not computed. GPS+EGNOS+S-QZSS constellation provide a continuous service but they couldn't guarantee high accuracy: VSN>5 probability is near to 100% but GDOP<6 probability is about 55%. In third urban masking scenario (Fig. 28) the positioning service is not always guaranteed.

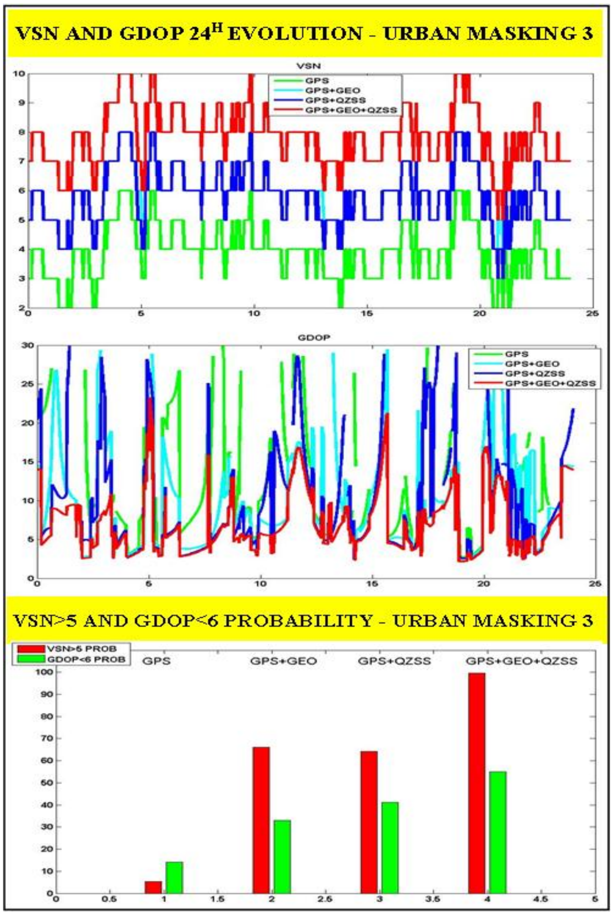

Fig. 28: Coverage evolution with very strong masking (Naples)

4. CONCLUSIONS

In this paper the coverage performances of four constellations are analysed: GPS, GPS+EGNOS, GPS+S-QZSS, GPS+EGNOS+S-QZSS. Coverage is globally examined; over european region, different masking angle conditions are considered. With a not severe environment, GPS constellation provides good coverage performances. In moderately adverse environment (masking up to 35°), EGNOS and S-QZSS constellations are useful augmentations. A wide service area, including Southern Europe and Africa can be defined, where the super-constellation GPS+EGNOS+S-QZSS guarantees good performances in terms of visibility and GDOP. In the near future we wish to simulate a theoretic constellation with orbital parameters suited to improve coverage performances at high latitude. The obtained results encourage the implementation of a European program dealing with launching of some geosynchronous satellites in order to improve navigation satellite coverage over Europe; such system could be used as gap-filler waiting Galileo system deployment.

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