МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра аеронавігаційних систем

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри

_____________Харченко В.П.

«__»____________ 2014р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬО-КВАЛІФІКАЦІЙНОГО РІВНЯ
«МАГІСТР»

Тема: «Позиціонування за далекомірними радіомаяками»

Виконавець: Лопатко Т.Б.

Керівник: Остроумов І.В.

Нормоконтролер: Ларін В.Ю.

Київ 2014

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Інститут аеронавігації

Кафедра аеронавігаційних систем

Спеціальність: 8.07010203 « Системи аеронавігаційного обслуговування»

ДОПУСТИТИ ДО ЗАХИСТУ

Завідувач кафедри

_____________Харченко В.П.

«__»______________2014р.

ЗАВДАННЯ

на виконання дипломної роботи

Лопатко Тетяни Богданівни

1. Тема дипломної роботи «Позиціонування за далекомірними радіомаяками» затверджена наказом ректора від 30 серпня 2013р. №1897/ст.

2. Термін виконання роботи: 28.10.2013 по 16.02.2014.

3. Вихідні дані до роботи:

- міжнародні стандартизуючи документи ICAO, Eurocontro, FAA;
- інформація аеронавігаційних баз даних.

4. Зміст пояснювальної записки: аналіз систем та принципів альтернативної навігації, основні вимоги до системи позиціонування, дослідження доступності позиціонування за DME/DME методом для повітряного простору України, проведення аналізу точності позиціонування.

5. Перелік обов'язкового графічного (ілюстративного) матеріалу: графіки, таблиці, формули.

6. Календарний план-графік

№ п/п	Завдання	Термін виконання	Відмітка про виконання
1.	Підготовка та написання 1 розділу «Засоби навігації та визначення відстані»	30.10.13-15.11.13	виконано
2.	Підготовка та написання 2 розділу «Позиціонування повітряного корабля в просторі»	16.11.13-30.11.13	виконано
3.	Підготовка та написання 3 розділу «Позиціонування за далекомірним обладнанням»	31.11.13-18.12.13	виконано
4.	Підготовка та написання 4 розділу «Оцінка точності позиціонування для повітряного простору України»	19.12.13-14.01.14	виконано
5.	Підготовка презентації та доповіді	15.01.14-31.01.14	виконано

7. Дата видачі завдання: « 28 » жовтня 2013 р.

Керівник дипломної роботи ________________ Остроумов Іван Вікторович

(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання _______________ Лопатко Тетяна Богданівна

(підпис студента) (П.І.Б.)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Позиціонування за далекомірними радіомаяками»: 113 сторінок, 54 рисунки, 2 таблиці ,49 використаних джерел, 1 додаток.

Об'єкт дослідження – альтернативні методи позиціонування.

Предмет дослідження – метод оцінки точності та доступності позиціонування за далекомірним обладнанням для повітряного простору України.

Мета роботи – оцінка точності доступності позиціонування за сигналами далекомірних радіомаяків за DME/DME методом для повітряного простору України у випадку позиціонування за двома радіомаяками та за всіма наявними.

Метод дослідження – комп'ютерне моделювання.

Наукова новизна полягає в наступному: за допомогою спеціально створеної програми здійснено аналіз доступності DME станцій, які в даний час доступні на території України. Проведено оцінку точності позиціонування за всіма одночасно доступними DME. Для перевірки даних, отриманих в процесі дослідження, було використано програмне забезпечення DEMETER(DistancE Measuring Equipment TracER) створене EUROCONTROL для відтворення та аналізу процесів пов'язаних з впровадженням концепції PBN.

Розвиток альтернативних методів позиціонування, зокрема DME/DME позиціонування, є одним із важливих етапів на шляху впровадження прийнятих концепцій структури повітряного простору країни. На сьогоднішній день уже існує налагоджена мережа DME станцій по всій території, тому значно дешевше і швидше буде розробити нові алгоритми роботи для даного типу обладнання ніж впроваджувати абсолютно нову.

НАВІГАЦІЯ, ПОЗИЦІОНУВАННЯ, МЕТОД, ДОСТУПНІСТЬ, ДАЛЕКОМІРНІ МАЯКИ, DME/DME ПОЗИЦІОНУВАННЯ, ТОЧНІСТЬ ПОЗИЦІОНУВАННЯ, ОЦІНКА.

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY

Air Navigation System Department

PERMISSION TO DEFEND
GRANTED
Head of the Department
___________V.P. Kharchenko

«__»_________________2014

MASTER'S DEGREE THESIS

Theme: «Positioning by distance measuring equipment»

Completed by: Lopatko T.B.

Supervisor: Ostroumov I.V.

Standarts Inspector: Larin V.Yu.

Kyiv 2014

NATIONAL AVIATION UNIVERSITY

Institute of air navigation

Air Navigation Systems Department

Specialty: 8.07010203 « Systems of Aeronavigation Service »

APPROVED BY

Head of the Department

_____________ V.P. Kharchenko

«__»___________________2014

Graduate Student's Degree Thesis Assignment

Lopatko Tetyana

1. The Project topic: «Positioning by distance measuring equipment» approved by the Rector's order of « 30 » August 2013 № 1897/st

2. The Project to be completed between: 28.10.2013 – 16.02.2014.

3.Initial data to the project:

- International standardizing documents ICAO, Eurocontro, FAA;
- Aeronautical information database.

4. The content of the explanatory note (the list of problems to be considered): analysis of systems and principles of alternative navigation, basic requirements for positioning systems, the study of accessibility positioning DME / DME method for airspace Ukraine, analysis of accuracy of positioning.

5. The list of mandatory graphic (illustrated) materials: graphs, tables, formulas.

6. Calendar timetable

№ п/п	Completion stages of Degree Project	Stage completion dates	Remarks
1	Preparation of chapter 1: « Navigation aids and distance measurement »	30.10.13-15.11.13	completed
2	Preparation of chapter 2: « Positioning of aircraft in airspace »	16.11.13-30.11.13	completed
3	Preparation of chapter 3:« Positioning by distance measuring equipment»	31.11.13-18.12.13	completed
4	Preparation of chapter 4: « Accuracy estimation for Ukraine airspace »	19.12.13-14.01.14	completed
5	Preparation of report and graphic materials	15.01.13-31.01.14	completed

8. Assignment accepted for completion «28» October 2013

Supervisor____I.V.Ostroumov

Assignment accepted for completion ______________________T.B. Lopatko

ABSTRACT

Explanatory note to the master's thesis, « Positioning by distance measuring equipment »: 113 pages, 54 figures, 1 table, 49 references, 1 appendix.

Investigation object – alternative positioning technique, particularly by using distance measuring equipment.

Investigation subject – method of accuracy and availability estimation for positioning by distance measurement equipment for Ukrainian airspace.

Purpose of the work – estimation of accuracy of positioning by the DME/DME method for Ukraine, in the case of the availability of more than two stations.

Investigation method – computer based imitation simulation method.

Scientific innovation is the following : using a specially created program was analyzed the availability of DME stations that are currently available in Ukraine.Estimation of the accuracy of positioning by all DME stations. To verify the data obtained as a result of the work was used DEMETER(DistancE Measuring Equipment TracER) program made by EUROCONTROL.

The new step for future structure of Ukraine airspase is development of DME/DME positioning method like one of alternative positioning technique. Each DME provides a true range measurement and so two or more DME ranges can provide horizontal positioning and area navigation capability. Scanning DME or DME/DME supports this functionality. Additionally, it is attractive from a stakeholder perspective because it is an operational system and major air carriers already carry DME/DME.

NAVIGATION, POSITIONING, METHOD, AVAILABILITY, DISTANCE MEASURING EQUIPMENT, DME/DME POSITIONING, POSITIONING ACCURACY, ESTIMATION.

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LIST OF ABBREVIATIONS AND EXPLANATION OF TERMS

ADF - Automatic Direction Finder

AM - Amplitude Modulated

ANSP - Air Navigation Service Provider

CDU - Control Display Unit

CNS - Communication, Navigation, Surveillance

ATM - Air Traffic Management

DME - Distance Measuring Equipment

DME/N - Narrow Distance Measuring Equipment

DME/P - Precision Distance Measuring Equipment

DME/W - Wide Distance Measuring Equipment

DOC - Designated Operational Coverage

DOP - Dilution Of Precision

ECEF - Earth-Centered, Earth-Fixed coordinate system

EPU - Estimated Position Uncertainty

ERP - Effective Radiated Power

FIS - Flight Instrument System

FMS - Flight Management System

GDOP - Geometric Dilution of Precision

GNSS - Global Navigation Satellite System

GPS - Global Positioning System

HDOP - Horizontal Dilution of Precision

ICAO - International Civil Aviation Organization

IFR - Instrument Flight Rule operations.

ILS - Instrument Landing System

IMA - Integrated Modular Avionics cabinet

IMC - Instrument Meteorological Conditions

LF - Low-Frequency

MF - Medium-Frequency

LLA - latitude, longitude and elevation system

LSSIP - Local Single Sky ImPlementation

NED North-East-Down coordinate system

NDB - Non-Directional Beacon

PBN - Performance Based Navigation

RNP - Required Navigation Performance

PPS - Pulse Pairs per Second

PRF - Pulse Repetition Frequency

TACAN - Tactical Air Navigation System

TDOA - Time Difference of Arrival

TDOP - Time Dilution of Precision

TOA - Time of Arrival

VHF - Very High Frequency

VDOP - Vertical Dilution of Precision

VOR - VHF omnidirectional range

UERE User Equivalent Range Error

INTRODUCTION

Thesis actuality. As is known, the demand for aviation services is growing every year. Accordingly, ICAO adopted a new service concept for future aviation. Primary objective of ICAO is that of ensuring the safe and efficient performance of the global Air Navigation System.

Resolution adopted by the ICAO Assembly on 37th session 2010 affirms new requirements to the organization of airspace structure. Resolution A33-16 requested the Council to develop a programme to encourage States to implement of positioning system and approach procedures with vertical guidance utilizing such inputs as GNSS or distance measuring equipment (DME)/DME, in accordance with ICAO provisions[22].

According to proposed approach, efforts should be focused on improving safety through the use of multiple satellite sistem GNSS and use of terrestrial infrastructure. Terrestrial infrastructure will implement as a means of alternative navigation.

According to the plan of implementation of developed RNAV procedures in Ukraine - to 2025 VOR and NDB systems will gradually put out of operation. As stated in the plan of implementation PBN in Ukraine, DME will remain in operation as a backup tool for the implementation of operations in the case of unavailability of GNS systems because of the impact of interference or other obstacles.

Consequently, the actual is evaluation of the current state of DME stations in Ukraine and the possibility of positioning by available DME by the DME/DME method.

Thesis relation with scientific research programs, schedules and themes

Scientific research was done in the framework of international fundamental researches of FAA and Eurocontrol.

Investigation object – alternative positioning technique, particularly by using distance measuring equipment.

Investigation subject – method of accuracy and availability estimation for positioning by distance measurement equipment for Ukrainian airspace.

Purpose of the work – estimation of accuracy of positioning by the DME/DME method for Ukraine, in the case of the availability of more than two stations.

Investigation method – computer based imitation simulation method.

Science research novelty is in using a specially created program was analyzed the availability of DME stations that are currently available in Ukraine.Estimation of the accuracy of positioning by all DME stations.

Practical results of science research. The result of simulation are shown on special graphs. To verify the data obtained as a result of the work was used DEMETER(DistancE Measuring Equipment TracER) program made by EUROCONTROL.

Results of research which were set out in this work was published in Theoretical and applied science journal engineering academy of Ukraine issue 4 in 2013, represented in diferent scientific conferences and has got a patent.

5.4.5. ECEF and Local NED Coordinate Systems

The position transformation from the ECEF frame to the local NED frame is required together with the transformation from the geodetic system to the ECEF frame to form a complete position conversion from the geodetic to local NED frames.

More specifically, we have

$$P_n = R_{n/e}(P_e - P_{e,ref}) \tag{5.36}$$

where $P_{e,ref}$ is the position of the origin of the local NED frame (i.e., O_n, normally the takeoff point in UAV applications) in the ECEF coordinate system, and Rn/e is the rotation matrix from the ECEF frame to the local NED frame, which is given by

$$R_{n/e} = \begin{bmatrix} -\sin\varphi_{ref}\cos\lambda_{ref} & -\sin\varphi_{ref}\sin\lambda_{ref} & \cos\varphi_{ref} \\ -\sin\lambda_{ref} & \cos\lambda_{ref} & 0 \\ -\cos\varphi_{ref}\cos\lambda_{ref} & -\cos\varphi_{ref}\sin\lambda_{ref} & -\sin\varphi_{ref} \end{bmatrix} \tag{5.35}$$

and where $\lambda_{ref}$and φ_{ref} are the geodetic longitude and latitude corresponding to $P_{e,ref}$.

5.5. Simulation for ukranian airspace

On chapter 5.3 was described program for modeling the availability of DME stations in Ukraine and estimation of DOP coefficients.This program was used for simulation of issues which explored in this work.

In program used information about all ukrainian DME stations according to AIP. In table 5.1. represents data about available DME stations.

Table 5.1 – DME beacons in Ukraine

№	**Latitude**	**Longitude**	**Identification**	**Title**
1	485303.0N	0244129.0E	IVF	IVANO-FRANKIVS'K
2	450306N	0335847E	SMF	SIMFEROPOL
3	510354N	0325312E	BAH	BAKHMACH
4	501708.5N	0305403.5E	BRP	BORYSPIL
5	482135.4N	0350611.0E	DNP	DNIPROPETROVS'K
6	480429.0N	0374058.0E	DON	DONETS'K
7	495544.1N	036*1810.2E*	IHA	KHARKIV
8	502359.9N	0302626.5E	IKI	KYIV/ZHYLIANY
9	502404.0N	0302744.4E	IKV	KYIV/ZHYLIANY
10	505645.5N	0305840.1E	KSN	KOSHANY
11	480304N	0331244E	KVR	KRYVYI RIH
12	494843.0N	0235705.0E	LIV	L'VIV
13	470431.29N	0372708.06E	MRP	MARIUPOL'
14	462549.0N	0304015.0E	ODS	ODESA
15	501112.5N	0293412.5E	SLV	SOLOVIIVKA
16	492418.7N	0310436.4E	STB	STEBLIV
17	491424.0N	0283715.0E	VIN	VINNYTSIA
18	501554.4N	0314740.3E	YHT	YAHOTYN

The simulation was made for two altitudes: 9753 m and 6000 m.

Estimation of availability of DME/DME positioning for Ukrainian airspace for altitude 9753 m have been represented at figure below:

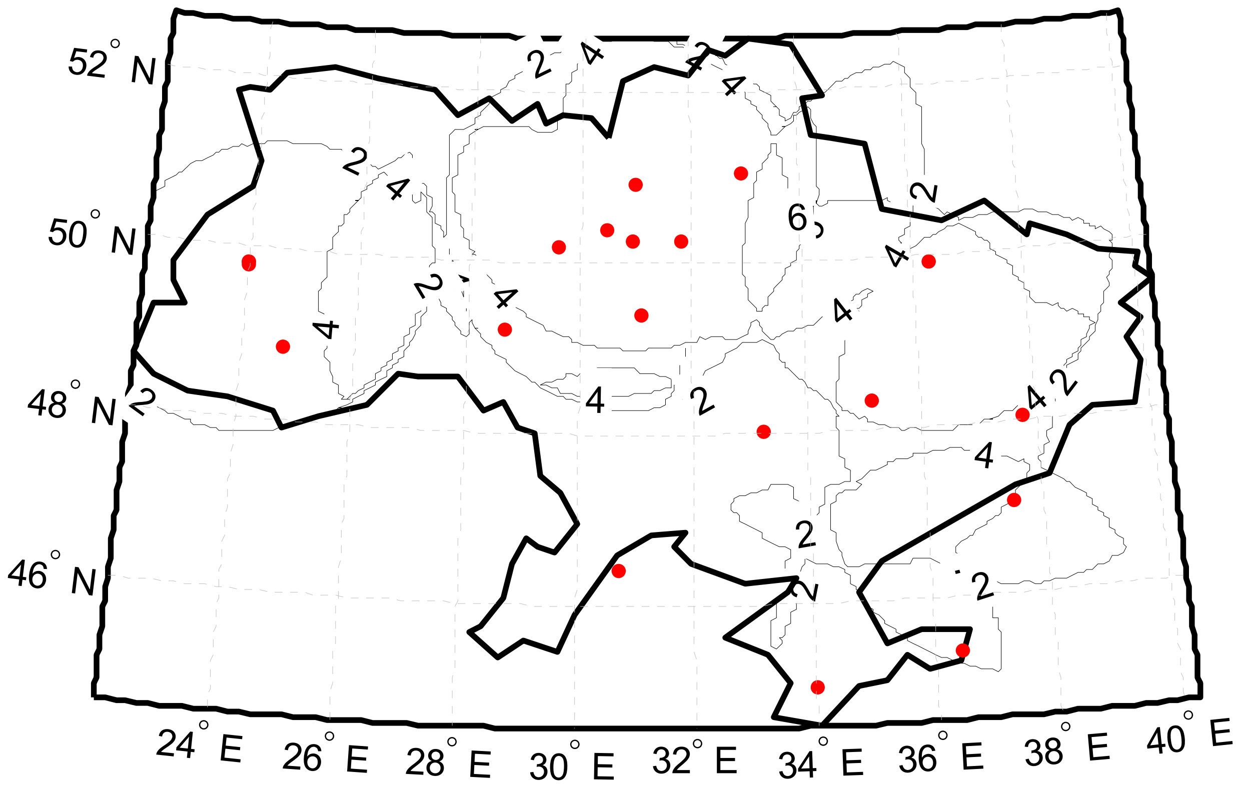

Figure 5.7 – Availability of DME / DME navigation in Ukraine airspace for altitude 9753 m using Ukrainian DME stations

Overall positioning accuracy by DME beacons depends on the geometry of the location of the ground equipment, areas of performance and accuracy of navigation equipment DME. The influence of the geometry of the arrangement of ground equipment are taken into account by DOP (Dilution Of Precision).

Contour lines on fig. 5.7 and fig. 5.8 display zone with the corresponding values of the coefficients HDOP and VDOP. The results of simulation shows areas where HDOP <1. It's means increasing of accuracy according to the successful geometry of location of ground stations.

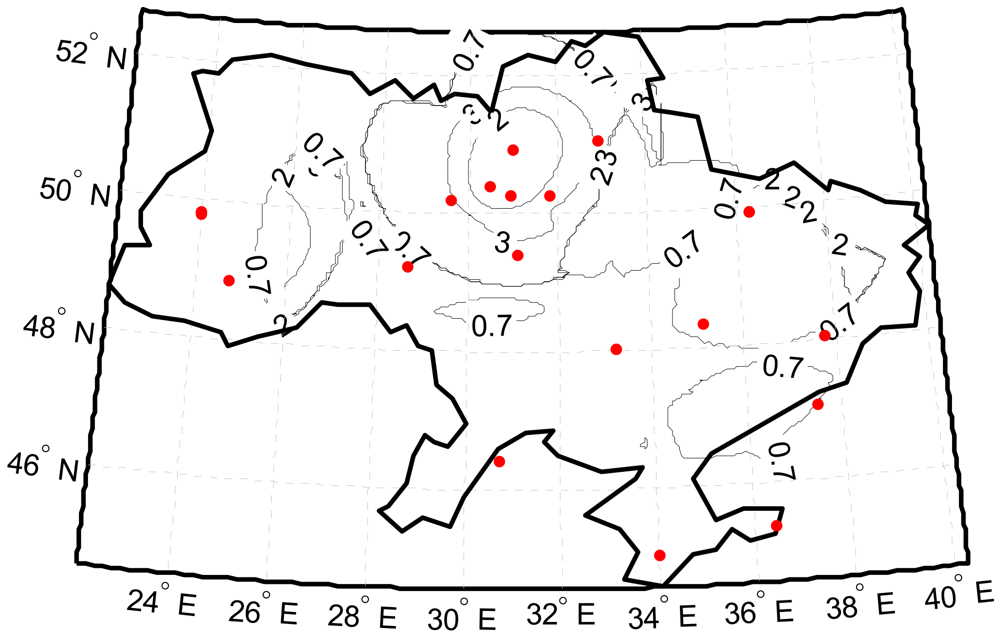

Figure 5.8 – Geometric dilution of precision factor
in the horisontal plane for altitude 9753 m

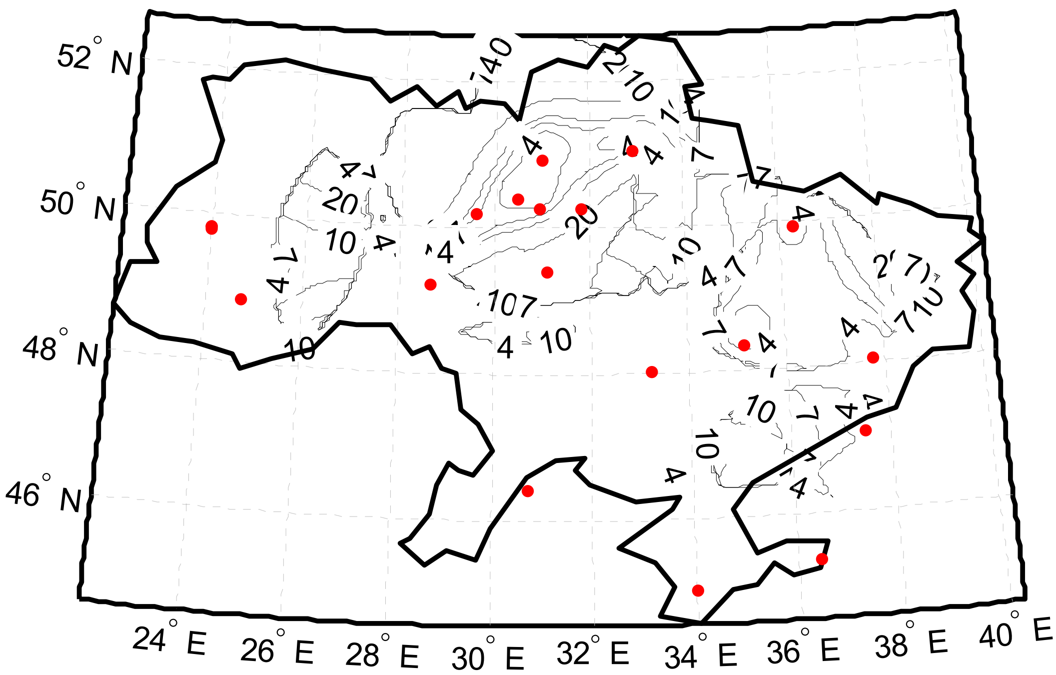

Figure 5.9 – Vertical DOP factor for altitude 9753 m

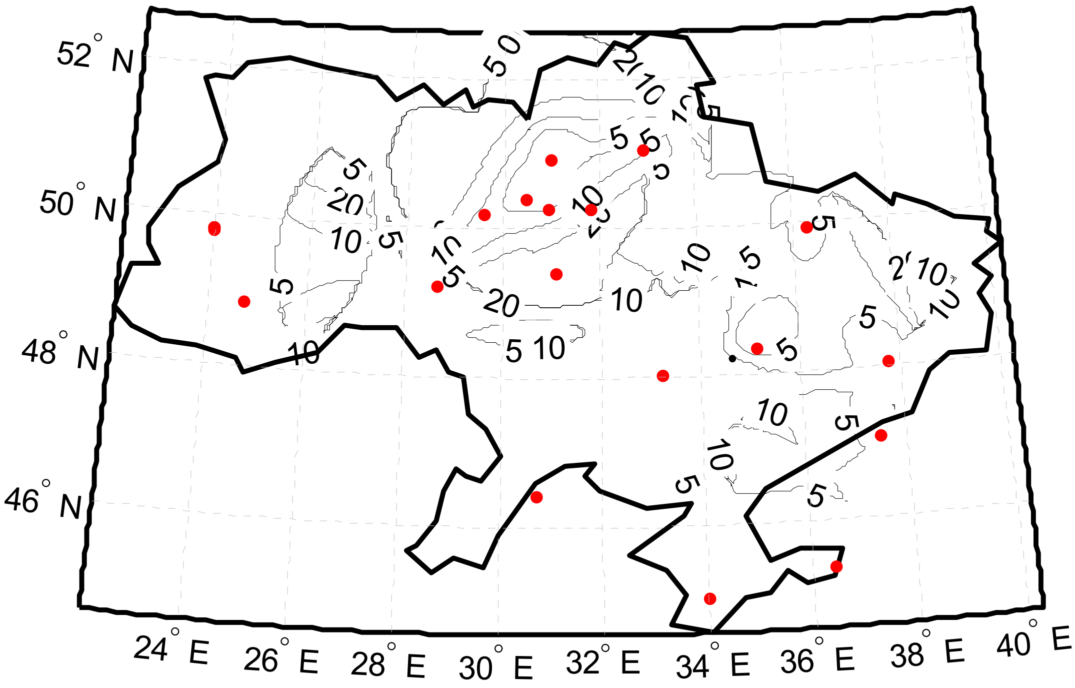

Figure 5.10 – Position DOP factor for altitude 9753 m

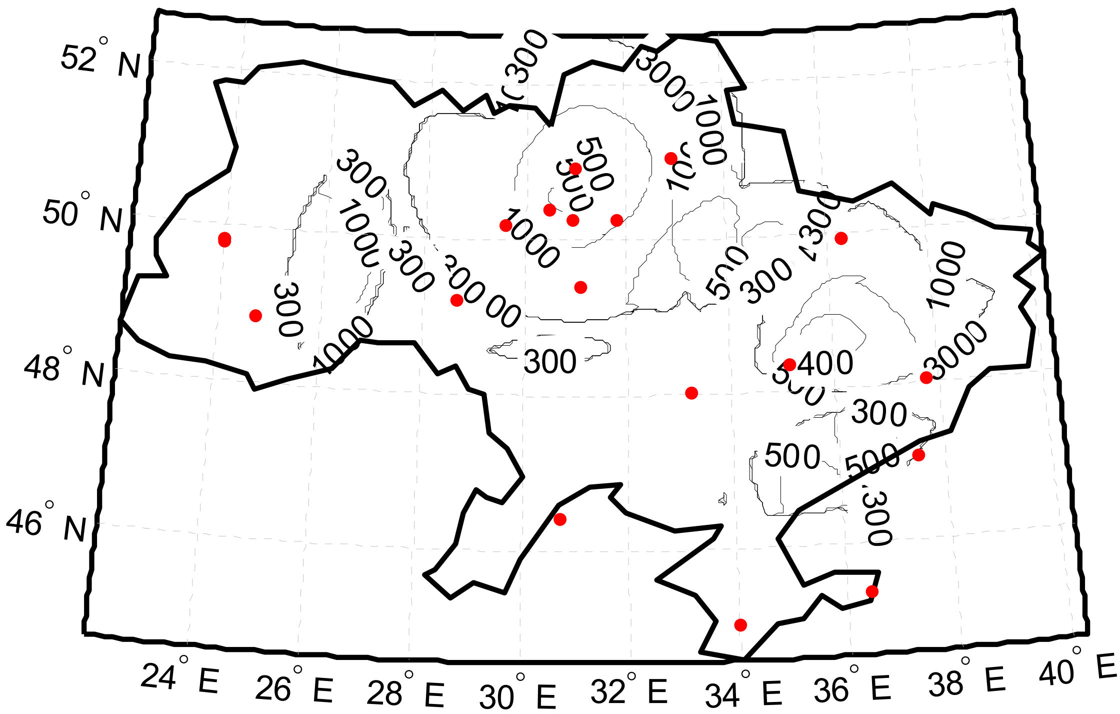

Figure 5.11 – Overall accuracy for positioning by all available Ukrainian DME station for altitude 9753 m

The fig. 5.11 shows the areas with total error for positioning by all available Ukrainian DME station. As could be seen, there are areas where we need more station for accurate positioning. For solving this problem was used DME stations of neighboring states. This also increased the accuracy.

On the figures below shows the results of simulations for DME/DME positioning by all available stations (including foreign).

Estimation of availability of DME/DME positioning for altitude 9753 m when are used Ukrainian and foreign DME stations:

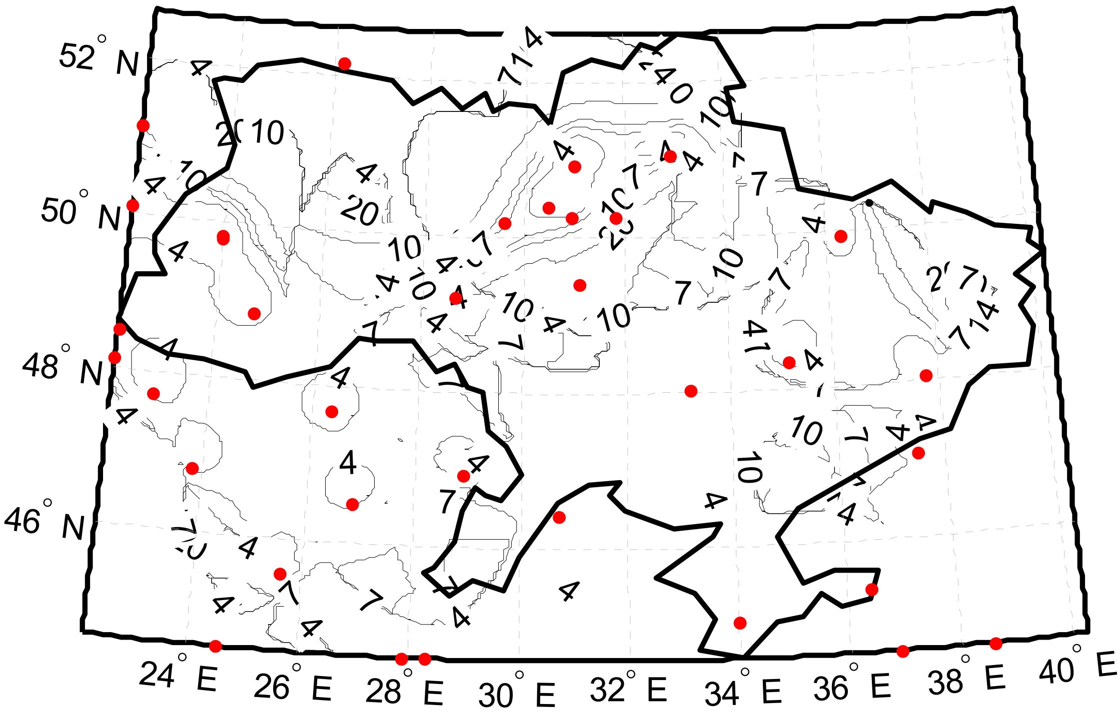

Figure 5.12 – Availability of DME / DME navigation for altitude 9753 m

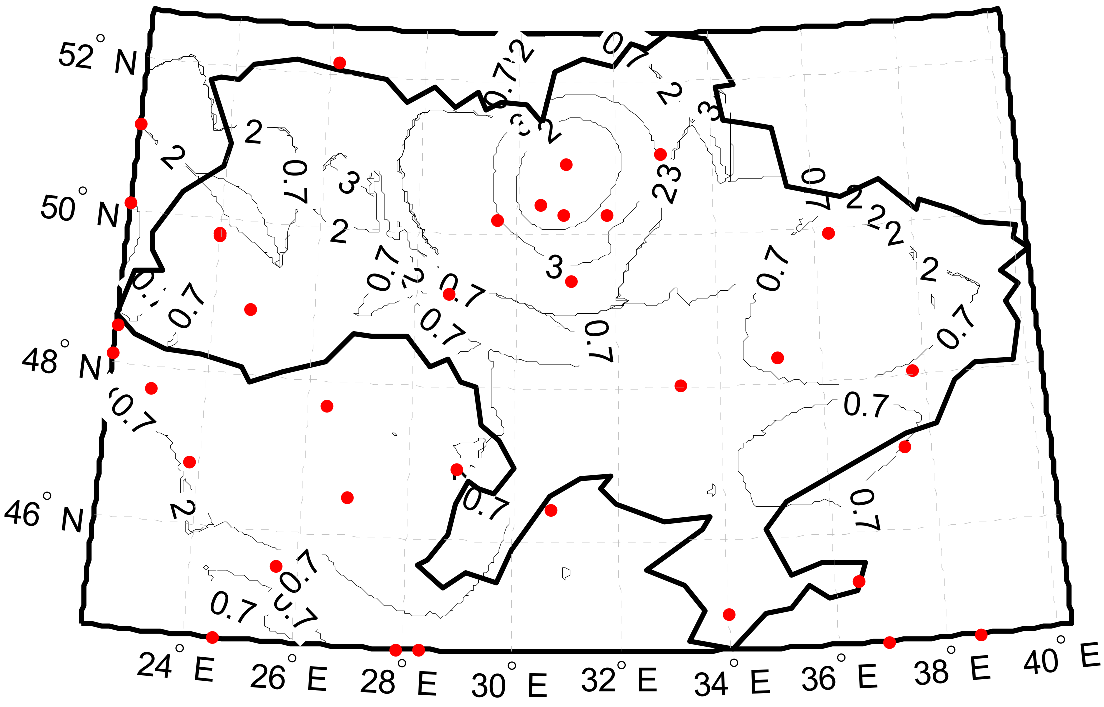

Figure 5.13 – Geometric dilution of precision factor in the horizontal plane for altitude 9753 m

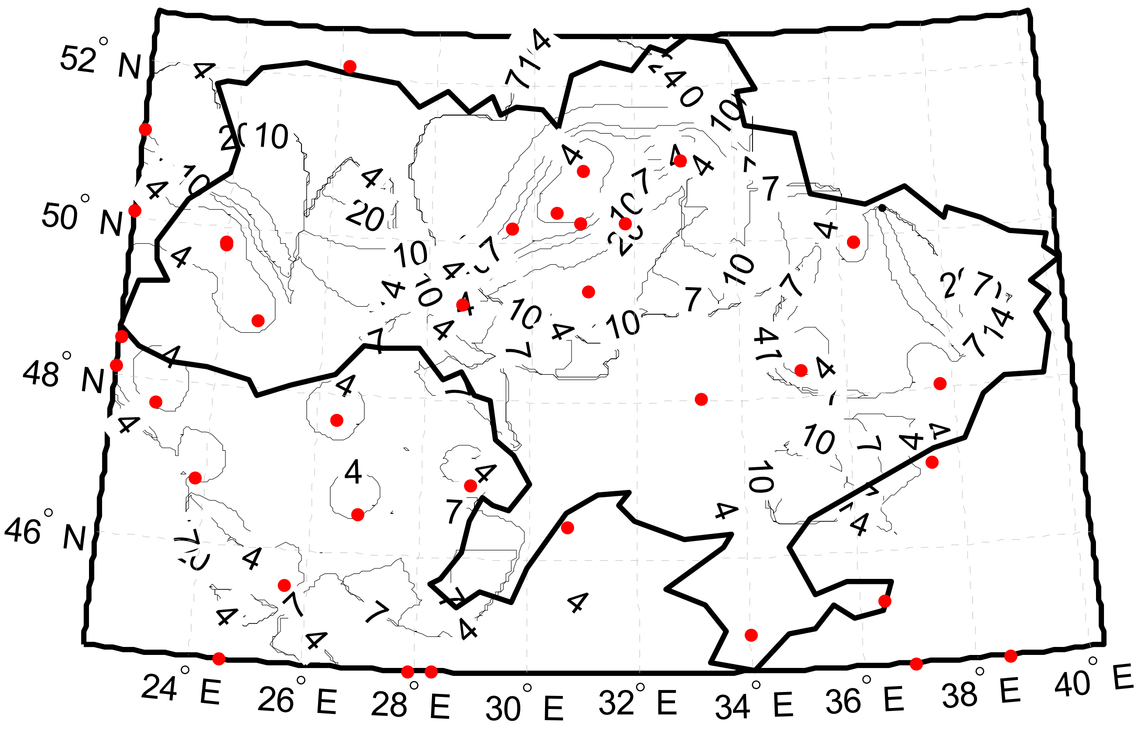

Figure 5.14 – VDOP factor for altitude 9753 m

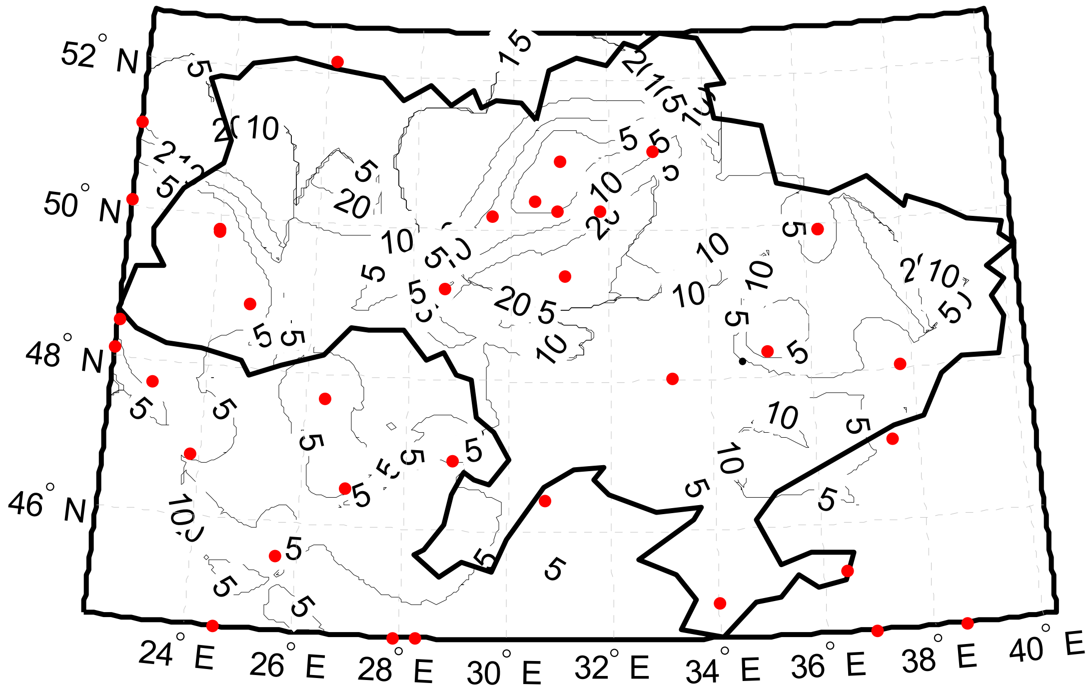

Figure 5.15 – PDOP factor for altitude 9753 m

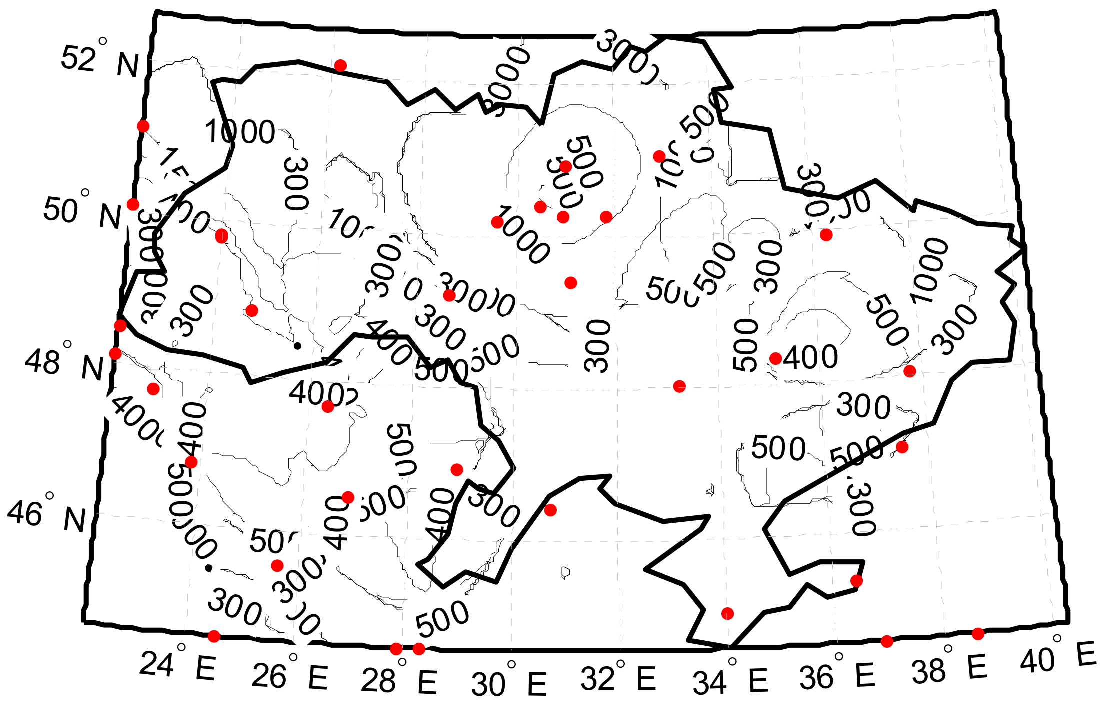

Figure 5.16 – Overall accuracy for positioning by all available Ukrainian DME station for altitude 9753

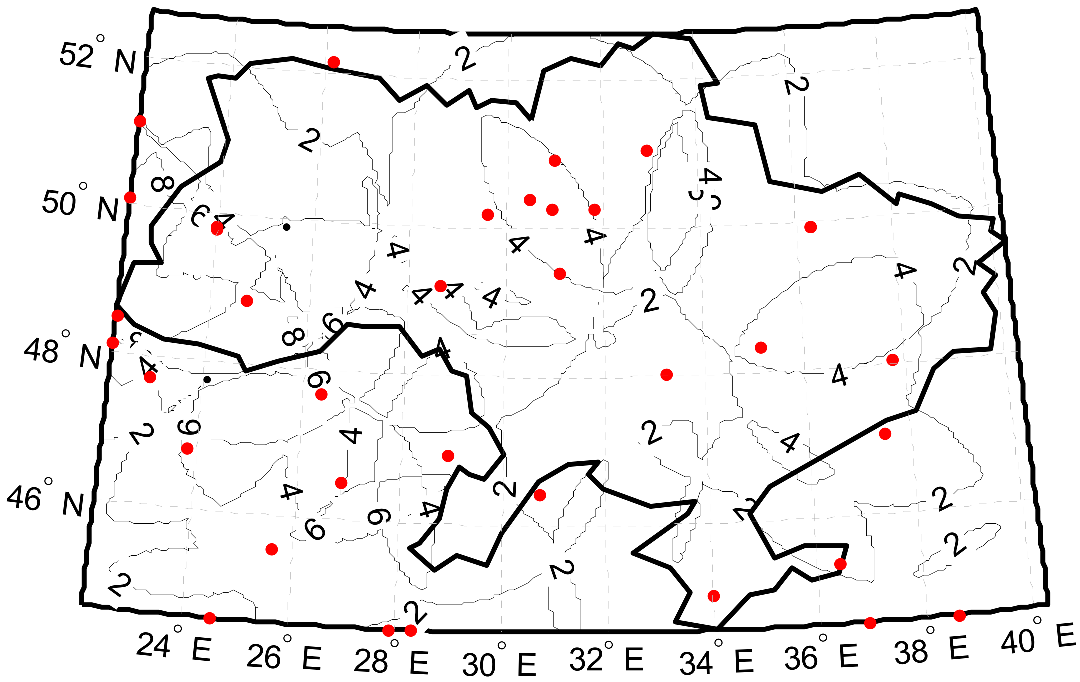

Figure 5.17 – Availability of DME / DME navigation in Ukraine airspace for altitude 6000 m

As can be seen from fig. 5.17, in the territory of Ukraine are available at the same time more than two beacons, so we can talk about the use of a positioning method for more than two DME beacons (DME / DME positioning).

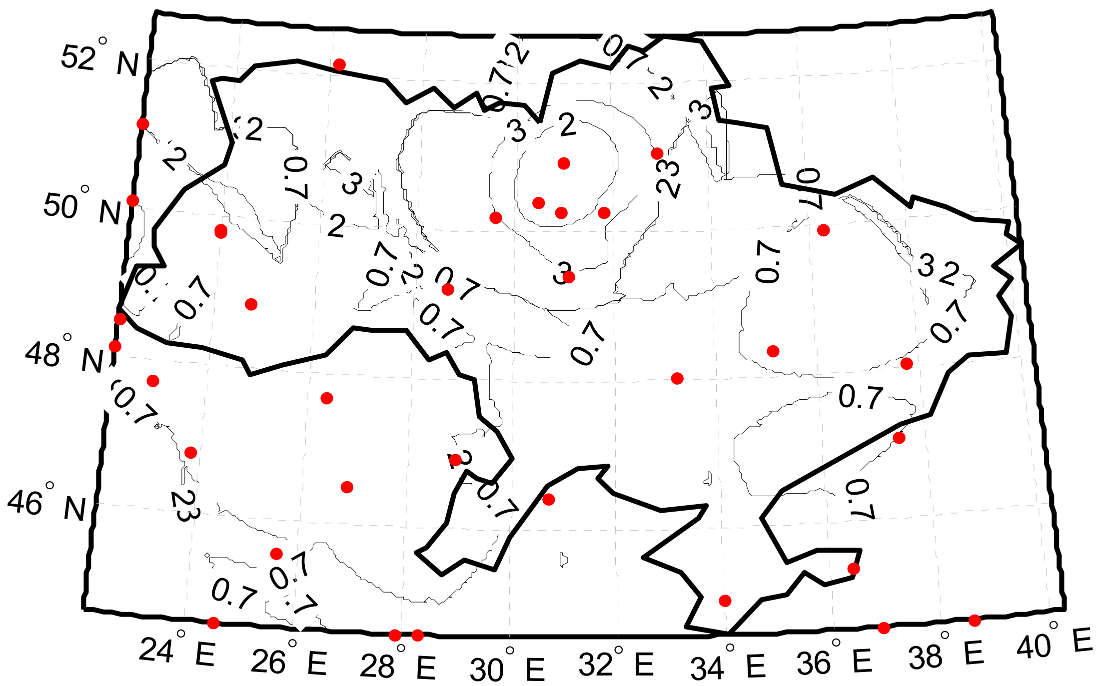

Figure 5.18 – Geometric dilution of precision factor in the horizontal plane for altitude 6000m

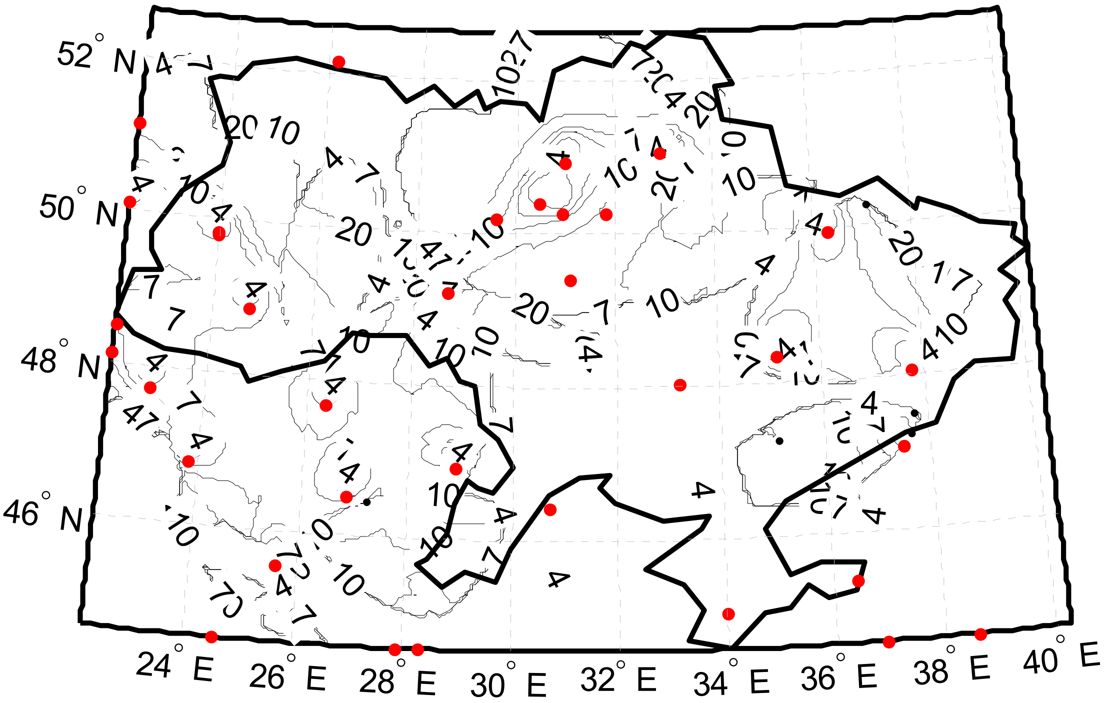

Figure 5.19 – VDOP factor for altitude 6000 m

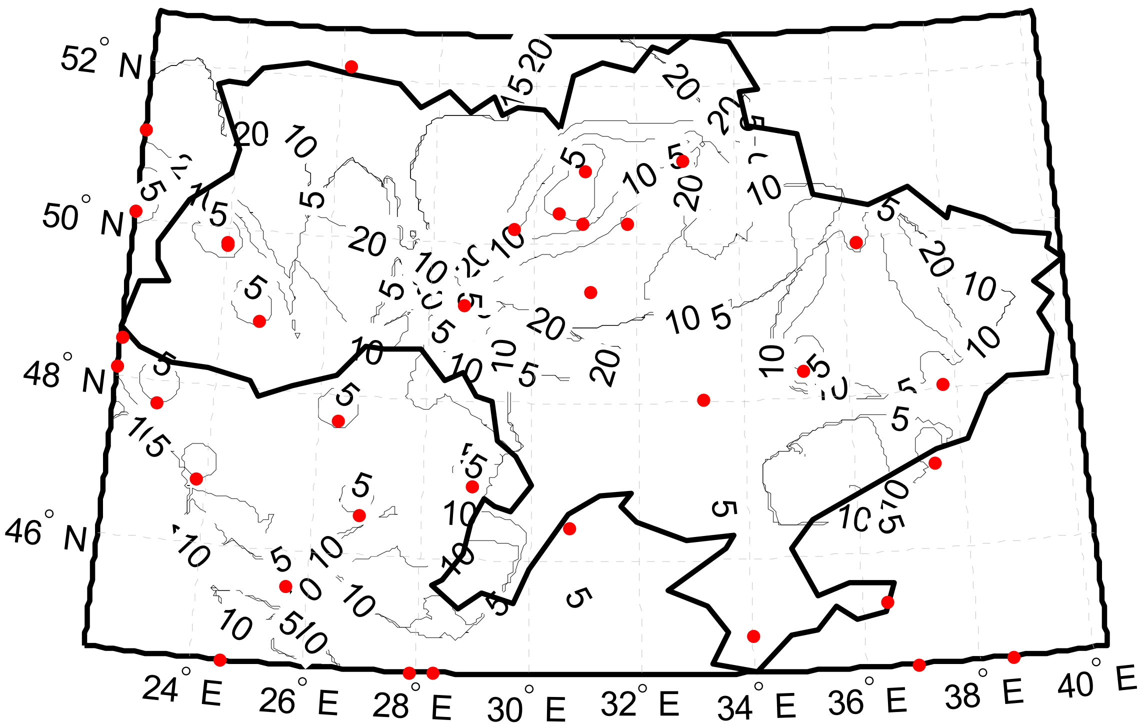

Figure 5.20 – PDOP factor for altitude 6000 m

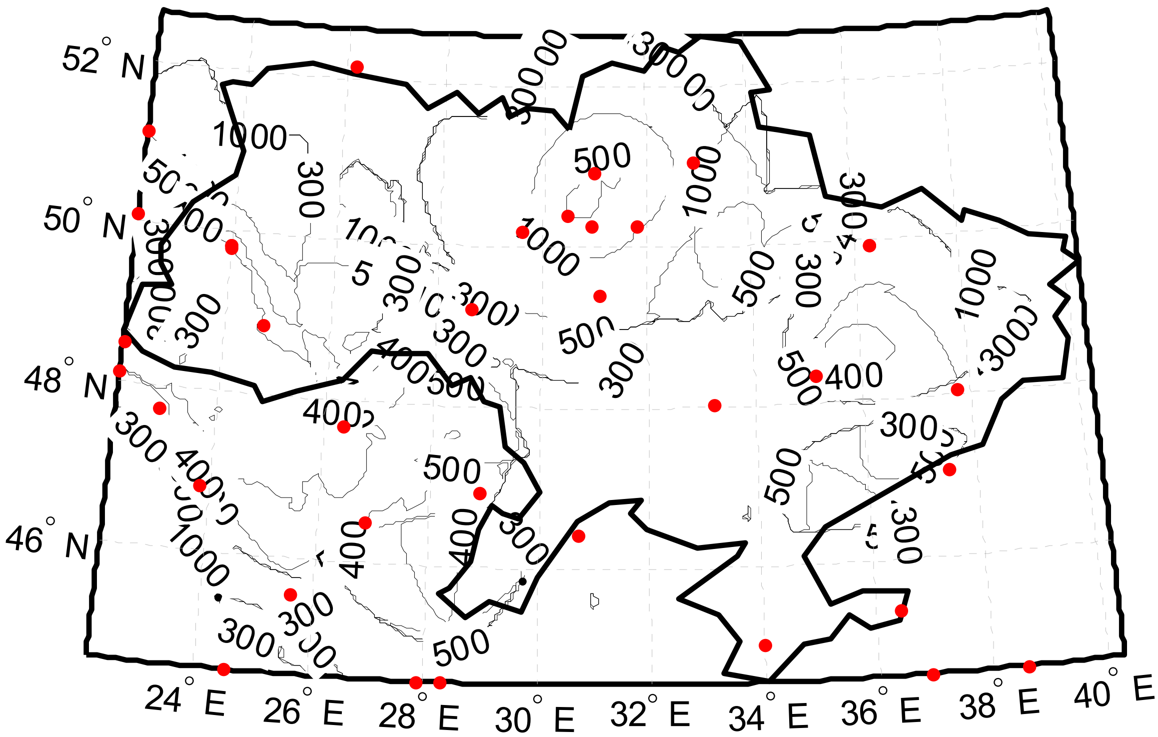

Figure 5.21 – Overall accuracy for positioning by all available Ukrainian DME station for altitude 6000 m

5.5. Result with validation with Demeter software

EUROCONTROL has created software DEMETER (DistancE Measuring Equipment TracER), which helps to reproduce and analyze the processes associated with the introduction of the concept of PBN [10].

It allows service providers to determine the minimum navigation infrastructure needed to support B-RNAV (or RNAV-5, by looking at VOR/DME) and P-RNAV (or RNAV-1, by looking at DME/DME navigation service). DEMETER uses a terrain database to determine facility coverage and processes the results by evaluating RNAV criteria according to the ICAO PBN Manual. Digital Terrain Elevation Data Levels 0, 1 and 2 can be processed [21].

After an upgrade project of 2 years completed in 2010 in coordination with stakeholders, DEMETER has been extended with a specific focus to integrate implementation processes. It allows the visualization of simulation results in the context of operational requirements that are set by airspace planners, and supports the planning of flight inspection. Flight inspection planning within DEMETER ensures that only the minimum set of DME need to be inspected. Any existing data can be collected on a single platform. Flexible interfaces allow importing flight inspection results to enable direct comparison between simulation and flight inspection. Thus the software enables the cooperation needed between airspace planners, procedure designers, Navaids engineers and flight inspectors. Furthermore, a Navaids database allows exchanging key technical data (not normally contained in AIPs) in a common format between Eurocontrol and ANSP stakeholders.

DEMETER ensures harmonized PBN implementation in accordance with the EUROCONTROL Guidelines for P-RNAV Infrastructure Assessment (EUROCONTROL-GUID-0114), which have been developed in cooperation with the ICAO Navigation Systems Panel (NSP). DEMETER is used by State PBN Implementers as well as SESAR projects, the latter with a view to establish DME-DME positioning as a ground based back-up solution to GNSS.

Main DEMETER features:

- Navaid database for VOR, DME, VOR-DME, TACAN, VORTAC and NDB. The database can be updated from both EAD and ARINC424 data files.
- High quality terrain database supporting GTOPO30 and DTED levels 0, 1 and 2. Best quality data available in the database is selected by the application and used for calculations. DEMETER comes with GTOPO30 and DTED level 0 data.
- Possibility to visualize terrain in 2D and 3D using NASA World-Wind (internet connection required to connect to NASA WorldWind database).
- Site analysis: horizon view and predicted coverage

DME-DME coverage and performance assessment (available pairs, subtended angle, redundancy and Navigation System Error-NSE). VOR-DME coverage and redundancy assessment [10].

- Procedure performance calculation giving the DME-DME redundancy along the procedure. The calculation takes into account the procedure width, the aircraft velocity and the 30 seconds rule.

- Procedure coverage report showing available DME pairs along the procedure. This feature supports the planning of Flight Inspections for defined procedures.
- Procedure coverage in vertical profile (by individual Navaids).
- Import of user layers in shapefile format
- Flight inspection data import function that allows the display of measured parameters and comparison of predicted and achieved coverage.
- Estimation of best location for a new DME site that together with the existing navigation infrastructure is to improve the DME-DME signal coverage in a designated area of interest [21].

DEMETER executes the performance calculation for an altitude specified by the user. The user can select 2 types of Performance calculations (DME-DME or VOR-DME). Depending on the performance type some calculations are performed:

- Coverage
- NavAid redundancy
- Name of Available NavAid pairs per zone
- Best subtended Angle
- Navigation System Error (NSE)

For the DME/DME performance all the calculations are executed. NavAid redundancy and Available NavAid pairs are calculated using the coverage area for each NavAid. For the Subtended Angle and NSE calculations the user specifies the minimum subtended angle allowed for the results (30º or 40º). DEMETER evaluates each point around the NavAids calculating the subtended angle for each available NavAid pair. If the best (highest) Subtended Angle value is smaller than the specified value the point is not considered for the calculations.

Simulation of DME coverage for Ukrainian airspace for altitude 9753 m (fig. 5.22)

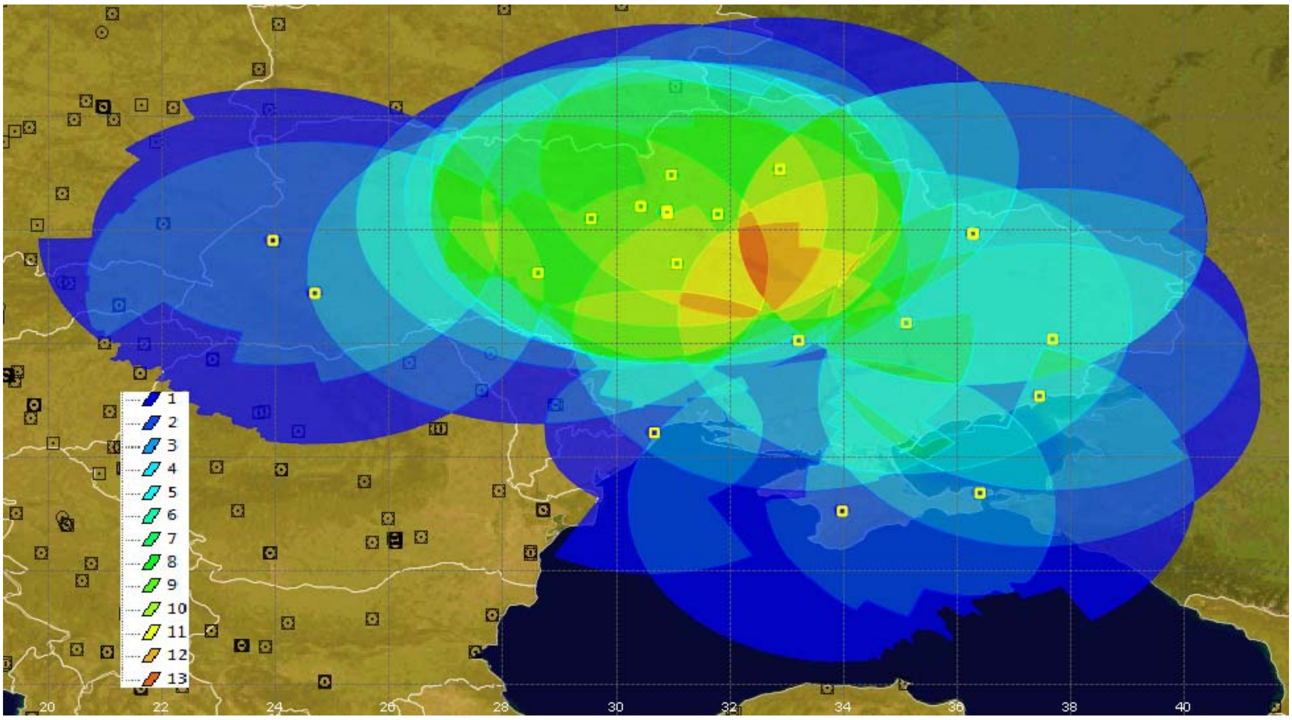

Figure 5.22 – DME coverage for Ukrainian airspace for altitude 9753 m

On layer's legend a different coloured area is used depending on the number of NavAids covering it. If selected NavAids area coverages do not overlap in any point the result will be only multiple zones with value 1 that corresponds to each NavAid individual coverage.

On the figure below is the results of calculating of Navigation System Error(NSE) (fig. 5.23). It represents the results given by this formula:

$$2\sigma_{DME1/DME2} \leq 2\frac{\sqrt{(\sigma^2_{DME1,air}+\sigma^2_{DME1,SIS})+(\sigma^2_{DME2,air}+\sigma^2_{DME2,SIS})}}{\sin(\alpha)} \quad (5.36)$$

$\sigma_{1,\,air}$ and $\sigma_{2,\,air}$ – error of determine the range for the first and second beacons (usually is 0.125% of range);

$\sigma_{1,\,sis}$ and $\sigma_{2,\,sis}$ – error of equipment (usually σ_{sis}=0,05 м.милі);

α – angle between the directions on the ground beacons(30°≤ α≤150°).

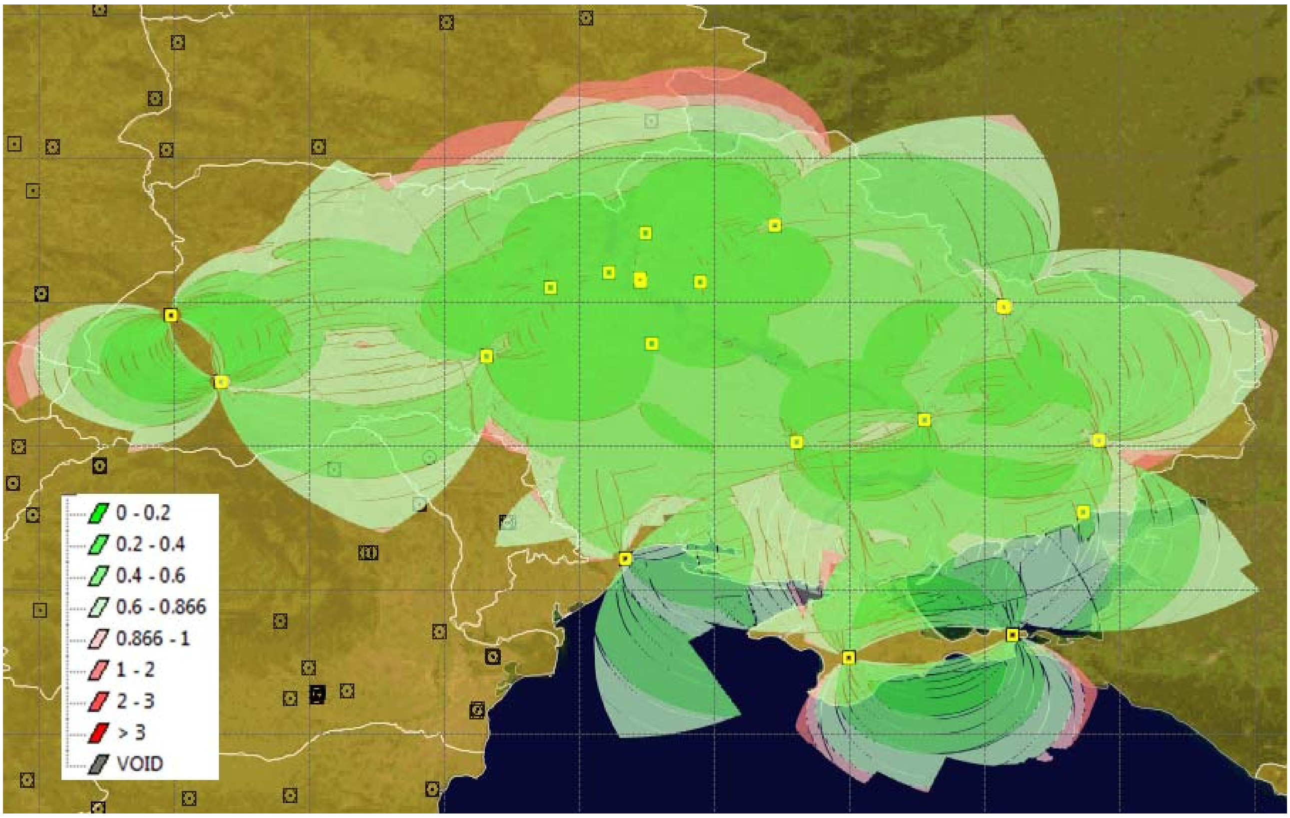

Figure 5.23 – NSE estimation for Ukraine airspace

Redundancy, as it is presented on the result layer legend, represents how many the coloured area in terms of redundancy:

- No coverage: there are no NavAid pairs covering that area.

- No Redundancy: there is only one NavAid pair covering that area.

- Limited Redundancy: there are two NavAids pairs covering that area but with a common

NavAid. There is one critical NavAid that, if it fails, the number of available pairs change to zero.

- Full Redundancy: there are two independent NavAid pairs covering that area. If any NavAid

fails (one at a time) the numbers of available pairs change to one.

- Excessive Redundancy: there are more than two independent NavAid pairs covering that area (fig. 5.24).

If any NavAid fails (one at a time) the numbers of available pairs is at least two.

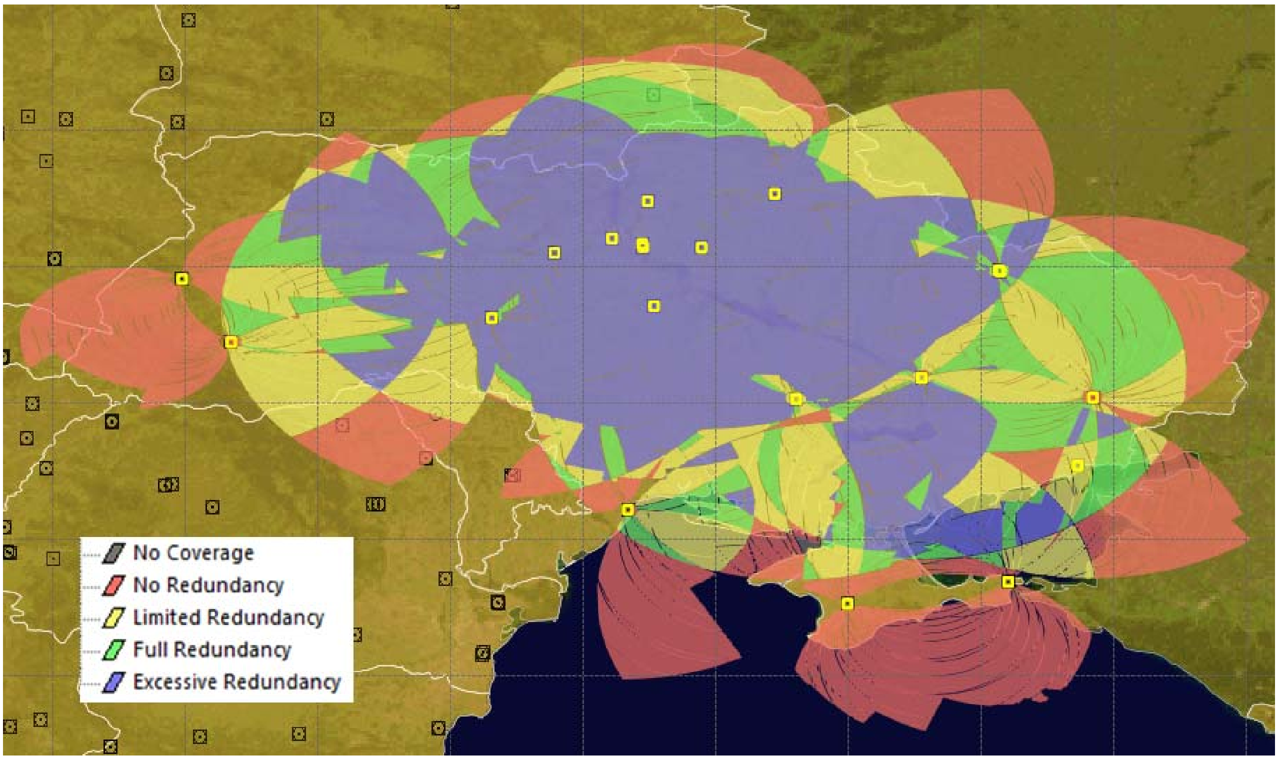

Figure 5.24 – Result of calculating redundancy for Ukraine airspace

Ther is a tool for calculating subtended angle. It shows the best subtended angle value on each point on the map analyzing the best NavAid pair from the list of selected NavAids. The result is divided in intervals of 10 degrees (fig. 5.25).

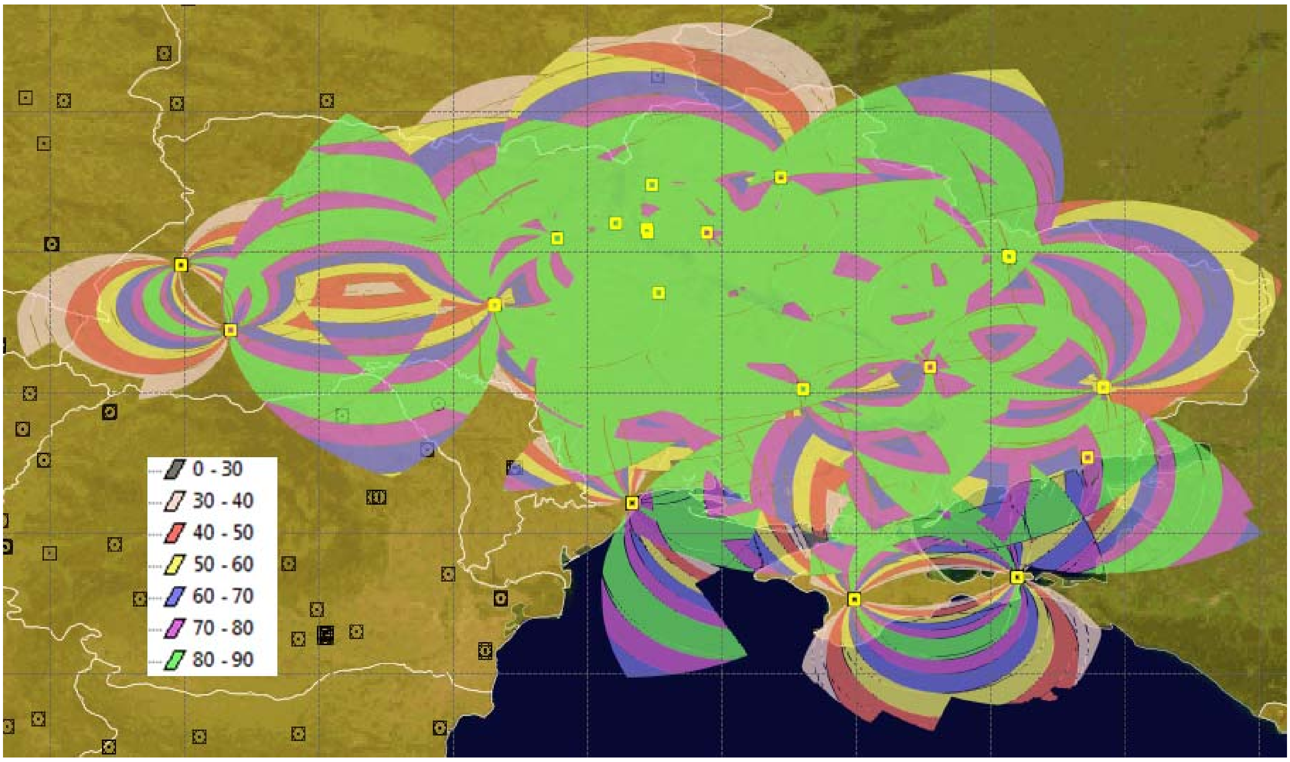

Figure 5.24 – Subtended angle results

Simulation of DME coverage for Ukrainian airspace for altitude 9753 m when native and foreign DME station are used (fig. 5.26)

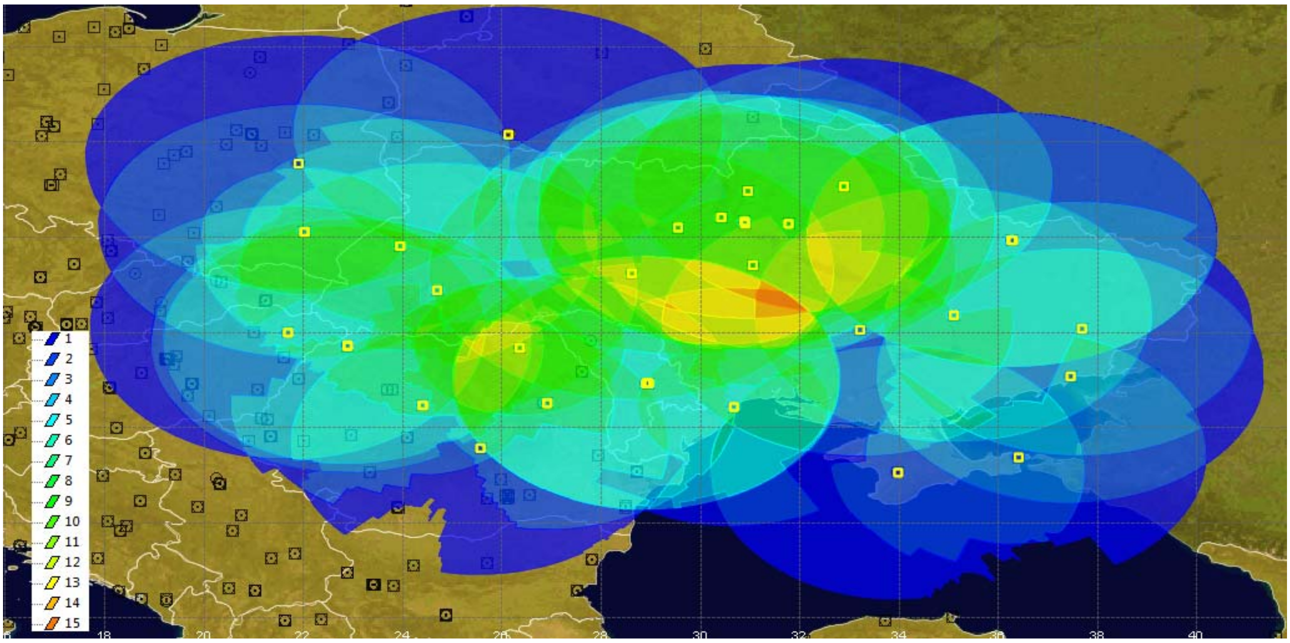

Figure 5.26 – NSE estimation for altitude 9753 m when national and foreign DME stations are used

On the figure below are shown results of the same simulations when are available DME stations of neighboring states for the same altitude (fig. 5.27, fig. 5.28, fig. 5.29).

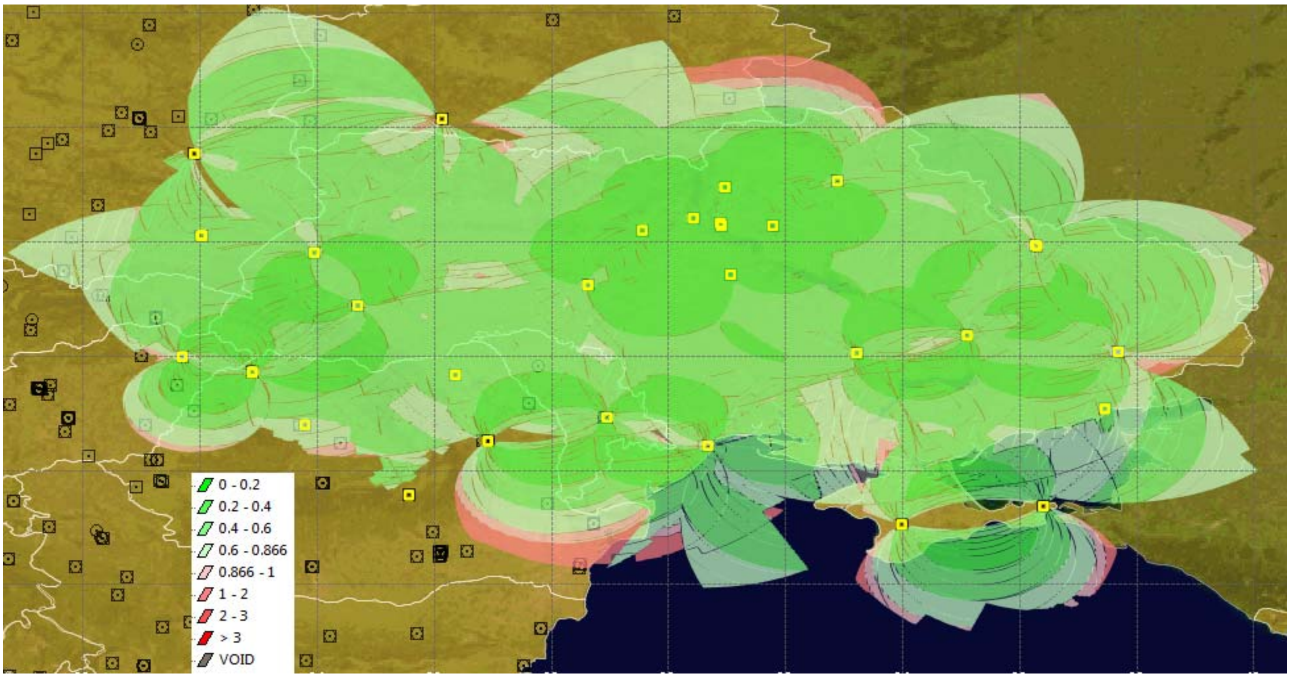

Figure 5.27 – NSE estimation for 9753 m when national and foreign DME stations are used

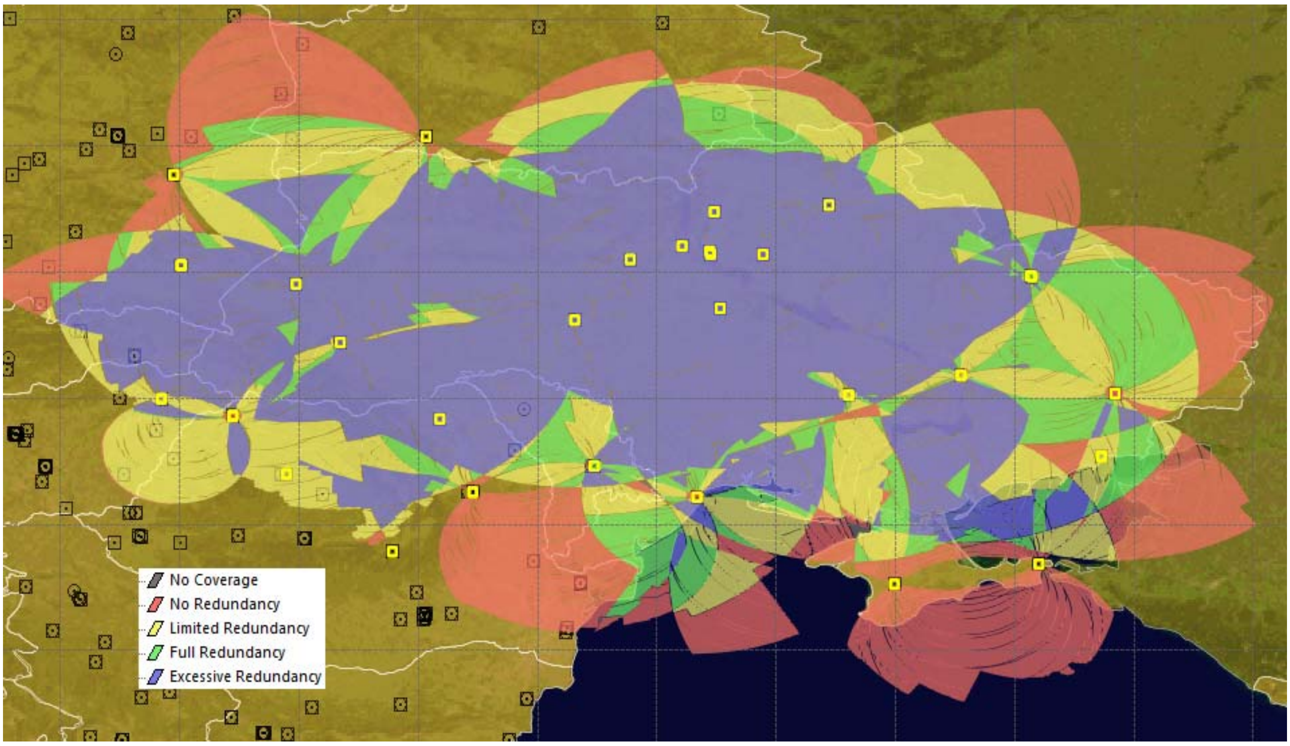

Figure 5.28 – Result of calculating redundancy for 9753 m when national and foreign DME stations are used

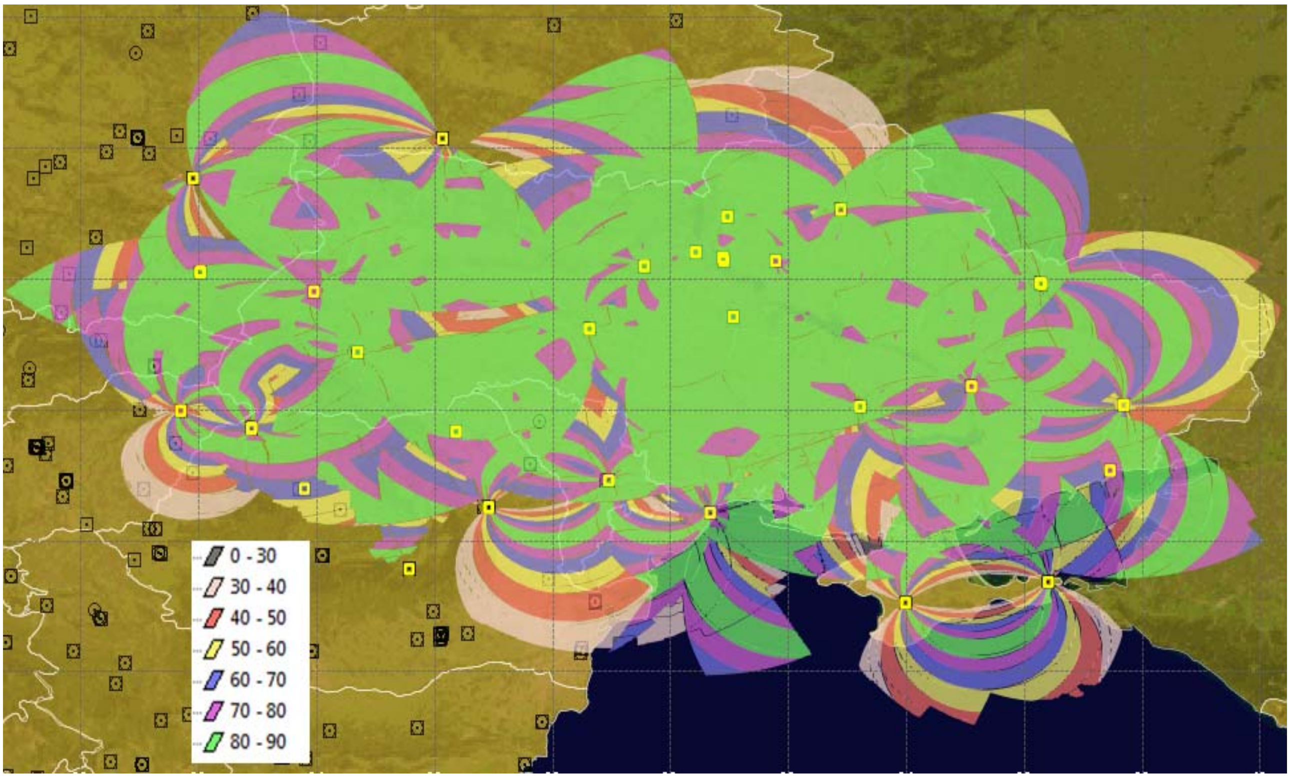

Figure 5.29 – Subtended angle results for 9753 m when national and foreign DME stations are used

Simulation of DME coverage for Ukrainian airspace for altitude 6000 m (fig. 5.30)

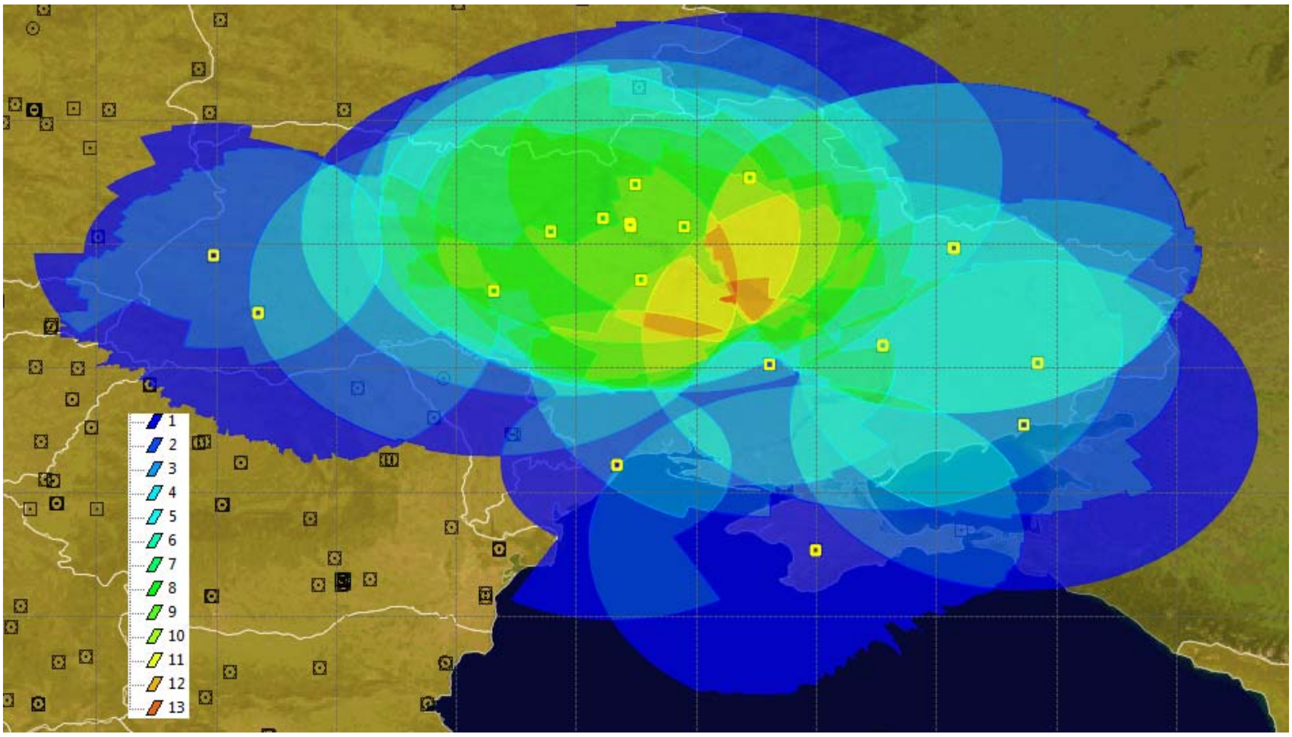

Figure 5.30 – DME coverage for Ukrainian airspace for altitude 6000 m

On the figure below are shown results of the simulations for altitude 6000 m when are available national DME stations (fig. 5.31, fig. 5.32, fig. 5.33).

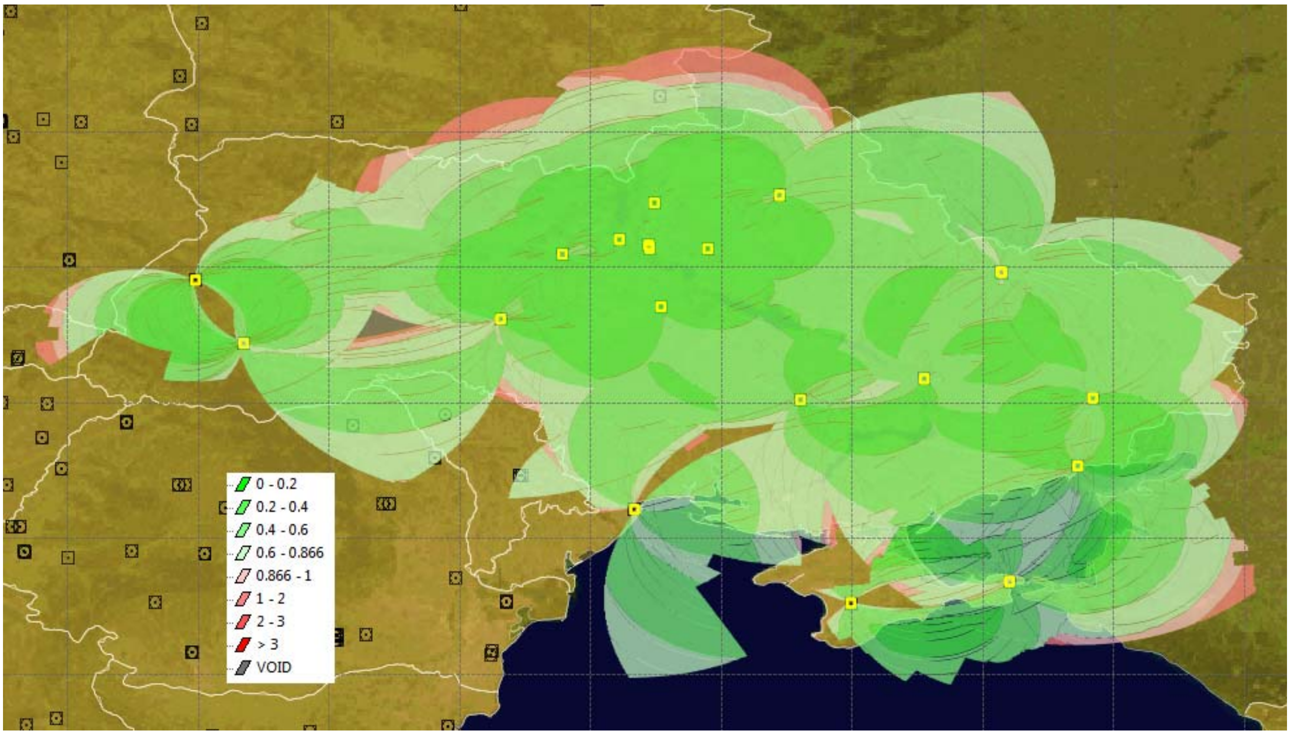

Figure 5.31 – NSE estimation for altitude 6000 m

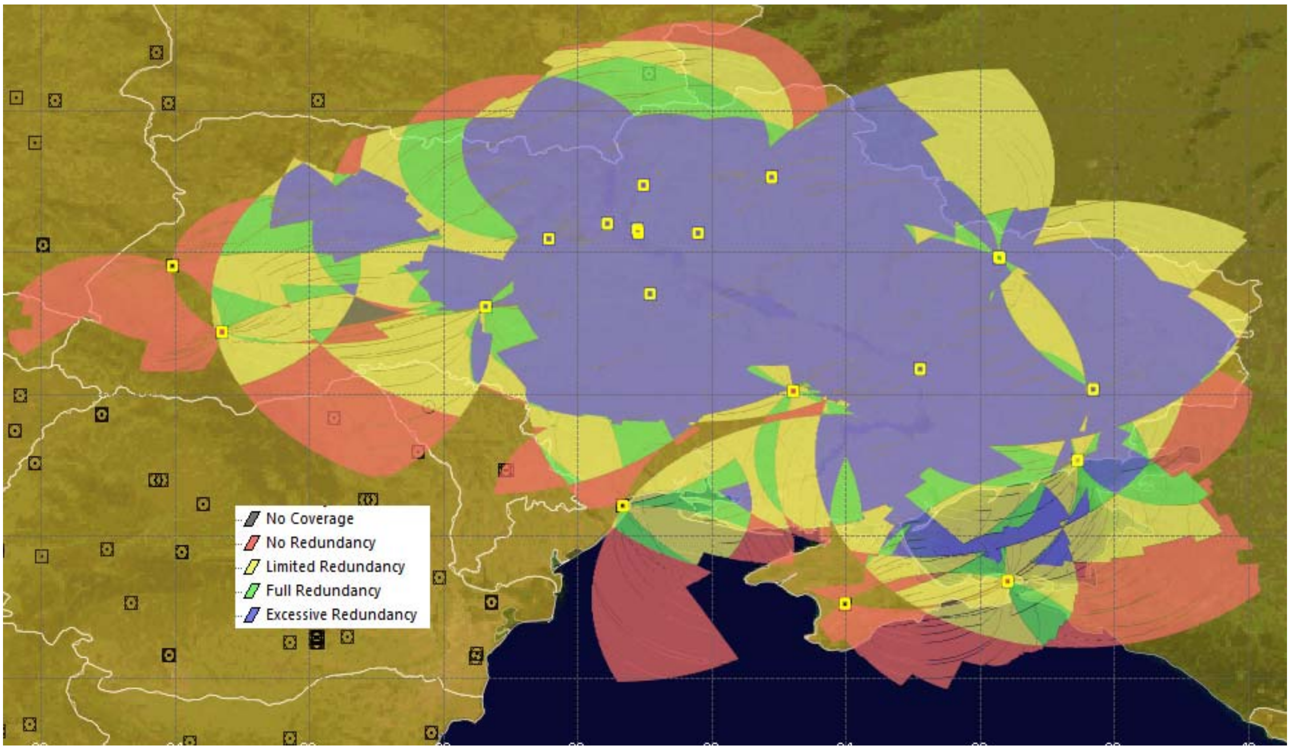

Figure 5.32 – Result of calculating redundancy for altitude 6000 m

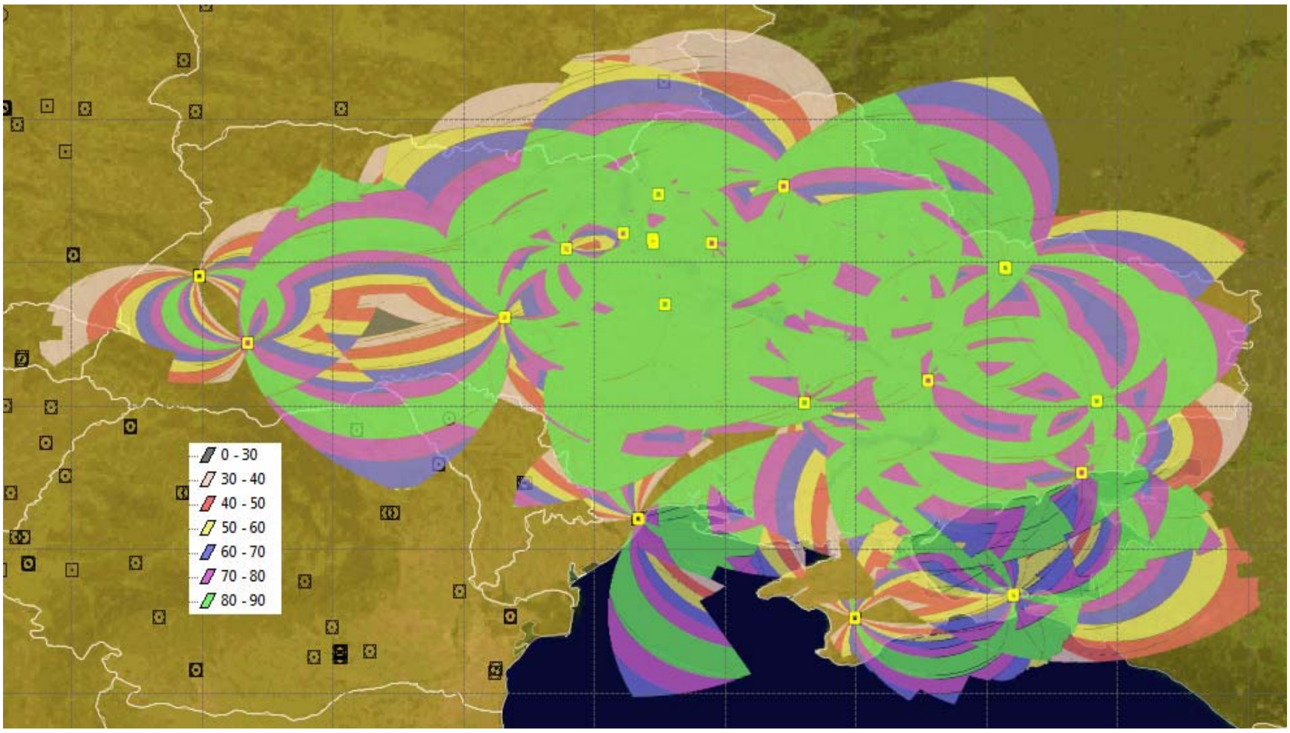

Figure 5.33 – Subtended angle results for altitude 6000 m

Simulation of DME coverage for Ukrainian airspace for altitude 6000 m when national and foreign DME station are used(fig. 5.34)

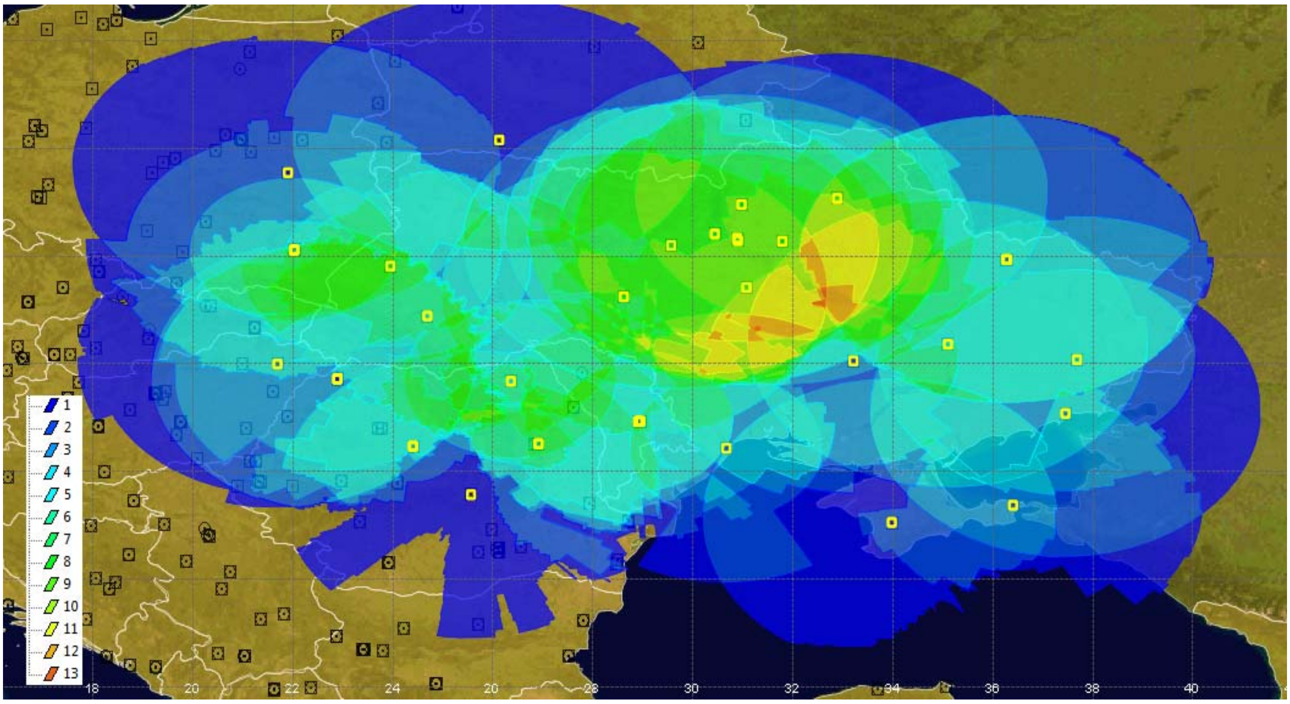

Figure 5.34 – DME coverage for Ukrainian airspace for altitude 6000 m when national and foreign DME stations are used

On the figure below are shown results of the same simulations when are available DME stations of neighboring states for altitude 6000 m (fig. 5.35, fig. 5.36, fig. 5.37).

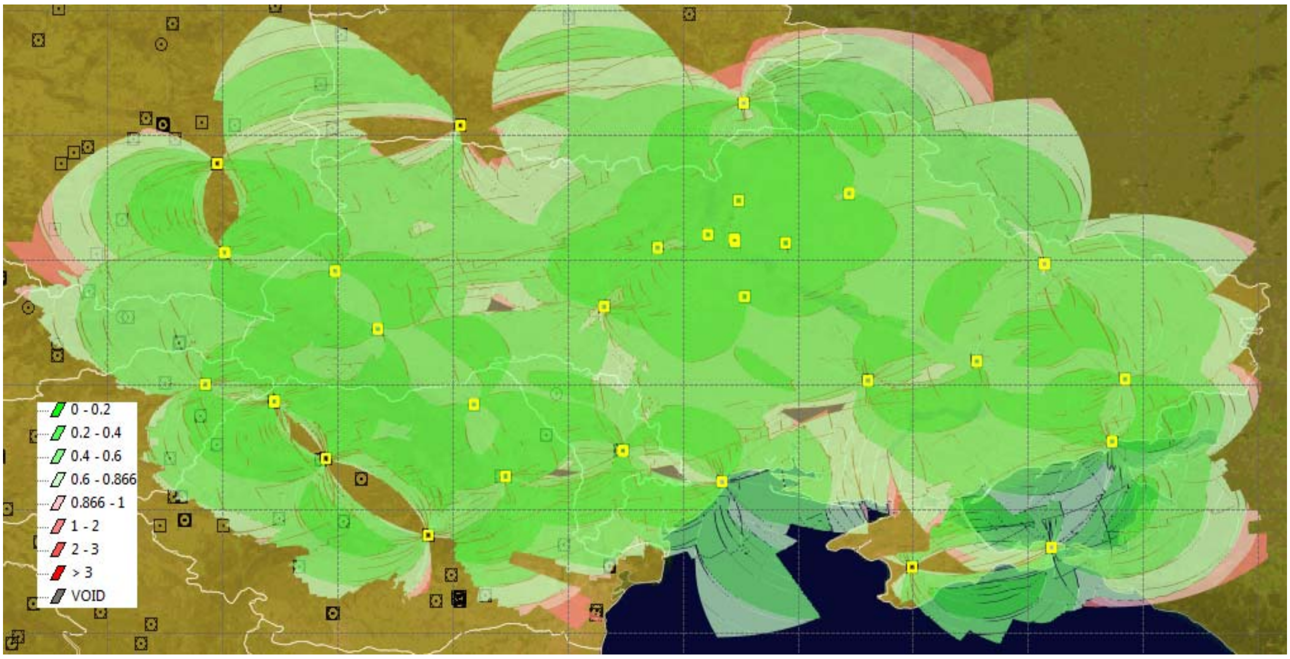

Figure 5.35 – NSE estimation for altitude 6000 m when national and foreign DME stations are used

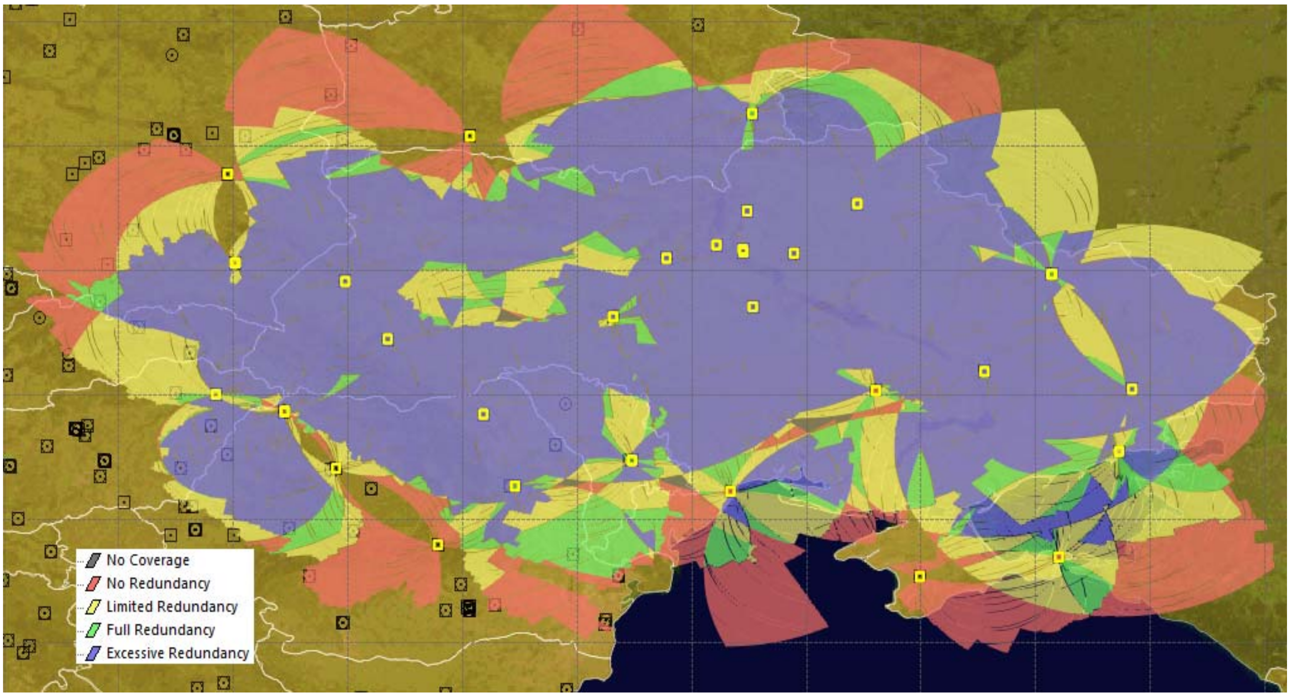

Figure 5.36 – Result of calculating redundancy for altitude 6000 m when national and foreign DME stations are used

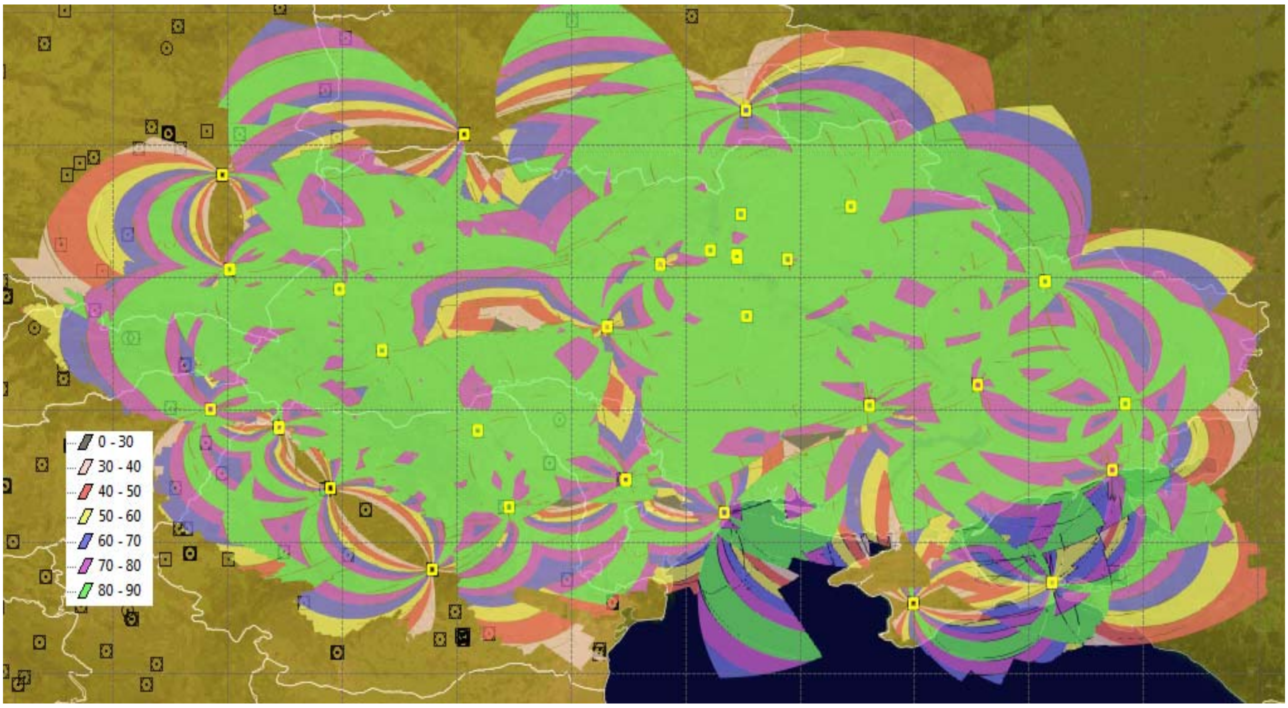

Figure 5.37 – Subtended angle results for altitude 6000 m when national and foreign DME stations are used

Conclusions to the chapter 5

The fourth chapter of the work include all final result of research.

This results represented in figures. The simulation was made for availability of DME station signal for Ukraine teritory for altitudes - 6000 m and 9754 m. Ther are dierent simulation for positioning by Ukrainian DME ststion and for Ukrainian and foreign states DME stations.

One of the main goal of this simulation was estimate the accuracy of positionin by DME/DME for Ukraine airspase. As could be seen from the figures, there are areas where HDOP <1. It's means increasing of accuracy according to the successful geometry of location of ground stations. This method of positioning is obtainable and available DME stations provide high level of positioning accuracy.

CONCLUSIONS

Detailed analysis of the theoretical base and the results of practical part of work have allowed making the following conclusions.

Due to the analysis of trends in the aviation industry – DME as positioning means, is one of the most available decision for alternative navigation. This is evidenced by the following factors:

- DME systems have long been used in aviation, and a large number of beacons distributed in the territory;
- The system is not limited by the accumulation of errors;
- The system is still used for work;
- Positioning accuracy using two DME beacon, meets the standards according to PBN.
- It is cheaper to work on new algorithms of DME stations interactions than fully engaged in the implementation of the new system.

As the main source of information FMS uses GNSS. As reserv - inertial system. Positioning with this method is the most accurate for existing systems and reliable. For accurate positioning, FMS must update information from the navigation receivers by using data from the alternative autonomous sensors. System can use the data from DME/DME, VOR/DME, VOR/VOR, ADF/ADF positioning methods.

ICAO developed a programme of implementation DME/DME positioning method like alternative means of navigation. Consequently, the actual was evaluation of the current state of DME stations in Ukraine and the possibility of positioning by available DME by the DME/DME method. It was one of the goals of this research.

The results are represented in figures. The simulation was made for availability of DME station signal for Ukraine teritory for altitudes - 6000 m and 9754 m. Ther are diferent simulation for positioning by Ukrainian DME ststion and for Ukrainian and foreign states DME stations. As could be seen from the figures, there are areas where HDOP <1. It's means increasing of accuracy according to the successful geometry of location of ground stations. This method of positioning is obtainable and available DME stations provide high level of positioning accuracy.

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Appendix A.
Listing of program in MATLAB software

```
clear all
clc
 u_lat u_lon]=ukraine();
u_lat=deg2rad(u_lat);
wgs84 = referenceEllipsoid('wgs84');
u_lat=convertlat(wgs84,u_lat,'geocentric','geodetic', 'radians');
u_lon=deg2rad(u_lon);
height= 8*10^3; % altitude of flight
%DME and VOR/dme location
vor=[
51.065   32.88666667      489 3
 50.28583333     30.90083333      423 3
 48.35972222     35.10305556      510 3
 48.07194444     37.73694444      793 3
48.88416667      24.69138889      937 3
45.37108333      36.40566667      175 3
48.051   33.21213889      430 1
49.81194444      23.95138889      1094 3
47.07527778      37.45222222      269 3
46.43027778      30.67083333      197 3
45.05166667      33.97972222      622 3
49.24     28.62083333      994 3
49.929   36.291 538 2
49.815   23.948 0 2
49.801   23.968 0 3
49.929   36.303  0 3
49.927   36.278 0 3
50.4      30.441 0 3
50.401   30.462 0 2
50.946   30.978 0 3
50.187   29.57 0 2
49.405   31.077 0 2
50.265   31.794 0 2];
% 43.4033012390137      39.948299407959            36 3
% 50.1099014282227      22.0988998413086           689 3
% 48.6831016540527      21.2481994628906           787 3
% 46.926399230957       28.8992004394531           418 3
% 47.6722984313965      26.3607997894287           1302 3
% 46.5108985900879      26.8255004882812           1752 3
```

```
% 46.8000984191895      23.7873001098633        1549 3
% 47.7274017333984      22.8938999176025        405 3
% 49.0648002624512      20.3500003814697        2388 3
% 49.4828987121582      19.6786003112793        2264 3
% 50.6473007202148      20.25119972229 984 3
% 52.1533012390137      26.1317005157471        476 2
% 43.0950012207031      24.2206001281738        1378 3
% 44.2944984436035      28.4794998168945        269 3
% 45.5676002502441      25.5646991729736        5866 3
% 42.0222015380859      35.0766983032227        49 3];
d_lat=vor(:,1);
d_lon=vor(:,2);
alt=vor(:,3)*0.3048;
lat=deg2rad(d_lat);
lat=convertlat(wgs84,lat,'geocentric','geodetic', 'radians');
lon=deg2rad(d_lon);
%[x,y,z]=lla2ecef(lat,lon,alt) ;
[x,y,z] = geodetic2ecef(lat,lon,alt,wgs84)
% aircraft location
n=200;
alat=linspace(min(u_lat),max(u_lat),n);
alon=linspace(min(u_lon),max(u_lon),n);
aalt=height*ones(1,n);
a_lat=alat(1)*ones(1,n);
a_lon=alon;
a_alt=aalt;
for j=2:n
   a_lat=[a_lat alat(j)*ones(1,n)];
   a_lon=[a_lon alon];
   a_alt=[a_alt aalt];
end
ai_lat=a_lat;
ai_lon=a_lon;
%[xx1,yy1,zz1]=lla2ecef(ai_lat,ai_lon,a_alt) ;
[xx1,yy1,zz1] = geodetic2ecef(ai_lat,ai_lon,a_alt,wgs84)
%convert to NED
[xx,yy,zz]= ecef2ned(xx1,yy1,zz1,ai_lat, ai_lon,a_alt,wgs84,'radians');
%convert to NED VOR's coordinats
for i=1:size(xx,2)
[xvor(i,:),yvor(i,:),zvor(i,:)]= ecef2ned(x,y,z,a_lat(i).*ones(size(x,1),1),
a_lon(i).*ones(size(x,1),1),a_alt(i).*ones(size(x,1),1),wgs84,'radians');
end
```

```
% %detect nearest grond stantions
mma=msr(vor(:,4), alt+height);
for q=1:size(zz,2)
   d(q,:)=sqrt(((xx(q)-xvor(q,:)).^2)+((yy(q)-yvor(q,:)).^2)+(zz(q)-zvor(q,:)).^2);
 maxrange(q,:)=mma;
end
[dd dg]=find(d<maxrange);
% dd - a vector of row indices of the nonzero entries of X
% dg - a vector of column indices of the nonzero entries of X
visibl=zeros(size(d));
for i=1:size(dd,1)
visibl(dd(i),dg(i))=d(dd(i),dg(i));
end
% filtring more then two stantion
visiblw=visibl;
for i=1:size(visiblw,1)
   clear mr
   mr=0;
   for j=1:size(visiblw,2)
      if visiblw(i,j)
      mr=mr+1;
      end
   end
   if mr<=3
      visiblw(i,:)=zeros(1,size(vor,1));
   end
end
% G matrix
for i=1:size(xx1,2)
   if(sum(visiblw(i,:)))
   clear G GG m x2 y2 z2 d2
   m=0;
     for j=1:size(vor,1)
      if (visiblw(i,j))
      m=m+1;
      x2(m)=xvor(i,j);
      y2(m)=yvor(i,j);
      z2(m)=zvor(i,j);
      d2(m)=visiblw(i,j);
      xxx(i,m)=d2(m);
      end
     end
```