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A zone GPS/GLONASS monitoring network of the integrity and navigation signals quality

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In paper the state and the prospects for satellite navigation systems (SNS) GPS/GLONASS in Bulgaria are presented. Following ICAO, sever requirements were imposed on the integrity and accuracy characteristics of air positioning, in the last flight stages. The potentialities for control stations siting in zones of higher accuracy and integrity requirements of civil users is discussed. Such station will provide continuous integrity and quality monitoring of navigation signals and function as NAVSAT pseudosatellite.

The results obtained from simulations prove the advantages of the proposed approach.

1. SNS use in Bulgaria — state and prospects

Navigation is one of pioneer fields of utilization of the first satellite, launched on October 4th, 1957. The experimental results served as basis of the TRANZIT and TZICADA navigation systems, proving the advantages of such systems for more than 20 years. Now we are on the threshold of configuration completion of the so-called second generation space navigation systems — GPS NAVSTAR and GLONASS, having the potentials to meet the demands for positioning of wide area of users. However, they are designed and developed for military purposes.

In Bulgaria, SNS use was limited — mainly for marine navigation. The reasons are as follows:

— lack of information among potential users;

— no guarantees for civil users because the systems are owned by USA and RUSSIA respectively, and are under military control;

— comparatively high costs of users' equipment;

However, the economic stabilization processes and the transport infrastructure development in Bulgaria are expected to rise the interest towards SNS services. Besides, due to the geographic situation and the groving transportation traffic, development of the ground-based support for local (regional) system accuracy and reliability is imposed.

The space navigation and communications division at the Space Research Institute is investigating into the potential SNS differential mode use in marine, land and air transport, as well as research experiments for high-accuracy positioning in the fields of geodesy and surveying.

2. Disadvantages of GPS and GLONASS

The major GPS/GLONASS disadvantages concerning civil use incorporates technical, economic and political elements, namely:

1) air and marine users demands for accurasy and integrity are not satisfied for certain flight and ship navigation phases;

2) both systems design and first stage took place in the cold war period as military support systems and as such their acceptance as international navigation systems is difficult. The geopolitical changes impose gradual internationalization on the systems and probably the control functions should be executed by international body, like INMARSAT. Thus, necessary guarantees will be provided for their future civil utilization and maintenance costs recovary;

3) another SNS disadvantage is the contradiction between their global character, the high accuracy requirements of civil users and national security restrictions. For example, in military conflict regions, the system desactivation is impossible without disturbing the system functioning in other parts of the earth. Thus, the future discussion and legalization of the following is needed:

— limits should be imposed on maximum autonomous positioning accuracy of objects on the territory, air-space and territorial waters of souvereign countries via global satellite navigation systems;

— zones requiring higher accuracy positioning should be controlled and defined by state authorities;

3. System integrity and navigation signal quality

3.1. Integrity

Integrity is the capability of in — time wornings emission during periods of redused navigation system positioning accuracy. Criterion for integrity is the time, necessary to warn the user, while criterion for decision-making whether system failure is present is the real position accuracy. The civil aviation imposes certain requirements for navigation support precision and integrity, depending on the flight phases, see Table 1 [1].

The satellite navigation message contains information bits about health status, but they may be erroneus for 15 minutes to several hours, to rectify. There are three alternatives for resolve the above mantion problem:

1) Autonomous integrity control in the navigation receiver. Then at least 6 satellites in good geometric configuration are recuired for detection and elimination of satellite mulfunctions, and if it is used a GPS/GLONASS receiver, configuration complexity is enhanced, while response time is redused.

Table 1

The FAA navigation system accuracy and integrity requirements

Operational phase	Accuracy (2 drms)			Integrity Time to alarm
	Min. alt.	Lateral	Vertical	
En route / terminal	152 m	7,4 km	500 m	60 s / 30 s
Approach landing:				
Non-precision	76,2 m	3,7 km	100 m	10 s
Precision I	30,5 m	9,1 m	3 m	6 s
Precision II	15,2 m	4,6 m	1,4 m	1 s
Precision III	0 m	4,1 m	0,5 m	1 s

2) Wideband GPS/GLONASS Integrity Chanel (WB GIC) [2], using 4 geostationary satellites. In this case, messages for satellite elimination may be transmitted due to higher accuracy requirements for the landing approach. However, the same satellite may fulfil the requirements for en rout or terminal flights (false alarm). Besides, it is possible to use a satellite in non-precision approach, which signals, due to local, atmospheric or other jamming is disturbed, but WB GIC does not transmit alarm signal (missed detection).

3) Selective approach for integrity support. Definite flight phases, like ocean and domestic routes and terminal area, are WB GIC supported, while the precision and non precision approach are ground suported simultaneously with differential SNS mode. Ground support may be executed by wide-area differential GPS /GLONASS (WDSNS) [3] with integrity control and zonal differential GPS/GLONASS (ZDSNS) with integrity control. WDSNS advantage is that the ground differential station number is limtited, however the vertical accuracy requirement for precision approach CAT I are not satisfied. Also, it has no capabilities for positioning accuracy control by state authorities over domestic territories. That's why ZDSNS using is most appropriate, where a receiver with pseudorange corrections in integrated dopler aiding mode is sufficient for CAT I precision approach [1], while the phase ambiguity problem solution in real-time will ensure a precision CAT II and CAT III approach. In Bulgaria, ZDSNS may be realised via two control stations (Fig. 1), sited in the eastern and western regions in the whereabouts of main international airports.

3.2. Quality

Navigation signal quality characterizes the potential positioning accuracy and is determined by the factors influencing the navigation measurement process. Thus, its control is connected with the systems integrity as a whole. The position coordinates for a given user are obtained by pseudorange measurements to 4 satellites and solving the basic navigation equation, whose linerized form is (1):

(1) $\boldsymbol{Z}=\mathbf{H}\boldsymbol{X}+\boldsymbol{v}$,

where $\boldsymbol{Z}$— measurement vector; $\boldsymbol{X}$ — state vector of the position coordinates and user clock offset; $\boldsymbol{v}$ — measurement noise; $\mathbf{H}$ — measurement matrix.

Or the position accuracy depends on the measurement errors and satellite geometry. The measure of the sensitivity to error inherent in navigation solution

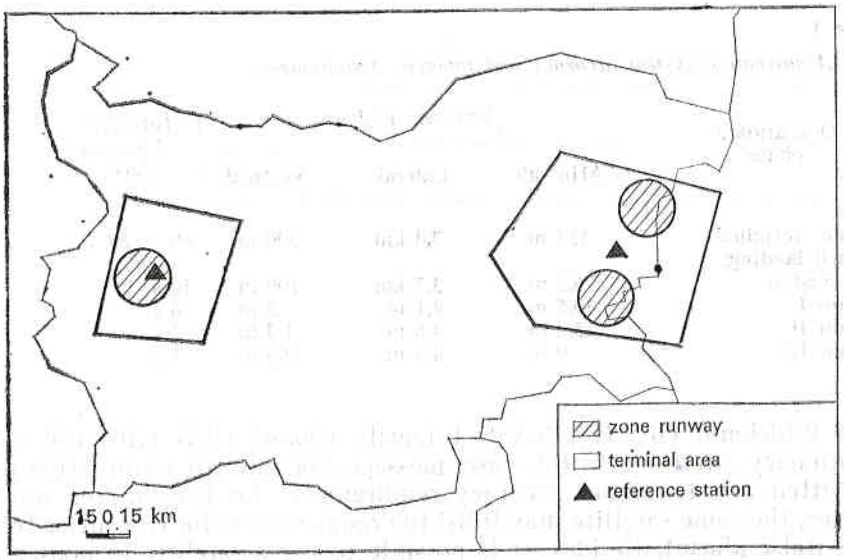

Fig. 1. A zone DSNS

Table 2

Pseudo-range errors with and without differential corrections

Source of error	Bias errors wo/DGPS (Meters)	Random errors wo/DGPS (1σ, Meters)	Bias errors w/DGPS (Meters)	Random errors w/DGPS (1σ, Meters)
Space segment and SA error				
Ephemeris data	4,0	0,0	$2\times 10\ \delta$	0,0
Satellite clock	1,5	0,7	0,0	0,7
Selective availabili[illegible]	30,0	0,0	$1{,}22\times 10\ \tau$	0,0
Communication link errors				
Ionosphere	4,0	0,0	2×10 [illegible]	0,0
Troposphere	0,5	0,5	0,5	0,5
Multipath	0,0	1,0	0,0	1,0

δ is the user — reference statio[illegible] [illegible]eparation (in meters);
τ is the age of correction (in seconds)

is determined by the term geometrical dilution of precision — GDOP

(2) $\mathrm{GDOP} = \sqrt{[\mathrm{Tr}\ (H^{T}H)^{-1}]}$.

The major error sources, systematic and random, summarized in Table 2, are due to:

— errors associated with space segment, as ephemeris data, satellite clock and selective availability S/A;

— errors associated with propagation of the signals in ionosphere, troposphere and multipath.

Real-time quality control should be realized by permanent estimation and identification of the errors introdused by various sources.

4. Performance of zone differential SNS with integrity monitoring

The best estimate of position accuricy is the aposterior error covariance in navigation solution

$$(3)\quad \mathbf{P}_1=[\mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}+\mathbf{P}_0^{-1}]^{-1},$$

where $\mathbf{P}_1$ is apriory error covariance.

It is clear, that **P** depends on satellite geometry and error covariance in navigation measurements. Hence, integrity monitoring will be based on geometry and navigation measurements accuracy assessment.

Goal of the simulated operations with primary 21 satellite GPS constellation was investigation of the influence of user, satellites and control station geometry on user position accuracy in controled zone. The results show, that:

1) The position dilution of precision variation PDOP in the airport zone towards PDOP in the control point will influence insignificantly the objects positioning accuracy (Fig. 2).

2) The performance of differential mode by pseudolite will increase possible combination for measurement with PDOP<6, and if GLONASS and INMARSAT-3 come into line, that increasing will be considerably (Fig. 3).

3) Considerably improving of vertical dilution of precision VDOP by using of a pseudolit (Fig. 4).

The navigation signals quality monitoring is performed (Fig. 5) by continuous assessment of the pseudorange and deltapseudorange measurements in the receiver (all in view with appropriate "mask" angle) on the basis of local atmospheric and satellite motion modells. Besides, in the error analysis block are determined offsets between local reference time and GPS/GLONASS system time and the corrections concerning the differencies between GPS and GLONASS. Then in the decision — making block, the most suitable satelli-

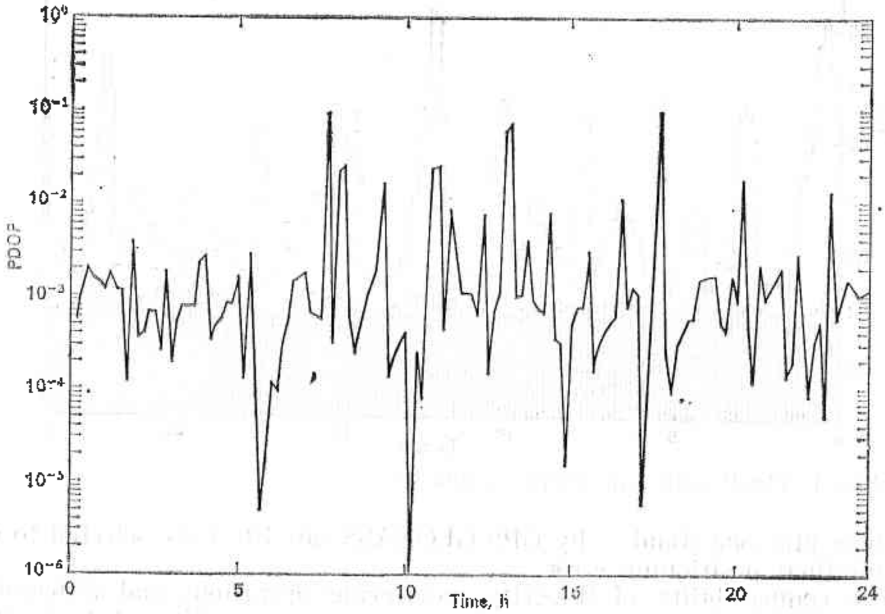

Fig. 2. PDOP versus time

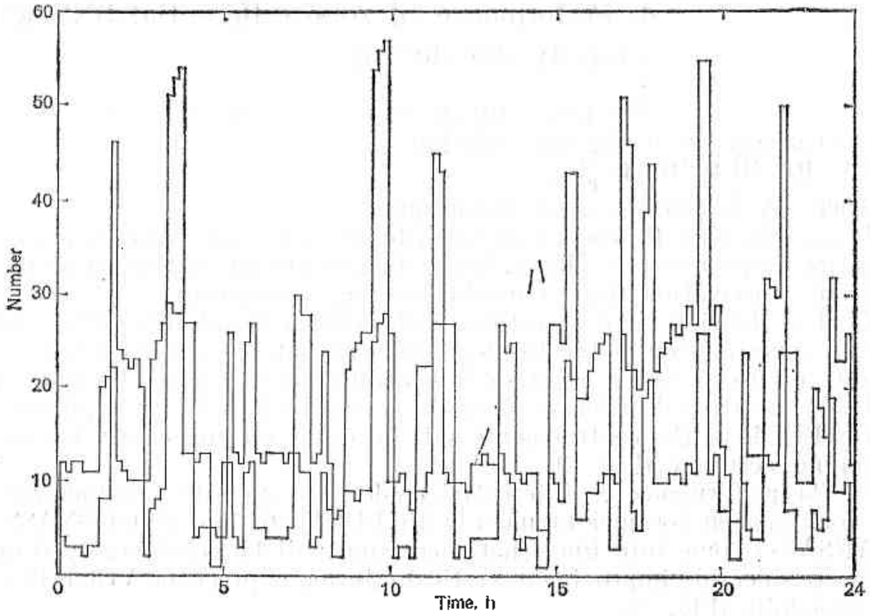

Fig. 3. Possible combinations for measurements with PDOP<6 with and without pseudolite

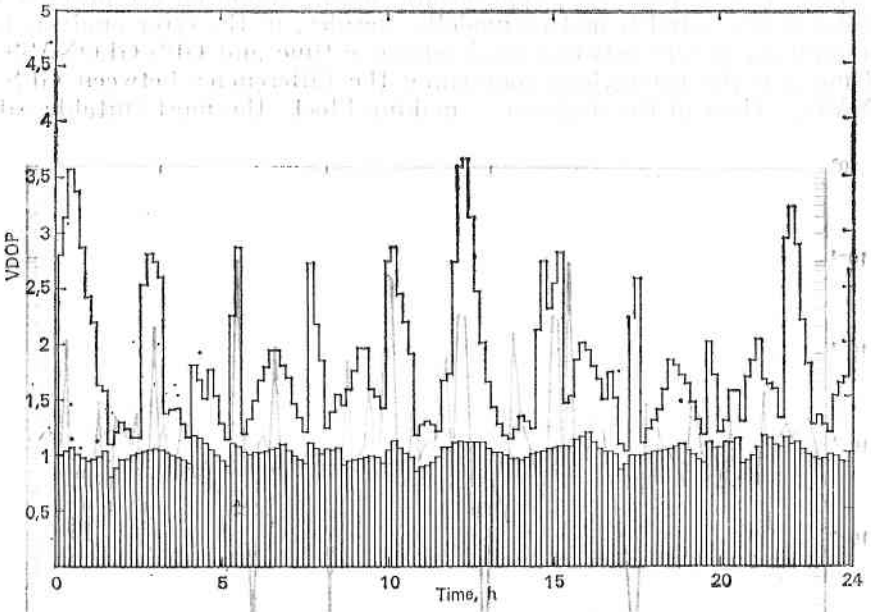

Fig. 4. VDOP with and without pseudolite

tes (three plus one stand — by GPS/GLONASS satellites) are selected to obtain minimal positioning error.

The compatability of integrity monitoring operations and differential mode via NAVSAT pseudolite requires alarm message different from "use- — don't use", as that will be in WB GIC. Navigation data should include following:

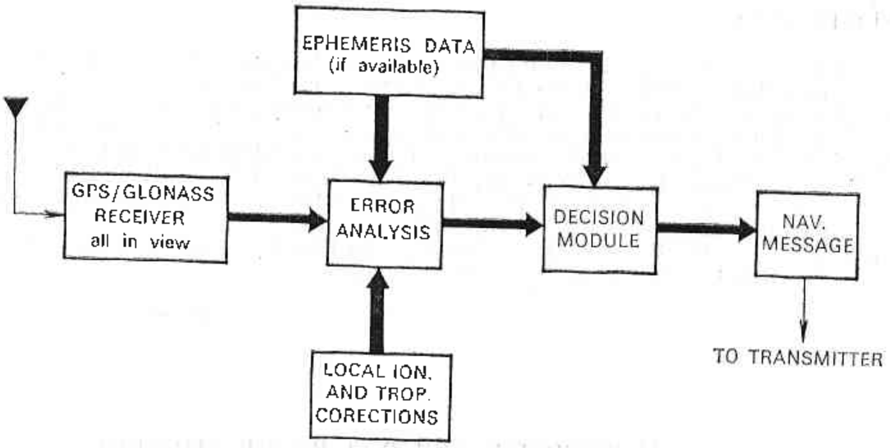

Fig. 5. Performance of DGPS with integrity monitoring

— the four GPS/GLONASS satellite number with their pseudorange corrections;

— orbital data version for those satellites, i. e. issue of data ephemeris (IODE);

— control station coordinates;

— time corrections to GPS and GLONASS system time, respectively;

— warning, if positioning with required accuracy is impossible;

The computation procedure is simpler for combined GPS/GLONASS receiver, if the navigation message contain also:

— clock offset between GPS and GLONASS system time;

— correction data for World Geodetic system (WGS 84) and Soviet Geocentric Coordinate System (SGS 85) local difference.

It has been suggested that the GPS receivers already have capability to demodulate data at any rate submultiple of the C/A code epoch (and that will enable to increase the advantages in the using NAVSAT pseudolite.

5. Conclusion

The accuracy and integrity requirements of avio users imposed the idea for zonal integrity monitoring of SNS like GPS and GLONASS simultaneous with differential mode realization via a NAVSAT pseudolite. The future solution of GPS/GLONASS institutional and international problems, or the NAVSAT concept realization [5], will provide for an independent civil aviation satellite navigation system. Such system with NAVSAT pseudolites, operating in universal coordinate system and utilizing also electronic airnautical maps and satellite communications will be set an entirely new basis for flight support operations in all flight phases.

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Регионален контрол на интегритета и качеството на сигналите от космическите навигационни системи GPS/GLONASS

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(Резюме)

В статията са анализирани основните методи за разрешаване на проблемите, свързани с интегритета и точността на спътниковите навигационни системи (СНС) — GPS — NAVSTAR и GLONASS и е изложена структурата на схема за зонален мониторинг на интегритета и качеството на навигационните сигнали в комбинация с реализиране на диференциален режим на работа.

Изхождайки от препоръките на Международната организация за гражданска авиация (ICAO) и Международната морска организация (IMO), поставящи твърде високи изисквания по отношение интегритета и точностните характеристики на позициониране на самолетите в завършващите фази на полета и на корабоводенето при навлизане в пристанища и във води с ограничена свобода на маневриране, то е удачно в зоните, свързани с подобни изисквания да бъдат изградени контролни станции. Такива станции (псевдосателити) непрекъснато ще контролират интегритета и качеството на навигационните сигнали и ще изпълняват някои от функциите на спътниците INMARSAT-3, като:

— излъчване на навигационен сигнал;

— предаване на данни за интегритета на GPS и GLONASS.

Освен това локалните станции ще осигуряват диференциални корекции за постигане на точностните изисквания на потребителите в обслужваната зона.