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GLOBAL INTEGRATED COMMUNICATION, NAVIGATION AND IDENTIFICATION BASED ON SATELLITES

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Abstract

An important demand on future satellite based navigation systems is the capability of additional communication services. These include the possibility of retransmitting the position determined by a navigation receiver, associated with an identification and parameters which characterize the status of the user.

Satisfying this demand, a new satellite based radio navigation system, called GRANAS-IC (Global Radio Navigation System with Integrated Communication), is presented. It is an extension of the original GRANAS system designed for a highly precise and continuously available navigation service. Emanating from an overview of the basic features and system structure, a concept of integrating additional communication functions is described.

I. Introduction

Due to the increasing complexity and safety requirements of modern traffic systems, there is a corresponding demand especially of the aeronautical but just as well of the shipping and land mobile community for enhanced capabilities of integrated communication, navigation and identification. The present situation in this field is characterized by a varity of different systems each of which covers only a small range of applications. Additionally, the actual systems do not meet future operational requirements.

Emanating from the future civil demand for a highly precise and continuously available navigation service, SEL started an investigation in 1982 funded by the German Ministry of Research and Technology. It results in a system concept for a new satellite-based radio navigation system, called GRANAS-IC (Global Radio Navigation System with Integrated Communication). This system copes favourably with the full set of following requirements:

- Three dimensional position determination and high accuracy of at least 40 m (CEP = circular error probability).
- Global coverage from high altitudes down to the earth surface.
- Continuous availability at all times and locations.
- Unrestricted access by everybody.
- Unlimited number of users implying passive user equipment.
- Guaranteed operation based on international agreements.
- Integrated communication.

Because of the primary civil application political and economic aspects concerning implementation and operation are taken into account from the beginning. The considerations resulted in a completely decentralized system structure. In connection with a very effective functional principle and signal processing the concept provides minimum possible complexity and cost. Additionally, it is an economic requirement to restrict such a satellite system not to only one function like navigation or communication. Therefore, it is proposed to integrate primarily those services in which a position determined by the navigation receiver is retransmitted together with an identification and status of the user back to a service or control center.

However, one should keep in mind that each extension to additional capabilities will increase the cost of development, system set up and user equipment. Thus, a trade-off has to be made between the operational requirements and the economic constraints concerning their realization. Therefore, we give a priority to the above mentioned selection of applications, though further communication functions are not generally excluded by the functional principles of the GRANAS concept.

II. Description of the Navigation Function

System Concept

The principle of user position determination with GRANAS is similar to that of NAVSTAR/GPS[1] or NAVSAT[2] in making pseudo-range measurements to a number of satellites visible above 5° elevation angle. However, the key difference to those systems is the important feature[3], that the GRANAS satellites autonomously determine their own position by means of two-way ranging to the visible ground stations at the earth surface. From this autonomous position determination the following advantages result:

- No request for precise orbit determination and attitude control of the satellites by the ground stations.
- No need to exchange operational data like ephemerides.
- Distributed ground segment with unattendedly operating transponders.
- Decentralized system organisation: no single nation is able to prevent the system from operation.
- Low system complexity and cost.
- High system redundancy and inherent monitoring.

The space segment as shown in Figure 1 consists of 20 satellites in 5 orbits, each inclined 65° with respect to the equatorial plane. In turn in each orbit plane 4 satellites are uniformly distributed in circular 12-hour orbits corresponding to an altitude of 20200 km. This configuration ensures that at least 5 satellites are always in radio line-of-sight from any point of the earth. On average, 6 to 8 satellites are visible. Thus the excess beyond the minimum number of 4 satellites results in an sufficient redundancy and guarantees a continuous service, if one ore more satellites will fail to operate.

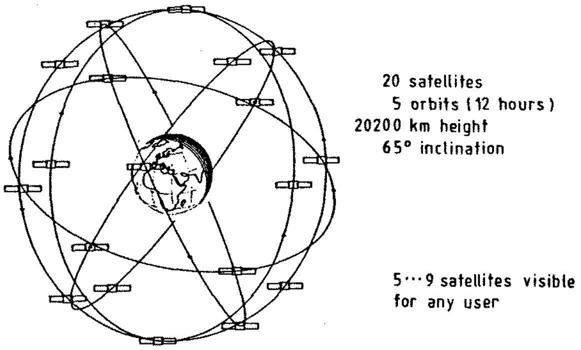

Figure 1 : The GRANAS Space Segment

The ground segment consists of approx. 16 ground stations. While one of them acts as an operational center providing the TTC function, the other 15 ground stations are equipped with simple transponders operating unattendedly to support the autonomous position determination of the satellites. An example of the ground station distribution is shown in Figure 2.

The basic principle of position determination of satellites as well as users is explained by means of Figure 3. The position determination of the satellites is based upon two-way ranging to at least 3 ground stations. The ranging operations are performed using time-of-arrival (TOA) measurements of the navigation signals transmitted by the satellites. These transmissions are received from the visible ground stations and answered by a respective response signal after a known delay time. From the time difference between transmission from the navigation signal and the reception of the response signals each satellite computes the ranges to the ground stations. Because the position of the ground stations are known and the response signals can be assigned to the respective stations by virtue of different codes, the satellites are able to determine their own position.

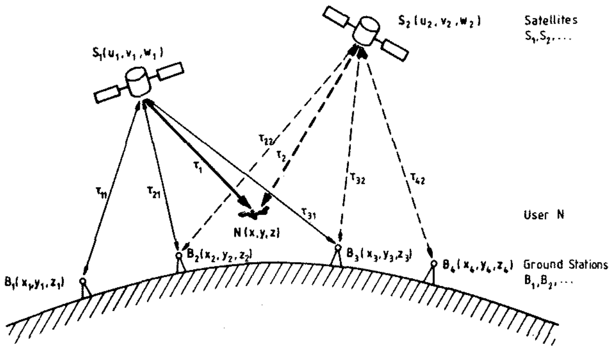

Figure 3 : Principle of Position Determination

Subsequently, the satellites extrapolate their position coordinates to the next transmission times and insert them into the navigation signals. With these updated signals the user performs one-way range measurements. Because initially his clock is not synchronized, he needs measurements to at least 4 satellites to determine his own position in three dimensions as well as his clock bias. The availability of the satellite position within the navigation signal facilitates this operation and substitutes the need to determine and transmit the ephemerides.

A further economic feature of GRANAS is the use of a simple crystal oscillator on board the satellites. Since the response signals of the ground stations include the TOA of the navigation signal, the crystal oscillators can be synchronized in a very effective way.

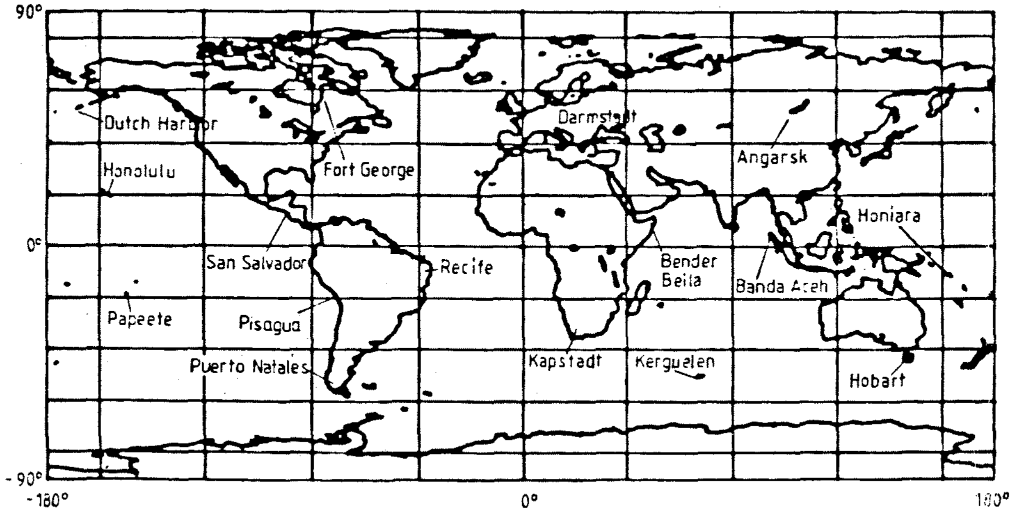

Figure 2 : The GRANAS Ground Segment

Signal Transmission

To perform the ranging function in the receivers of users and ground stations it is necessary to separate the signals of different satellites. For this purpose a time division multiplex (TDM) scheme is used. This offers the advantage to implement only one common PN code for all satellites resulting in significantly reduced acquisition time or effort respectively.

As shown in Figure 4 the TDM frame contains 10 bursts of 120 ms separated by a guard time of 20 ms. Satellites in the same orbit which are in an antipodal constellation may share a common time slot. Therefore, 10 time slots are sufficient yielding a frame length of 1.4 s equivalent to an information update rate of 0.7/s.

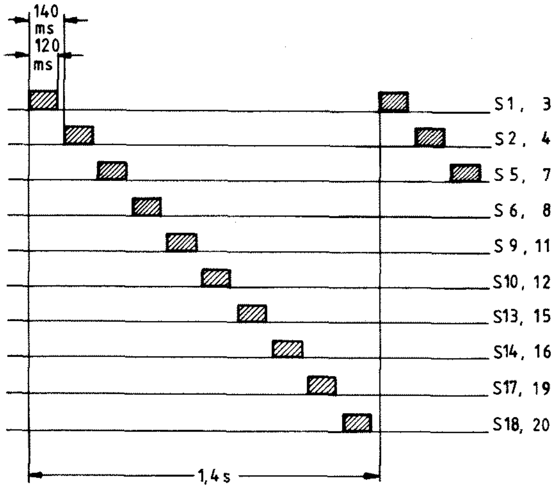

Figure 4 : Time Division Multiple Scheme of Satellite Transmission

Each burst consists of a synchronization preamble and 4 data words (each 20 ms) including the satellite position coordinates. After the data transmission a second synchronization preamble is repeated at another carrier frequency to allow compensation of atmospheric delay.

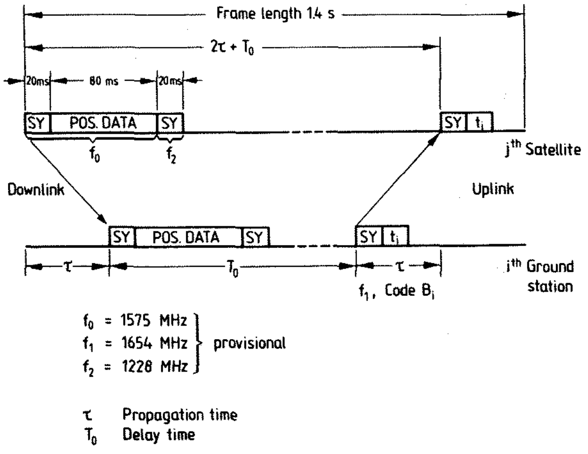

Figure 5 : Transmission of Navigation Signal

Figure 5 reveals the signal transmission scheme corresponding to the functional principle already explained by means of Figure 3. The uplink and downlink frequencies are selected on a provisional basis assuming that a respective assignment may be realized.

A satellite transmits its burst including the position data which will be received by a ground station or user after a propagation time of τ. The burst signal is a spread spectrum PN coded sequence with a chip rate of 4 MHz. The choice of this chip rate is appropriate for an optimal ranging accuracy while the design of the synchronization preamble and the corresponding PN code depends on the principles of signal processing within the navigation receiver.

The ground station answers after a delay time T_0 inserting the TOA t_i into the reply signal. The code B_i provides its correct identification by the satellite. The user performs the one-way ranging in the same way as the ground station but additionally utilizes the position data for its own position determination.

The special design of the code sequence allows a most effective and economic signal processing in the navigation receiver. To this efficiency contributes the pre-processing in a surface acoustic wave (SAW) device envisaged as a correlator. The subsequent processing functions like synchronization, bit detection and compensation for oscillator drift and Doppler shift are performed by a microprocessor. This widely software based signal processing in combination with the use of a SAW device makes it possible to realize a cost saving version of navigation receiver. A corresponding block diagram is sketched in Figure 6.

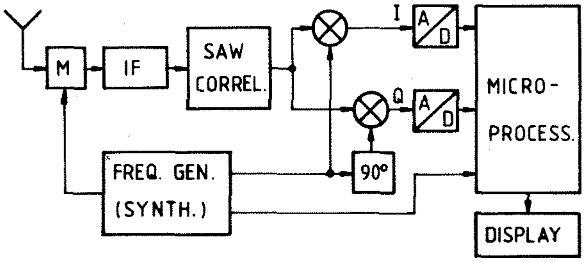

Figure 6 : Navigation Receiver Block Diagram

Performance of Navigation Function

The required accuracy of better than 40 m (CEP) can be provided by several design features. First, the two-frequency method is used to compensate for atmospheric propagation delay. Further, the high chip rate of 4 MHz contributes to the ranging performance under multipath condition.

Finally, extensive estimation methods are applied for the determination of the satellite and user position. These estimation methods are realized by computational algorithms running in the microprocessor on board the satellite or in the navigation receiver of the user. In order to determine the achievable accuracies, computer simulations are performed. For the satellite position yield an accuracy of 6 m (CEP).

However, the accuracy of the user position is dependent of the kind of dynamics of the motion. Thus, the flight pattern shown in Figure 7 was simulated. An aircraft was taken with constant horizontal velocity of 240 m/s and vertical velocity of 12 m/s. During the curved part of the flight pattern the acceleration reaches approximately 1 g.

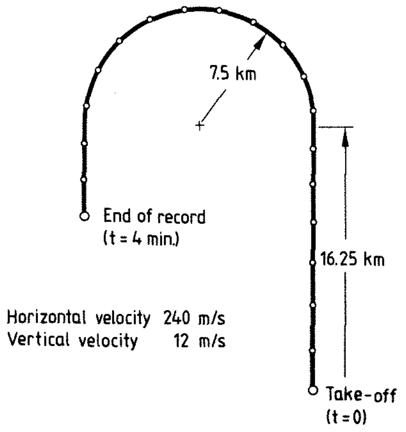

Figure 7 : Simulated Flight Pattern for Investigation of Position Accuracy

The results of this simulation, shown in Figure 8 , are very promising. At the straight flight the accuracy is approximately 10 m (CEP). It raises to about 25 m (CEP) during the curved path, but comes down to the initial value of 10 m (CEP) after the end of the curve.

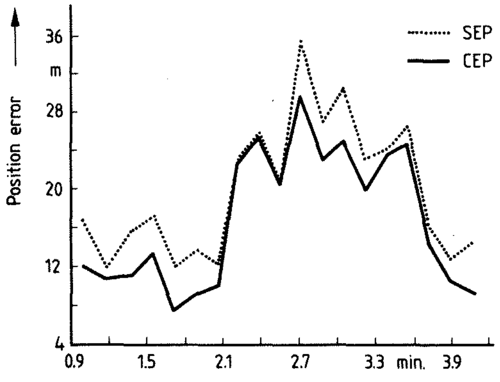

Figure 8 : Position Accuracy

III. Description of Communication Function

Operational Parameters

As it was already mentioned in the introduction, additional communication services are to be integrated into the original GRANAS system, which combine the possibility of position determination with the availability of a data link to an operational or service center. Another important application is the broadcasting of data to several users being in the same geographical area and interesting in common information. The most important examples for these applications are:

- Position reporting for surveillance of aeronautical, marine and land mobile users.
- Message of position and identity for distress alerting.
- General data transmission for collision warnings or weather forecast.

Though GRANAS is intended for different user groups the capability of position reporting is of most interest for automatic dependent surveillance (ADS) as a function of air traffic control (ATC). In this function an aircraft transmits its data automatically, either periodically or on request from an air traffic service (ATS) unit. The main benefit of this operation lies upon the possibility to control deviations from a cleared track and thereby to achieve reductions in separation minima. This operation is specially of great advantage for transoceanic flights or over sparsely populated land areas.

The content of an ADS message can be summarized as follows:

- Identification
- Aircraft's position and data source
- Vector data, like speed and coarse
- Aircraft's intent

Based on this summary, a first estimate results in a message length of approximately 100 bit. To specify an appropriate transmission capacity for GRANAS-IC peak instantaneous aircraft counts (PIAC) between 200 and 800 are supposed corresponding to assumptions of ICOA's FANS commitee. Finally, an update rate for atlantic areas of once per 5 minutes yields an information data rate in the range of 70 to 270 bps. These values will serve as a guideline for the design of the signal transmission.

The second important application for position reporting was referred to distress alerting. The advantage compared to a simple emergency location transmitter (ELT) is the avoidance of homing since the position is automatically transmitted. However it must be guaranteed by a suitable design of the system that the distress call is received and retransmitted by the satellite with highest priority.

Extension of System Configuration

The additional communication functions mentioned above have to be implemented into the original GRANAS system by appropriate modification of the space, ground and user segment. This modification relates to the transmitter and receiver section as well as to the antenna. While essentially the RF-section can be maintained the signal processing functions performed by software operations have to be extended. However, in order to obtain sufficient transmission rates the antenna gain of all segments needs to be increased. Thus, for ground stations steerable antennas with at least 20 dBi are provided. For the navigation functions the satellites already dispose of phased array antennas with a maximum gain of 14.7 dBi. For the communication function the radiation pattern has to be changed by switching different elements of the phased array increasing the maximum gain to 20 dBi. Finally, the users should be equipped with low-gain antennas of 3 dBi.

While a ground station so far designed for answering the navigation signal is now able to participate in communication, it is possible to install additional ground stations to provide the communication function only. This depends on the regional demand of communication capacity and the possibility of connections to terrestrial networks. This way of extending the ground segment may be illustrated by means of Figure 9. The attention is directed to the North Atlantic area. For a certain time this region is covered by the 4 satellites marked with a circled cross. The single covered areas are sketched by a line corresponding to the respective crosses. Thus the ground stations could be positioned nearby the ATS units responsible for different flight information regions (FIR).

Signal Transmission

The design of the signal format is based on different considerations. The first utilizes the advantage of the satellite position information within the navigation signal which enables the user to select the satellite providing the optimum link budget. Further, due the the acquisition of the navigation signal the user equipment is already synchronized onto the frame of 1.4 s. Since the propagation time is measured, the user can precisely access to a communication time slot. This access is so accurate that no additional bit synchronization needs to be performed for data detection.This contributes to a short acquisition time even at low signal to noise ratios. Therefore, the signal processing can be realized in a simple and effective way.

A signal burst starts with a pure carrier for recovery operation followed by data. The data length is considered to be 100 information bit. However, the bit length depends on the special application. Thus, the investigations to design the signal format start with the worst case application. This is represented by a distress call which is transmitted with lowest power and 0 dBi antenna gain. The so determined transmission parameters are then extrapolated on the basis of link budgets. An overview of the most characteristic transmission parameters is given in Table 1.

Table 1 : Transmission Parameters

	Distress call	Position report	Ground station satellite link
Transmission power (W)	10	100	200
Ground antenna gain (dBi)	0	3	20
Data packet length (ms)	860	43	40
Information bits	100	100	≤ 6000

To cope with multipath fading different coding techniques are employed. As a standard a convolutional code with rate 1/2 is used in combination with interleaving. If necessary under severe conditions, this code may be concetenated with an outer (16, 12) Reed-Solomon code. The data are modulated using BPSK. The signal processing functions are summarized in the receiver block diagram of Figure 10.

The transmission scheme is oriented by the TDM frame given by the navigation principle. The constraint of minimizing the power demand for the satellite transmission leads to the separation of time ranges for downlink and uplink of 0.6 s and 0.8 s respectively (see Figure 11). Finally, the different transmission rates in the user and ground station links results in corresponging time slots designated as UC and GSC.

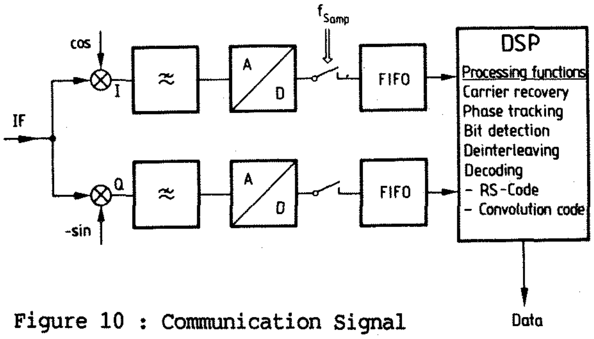

Figure 10 : Communication Signal Processing

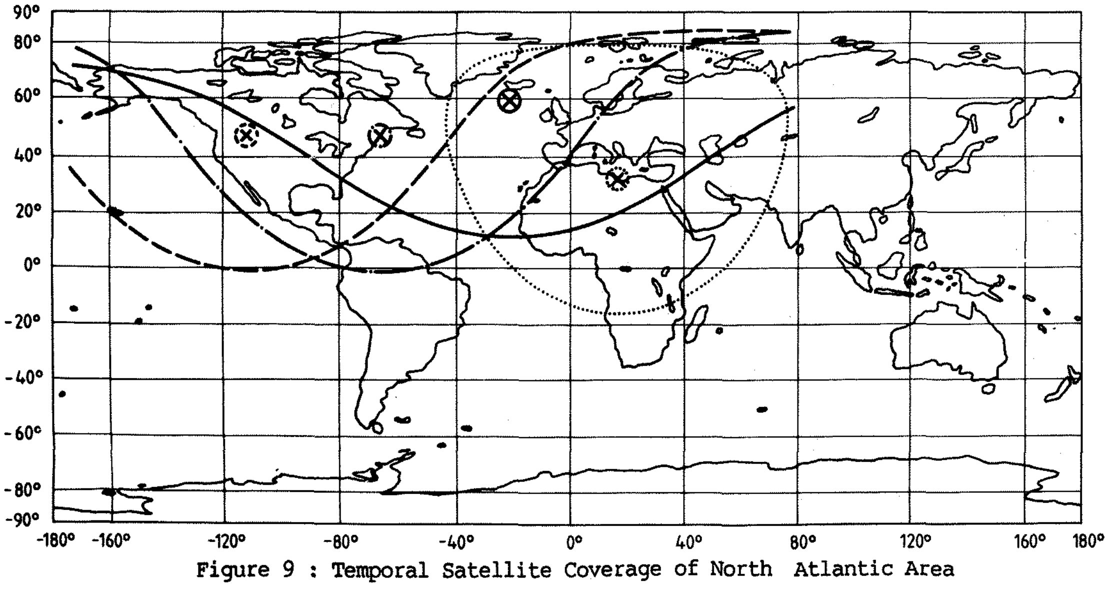

Figure 9 : Temporal Satellite Coverage of North Atlantic Area

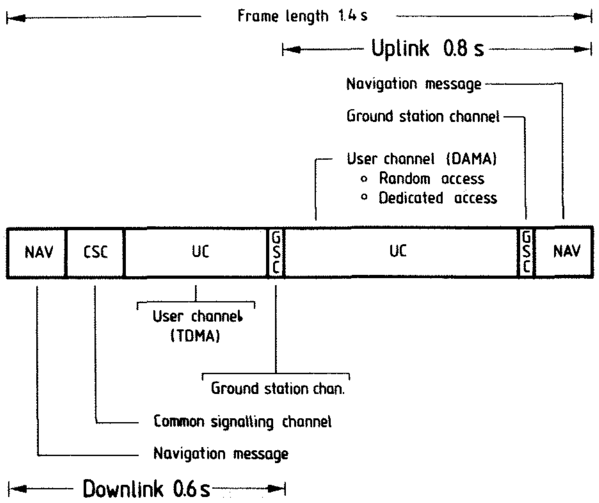

Figure 11 : Signal Transmission

Satellite Access Control

The applications of integrated communication offered by GRANAS-IC are characterized by

- randomly changing demand of capacity
- messages consisting of short and fixed length data packets

Mostly, data packets of users are transmitted on request, for instance of a service center, once or repeated periodically. Further, the length of a data packet is in the order of a request for assignment of a user channel. Since such a request can only be transmitted in a random acccess mode, it is more economic to transmit the data packet itself in the random access mode. This will be done in predestinated time slots to reduce the probability of overlapping of transmitted packets. Because of the different transmission rates in the user to satellite and satellite to ground direction the user cannot listen directly if a packet is transmitted successfully from the satellite to the ground. Thus a common signalling channel (CSC) is provided to retransmit an acknowledgement to the user. If the user doesn't receive an acknowledgement he waits a random amount of time and sends the packet again.

The way in which multiple users share a common channel is widely known as demand assignment multiple access (DAMA). For periodically repeated packet transmissions the user can piggyback a reservation request within the first packet. By means of the CSC he knows the actual reservation status of the system and will be informed if his request is accepted. Thus the user channels contains random as well as dedicated access channels. A first estimate of the transmission capacity relating to one satellite yields a value in the range of 250 and 750 bps. Taking into account that for a certain area like a FIR more than one satellite is available, the total capacity will be enhanced condiserably. The selection of different satellites will be provided by frequency to avoid mutual signal interference. Additionally, to guarantee that a distress call will be processed with priority, a separate distress frequency is intented. The access mode in this channel is random too, but only for users in distress.

IV. Conclusions

A new concept concerning a satellite-based navigation system with integrated communication is demonstrated. The navigation function provides global coverage, high accuracy (15 m CEP) and continuous availability.

By appropriate adjustments the same system can be used for different communication applications. Among others the most important are position reporting and emergency calls. The basis of additional data transmission is the TDM principle of the navigation function offering free capacity between the navigation bursts of each satellite.

Emanating from the navigation function the system will be completely decentralized in order to achieve the lowest possible complexity and cost. This objective is maintained for the communication function too. Using a simple principle of user access the effort of operational control is reduced. The signal processing functions are so designed that the performance just under severe link conditions as for the transmission of distress calls is sufficient.

An estimation of the transmission capacity yields that the system copes with the future requirements However, the concept is so flexible that it can be extended corresponding to the real demand.

References

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