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NAVIGATION SYSTEMS BASED ON GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS

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***Abstract*—*The development of a positioning algorithm on the board of a moving object using the information about the direction of signal reception from Global System for Mobile Communications base stations. The developed system may be used as the effective and reliable method of positioning. Mobile module can help to solve all the types of positioning problems.*

Index Terms—Positioning algorithm; signal reception; location area code; radio frequency; authentification center.

I. INTRODUCTION

As a rule, navigation complexes consists of: inertial navigation systems and satellite navigation systems. But inertial navigation system accumulate a lot of errors and satellite one has not the best one accuracy. That's why the work of navigation complexes can be based on some other physical principles.

Mobile communications is currently going through a period of rapid development. Modern digital standards of cellular communication allow to transmit not only a voice, but also a data, which gives a possibility to the operators of mobile communication to offer the subscribers an additional services. A number of such services, in particular, is based on the possibility of the subscriber's current positioning in the network coverage area. Of course, not a position of a subscriber is found, but a position of a mobile phone.

Mobile communication is one of the spheres that make the task of navigation of moving objects in general and individual navigation tasks in particular, is based on the use of mobile communication tools.

In the base of construction of cellular radio communication systems lies three principles:

– second usage of radio frequencies in the cells;

– provision of connection continuity during the movement of subscriber from one cell to another (handover);

– determination of the location of a mobile station in the network of cellular communication.

On these principles the systems of cellular communication of first (1G) and second (2G) generations. For the communication systems of third (3G) generation, the principle of repeated use of radio frequencies is combined with the repeated use of codes - random sequences, used to generate the signal ensemble, providing code separation of channels of communication (CDMA).

However, for the development of new generation services, associated with a location (navigation, assistance during crashes, emergency medical assistance, referral services, and so on), we need a higher accuracy of definition of geographical coordinates of the mobile station (MS) and their unequivocal link to digital map. In this case, the positioning accuracy of MS, available in the conditions of functioning of the second generation cellular networks, is insufficient. It is necessary to introduce new methods of determining the location of MS on the basis of the additional capabilities of digital cellular networks, and capabilities of the other systems, such as the global navigation satellite systems, such as Global Positioning System (GPS) and GLONASS, which provide more precise positioning of objects.

II. PHYSICAL PRINCIPLE AND NECESSITY OF USE OF GSM NAVIGATION SYSTEMS

All technologies connected with the determining of location in the cellular network are called Mobile Location Service (MLS). Wherein we should distinguish the services of determining the exact location(x, y coordinates, location-based service) and services that are bound to the user location (district, area, location-dependent service). In the first case, it is navigation services, services of obtaining actual information, connected with the coordinates, in the second case the knowledge of the exact coordinates is not required, the system operates with the notion of "district" (location). To provide the services associated with the knowledge of the district, where the user is located, does not require any investment from both parts, as from the operator, as from the user. The existing equipment is used, including mobile phones. An example of such services could be broadcast messages, they change depending on the location of the subscriber. So, in the Moscow "MTS" network, when you are in the city, it means "capital", and when outside – "district". This is a simple service, which is organized by a territorial principle, similarly, as the search nearby gas stations, hospitals, movie theaters and other necessary places: there comes a request from the phone, and the operator side provides information, from which base station it was proceeded. Using the object database the nearest is found, and then they are transferred to the user phone. It is interesting, that the quality of the service in this case depends only on the fact, how meticulously the objects database was compiled, and to which stations they were attributed. It can be often that a close object can be virtually unavailable due to the lack of roads coming to it, and the object, that lies further, vice versa, is more convenient. So the story about location-dependent services can be completed, adding only that such services are quite popular in I-mode standard (Fig. 1).

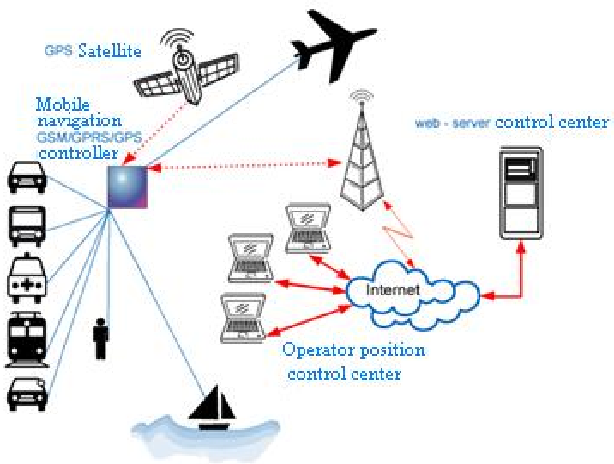

Fig. 1. Global System for Mobile Communications navigation system

So let's talk about technologies that are used for positioning in cellular networks. Nowadays, they can be divided into three large groups, depending on the methods of calculation of coordinates:

– Global Positioning System (GPS) – the usage of standard GPS receivers, embedded to the cell phones or A-GPS technology; in the last case, to calculate the coordinates, the additional information from the network is used;

– cell Identifications – the method of calculating coordinates, base on the cells of the network, has many variations, it is Service Area Identity for 3G, LocWAP, enhanced Cell-ID, Timing Advance (TA), round Trip Time (RTT), RX levels;

– methods based on calculating of the signal delay – Enhanced Observed Time Difference (E-OTD GSM), Advanced Forward Link Triangulation (AF-LT CDMA), Idle Period Downlink (DL WCDMA IP).

System of GPS/GSM tracking allows you to track on the map the movement of all the vehicles of your carport and to observe the current state of each of them (motion speed, temperature in the refrigerator, the opening of cargo compartment, etc.). The system will automatically monitor the condition of the vehicle in the working zone, its movement according to the route, a visit to the checkpoints and the time of arrival. About fact of deviation of the vehicle from the configured route conditions will be immediately reported to the user of the system (Fig. 2).

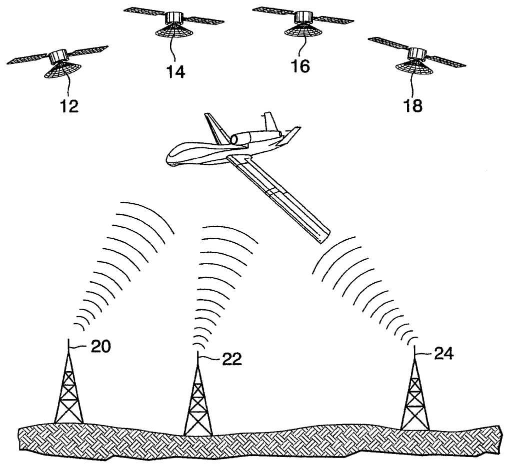

Fig. 2. Base station technology

III. Classification of GSM Positioning Technologies

Previously reviewed positioning principles of the subscribers in cellular communication systems define two functions that are directly related to the process of obtaining coordinates: signal measurement function during positioning (the level of signal, signal reception time) PSMF and the function of calculating the location coordinates RSF.

Numerous technologies, offered by individual companies for implementation of these functions, submitted to standardization, in general can be classified according to place of measuring the signal parameters and defining the location of the subscriber.

There are such categories of positioning technologies.

On the basis of the mobile station (MS-based): MS measures the signal level and specifies the location regardless of the cellular network. To the number of positioning technologies based on the MS relates the coordinate measuring with the help of satellite navigation systems (GPS, GLONASS) or technology Assisted GPS (A-GPS). And, in the case of A-GPS auxiliary data (differential corrections) can come not through the cellular network, but through separate, auxiliary transmitters of GPS signals, installed in the coverage of cellular network.

For example, information can be transmitted along with the data in the ensemble of digital audio broadcasting signals Digital Audio Broadcasting.

Networks with data support (Network-assisted): positioning process occurs primarily in MS, but MS is supported by the network. An example can be A-GPS technology, in the case when from the reference navigation receiver proceeds the specified data to the terminal through an external network, which let the terminal significantly increase the measurement results from the GPS satellite constellation. Another example is the technology of observed time difference of signal detection OTDoA (Observed Time Difference of Arrival): the network sends the necessary information about signal delay for calculating the location data to the mobile station (Fig. 3).

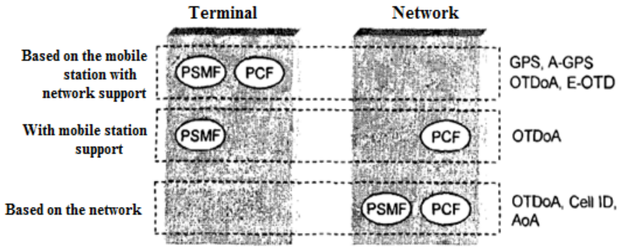

Fig. 3. Categories of positioning technologies

With mobile station support (MS-assisted): MS measures the levels of signals from BTS, and the network determines the location, for example, with the help of advanced measurement technology of the observable time difference of signal reception Enhanced Observed Time Differnrce (E-OTD) for Global System for Mobile Communications (GSM) systems or OTDoA technology for UMTS.

On the basis of network (Network-based): the network performs all the functions associated with a positioning. The most famous example is the technology of cell identification (Cell ID) that does not require definition of signal parameters, as it is an internal property of the mobile networks. Positioning accuracy decreases with increasing the radius of the cells from several hundred meters to several kilometers. To increase the accuracy of the definition in this case, we can use sector antenna. Some of the services, based on positioning data, such as billing in different tariff zones, are already realized by using the technology of cell identification. Another example of location-based technology is a technology of determining the time of signal reception (Time of Arrival, TOA), under which on the three base stations the time of signal reception from one mobile station are measured.

There are many ways to determine the location of mobile stations, many of which allow you to define the location of the subscriber with high accuracy. Some technologies require more elaborate design of MS and changing of software in them, as well as in the system of base stations. The introduction of other technologies more affects on the network infrastructure. The existence of a number of positioning technologies can hardly contribute to the expansion of the market of services based on them. Despite the fact that the described above architecture of positioning systems of mobile station provides for the use all the variety of existing technologies, the main technologies for GSM networks are the following: Cell ID-TA, ToA, E-OTD, A-GPS. Selection of coordinate measurement technology MS for networks UMTS depends on used network of radio access. For UTRAN is Cell ID-TA, OTDoA, A-GPS.

The application of GSM channel for UAV navigation is realized in “AutoGraph-GSM” (Fig. 4).

a b c

Fig. 4.“AutoGraph” system: (a) general view; (b) PCB; (c) applications

The area of application of board controllers of type "AutoGraph-GSM"

– Passenger and cargo transportation.
– Transport of enterprises and private persons.
– Agricultural and building machinery.
– Taxi stations and services of express delivery.
– First aid services and special machinery
– Urban community services.
– Small aviation (helicopters, planes, agricultural aviation).
– Water transport.
– Railway transport and others.

Main abilities of board controllers of type "AutoGraph-GSM"

– Control of transport positioning and parameters of motion in real time with high accuracy.
– Control of consumption (sensor DRT, VZO) and level (sensors LLS and state sensors) of fuel.
– Control of state and parameters of outside devices and mechanisms with the help of discrete and analog inputs
– Registration in the energy-dependent memory of contingencies.
– The ability to control the outside devices with the help of two discrete outputs (including SMS).
– Voice bidirectional GSM-connection of the driver with dispatcher.
– Remote modification of device setup by the user (including SMS).
– The ability to work with navigation systems of type GSM and GLONASS (depending on the type of receiver).
– Connection of outside GLONASS-receiver through the interface RS-485.
– Data transmission on the server through the internet by the protocol GPRS through GSM network.
– Readout of current parameters and positioning through SMS.
– Readout of "black box" through USB interface.
– Static regime GPS, function "GPS-mouse", control points.
– Simple setting of controllers to compile the concrete tasks.
– Simplicity of setup and connection of controller.
– The usage of outside antennas let us to provide stable signal reception and set the controller on the vehicle maximally comfortable.
– Special compressed exchange protocol, developed by the specialists of "TechnoCom" company, let us to minimize internet traffic.
– Presence of server program, as for MS Windows, as for Linux/FreeBSD let us to minimize the expenses on server unfolding.
– Free control software of high level by the "TechnoCom" company.

– Controllers AutoGraph-GSM or AutoGraph-GSM–GLONASS, established on the vehicles, permanently get the code signals from satellites of the system GPS (NAVSTAR) or GLONASS, on the vase of which the coordinates of exact location of vehicle are calculated, and also speed, direction and time.
– Then, with some periodicity, the cumulative data are transmitted with the help of GPRS of cellular mobile network GSM through the internet to the special server AutoGraph-GSM.
– Server is the computer under the control of OC Windows or Linux/FreeBSD, which is always connected to the internet network with constant IP-address.
– Controlled SMS-commands let us to get the coordinates of means of transport and different notifications on the common mobile phone of GSM standard through SMS.

Functional scheme of AutoGraph-GSM controller consists of several blocks

– GSM-module.
– Central processor.
– Driver of power supply.
– Block of inputs/outputs.
– Port USB.

Structural scheme of GSM navigation system is represented on Fig. 5.

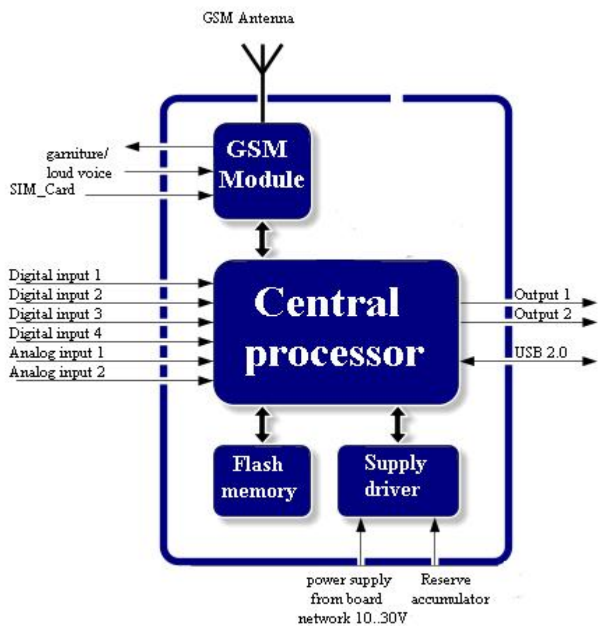

Fig. 5. Structural scheme of -GSM navigation system

IV. CELL IDENTIFICATION TECHNOLOGY WITH THE DEFINITION OF SIGNAL PROPAGATION TIME (CELL ID-TA)

Cell-ID operates in GSM, GPRS and UMTS networks. It is the simplest way to describe the general location of a handset. It requires the network to identify the BTS to which the cell phone is communicating and the location of that BTS. If this information is available, the Cell ID LS identifies the MS or UE location as the location of the base station and passes this information on to the location service application (Fig. 6).

Since the MS/UE can be anywhere in the cell, the accuracy of this method depends on the cell size, and can be very poor in many cases, since the typical GSM cell is anywhere between 2 km to 20 km in diameter. Further reducing the cell area by specifying cell sector is a typical strategy used to improve accuracy.

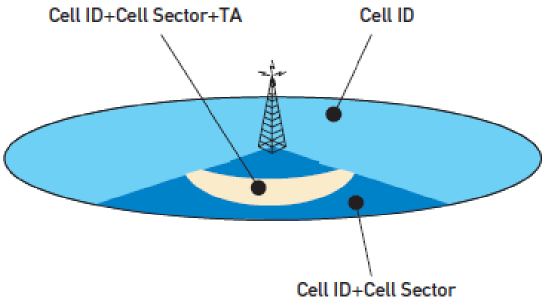

Fig. 6. Cell-ID with Cell Sector and TA

Positioning is generally more accurate in urban areas with a dense network of smaller cells than in rural areas where there are fewer base stations. If micro-cells are utilized, the cell size may be reduced significantly – to the range of several hundred meters. Ultimately, the diversity in cell-site size, density and operational characteristics across a network makes the accuracy of this technology inconsistent.

Cell-ID with TA or RTT. Cell ID accuracy can be further enhanced by including a measure of TA in GSM/GPRS networks or RTT in UMTS networks. TA and RTT use time offset information sent from the BTS/Node B to adjust a mobile handset's relative transmit time to correctly align the time at which its signal arrives at the BTS.

These measurements can be used to determine the distance from the MS/UE to the BTS or Node B, further reducing the position error.

Even with the enhancements, however, this technology is one of the most inconsistent and least accurate of the technologies discussed in this paper. It is an inexpensive approach to implementing a very coarse location solution. Generally, the yield and TTFF are very good, but the accuracy is poor and the consistency of the solution varies dramatically, depending on cell site density. It is particularly poor in rural areas where cells are a long distance apart. In terms of implementation, it supports roaming to other networks without major modifications, is easy to maintain, and requires no major cost expenditure to expand the network. Despite these advantages, the basic accuracy performance supports only the minimum of possible services.

V. THE ADVANCED TECHNOLOGY OF THE MEASUREMENT OF SIGNAL RECEPTION TIME DIFFERENCE (E-OTD)

E-OTD operates only on GSM and GPRS networks. In GSM, the MS monitors transmission bursts from multiple neighboring BTSs and measures the time shifts between the arrivals of the GSM frames from the BTSs to which it is communicating. These observed time differences are the underlying measurement of the E-OTD radio-location method and are used to trilaterate the position of the mobile device.

The accuracy of the E-OTD method is a function of the resolution of the time difference measurements, the geometry of the neighboring base stations, and the signal environment (Fig. 7). The mobile handset must measure time differences from at least three base stations to support two-dimensional position determination (no altitude measurement is provided).

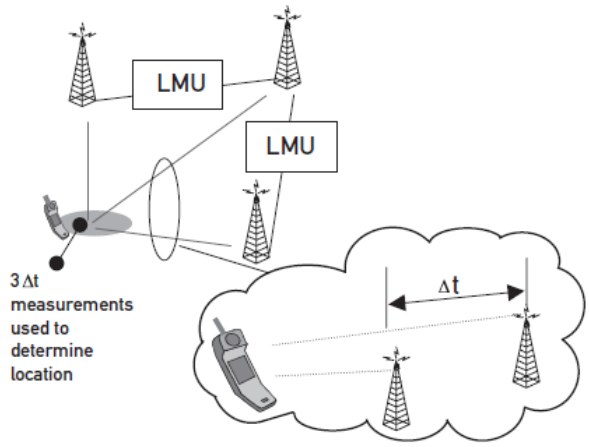

Fig. 7. E-OTD Operation

Because time is critical to the location measurement, E-OTD requires precise time information. For GSM and GPRS, this requires the addition of Location Measurement Units (LMUs) everywhere in the network where a location service is offered at an average rate of 1 per every 1.5 BTS sites [5]. This deployment constraint comes from the requirement for each of the BTS in the network to be observed by at least one LMU. Further, special software is required in the MS to support E-OTD. E-OTD does not support legacy handsets without software modifications, at a minimum. This software cannot be downloaded over the air.

The need for LMUs introduces significant infrastructure changes. To provide network-wide coverage could require the installation of thousands of LMUs at existing BTS sites or at new sites near existing BTS sites. This requires significant network planning, an assessment of the RF impact to the network, adherence to local ordinances where new sites are involved, and the expense to plan, install, test and maintain the network of LMUs. As the communications network grows or existing networks are acquired, the same process must occur for the new BTS sites. If a subscriber roams into a partner network, there must be LMU support in the partner network to provide an E-OTD location service. This level of intricacy complicates the operator's ability to provide roaming support for an E-OTD-based location service and extends the time required to deploy network-wide location service.

E-OTD solutions offer improved performance relative to Cell-ID, but require the use of LMUs. This increases the cost and complexity of implementation, as described above. E-OTD also requires a large number of data messages be exchanged to provide location information, and this information must be updated constantly.

This message traffic is much greater than that used for A-GPS or Cell-ID, and E-OTD uses more network bandwidth than these other technologies. Because E-OTD must interact with at least three base stations and utilize terrestrial measurement to derive a position estimate, the technology is vulnerable to accuracy degradation from multipath and signal reflections, and will fail completely in areas where there are too few BTSs, such as rural areas. This situation is worsened by the fact that, although BTSs are placed in specific spots to optimize communication efficiency, these spots may be poor choices for use in deriving position estimates. For example, an MS in a line with several BTSs can produce ambiguous results, so the technology may operate unreliably along linear road networks where this BTS configuration relative to the MS may be common. For roaming, implementation of E-OTD requires major modifications since the roamed-to network must have LMUs. This is true even if only one subscriber wants to roam into a network.

VI. THE ALGORITHM FOR DETERMINING THE COORDINATES OF THE UAV VIA GSM

The algorithm for determining the coordinates of the UAV VIA GSM is represented on Fig. 8.

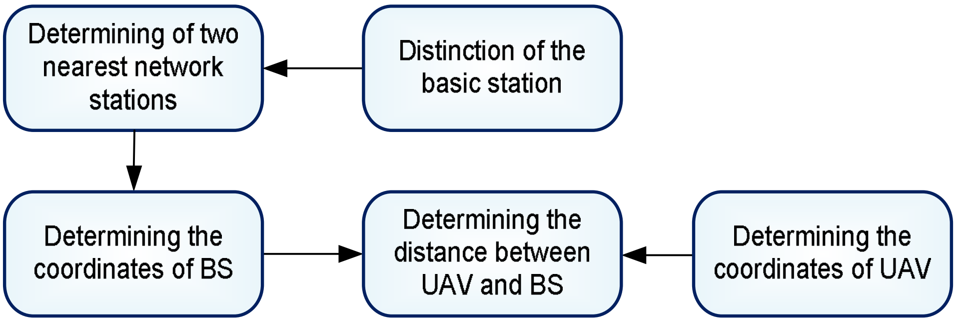

Fig. 8. Algorithm for determining the coordinates of the UAV VIA GSM

VII. DETERMINING OF TWO NEAREST NETWORK STATIONS

The scheme of two strongest signals from BS determination is represented on Fig. 9.

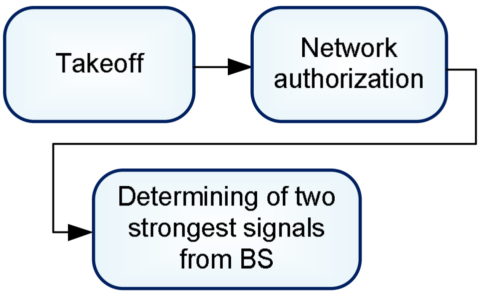

Fig. 9. Scheme of two strongest signals from BS determination

Authentication Center is designed to authenticate each SIM card that attempts to join the GSM network. Once completed the authentication process, the controller can receive data from the services, where the subscriber is signed. Also an encryption code (key) is generated which is periodically used to encrypt the wireless connection between the device and the network.

Authentication Center is not directly involved in the authentication process, but instead it generates data known as triplets, which are used during the procedure.

Each base station transmits to the broadcast the information about their ”neighbors”, indicating the frequency, on which the nearest base station of the same network are working. This unit in the standby mode is continuously measuring the signal from each of the “neighboring” base and, if necessary, selects as the duty base station that one, the signal of which is “better heard.”

If you know where (at what coordinates) are located the base stations, then it may attempt to calculate the area in which the area of the hypothetical cover of all “neighboring” bases are intersected. Somewhere within this area the device will be located. The more precisely knows (or estimates) the border coverage, the more accurate this method will work. If there is no location data about base station, then there will be no possibility to compute their location.

VIII. DETERMINING OF THE COORDINATES OF BS, DISTINCTION OF THE BASIC STATION

The scheme of two nearest stations coordinate determination is represented on Fig. 10.

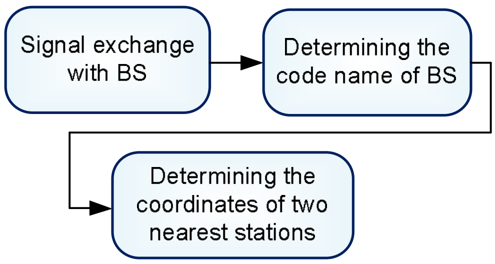

Fig. 10. Scheme of two nearest stations coordinate determination

The device is always in the range of at least one base station network. Any of the base stations has a set of parameters that receives a controller – thereby each BS can recognize it. One of these parameters – CellID (abbreviated as CID) – a unique number for each cell, issued by the operator. Knowing him, you can recognize the base station, and knowing the location of the base station, you can understand where you are. Accuracy varies from a few hundred meters to several kilometers, but it's a good starting point to deal with the coordinates.

So, having the plate, where, in accordance with each base station the coordinates will be matched, we can calculate the position of the caller.

Knowing the code name for the BS, we can find out their location coordinates from the map of BS.

IX. DEFINITION OF THE COORDINATE LOCATION OF THE OBJECT IN THE GSM AND UMTS NETWORKS

To determine the coordinates and motion parameters of the moving ground objects navigation systems are widely used. Composition of navigation systems is determined on the base of necessity to determine the coordinates of the current location of the mobile object by the method of notation correction and dead reckoning. For correction of the coordinates in navigation systems wide application have found satellite radio navigation system GLONASS (Global Navigation Satellite System) and NAVSTAR (Navstar – Navigational Satellite Time and Ranging – navigation satellite measurements of time and coordinates) or by its actual purpose GPS. The main advantages of these navigation systems are: unlimited range; high accuracy; unambiguous definitions of navigation; the possibility of measuring the orientation angles; high noise immunity; unlimited number of serviced sites.

The improvement of the navigation of mobile ground objects is possible by the use of systems, whose operation is based on the use of new technologies. For such systems, it is advisable to use a cellular terrestrial radio infrastructure capacity and its additional base control and correction stations.

Currently, mobile operators offer services to determine the location of the subscriber. Solution of the problem of determining the location of the subscriber in cellular networks start with a simple method - Cell ID. This method is based on determining the location of a subscriber with an accuracy of a cell. The error location in such a way is rather low and can be up to 30 km. There are other methods of positioning in GSM and UMTS networks, such as the Time of Arrival (TOA) and Observed Time Difference (OTD). TOA method is based on measuring and comparing the time intervals of the signal from the mobile phone to a few (at least 2) base stations. Achieved with this method positioning accuracy is up to 125 meters. OTD method is based on measurement and comparison of the time intervals of the signals from multiple base stations to a mobile phone. This method can achieve positioning accuracy of 50 meters.

Suppose that there are two GSM or UMTS base stations with known coordinates $A(x_1; y_1)$ and $B(x_2; y_2)$ (Fig. 11). Consider that on the board of a moving object, using the unidirectional antenna, the azimuth angles α_1 and α_2 are determined on the first and second base station respectively. Using the positional method, we need to determine the coordinates of the location point $0(x; y)$ of a moving object.

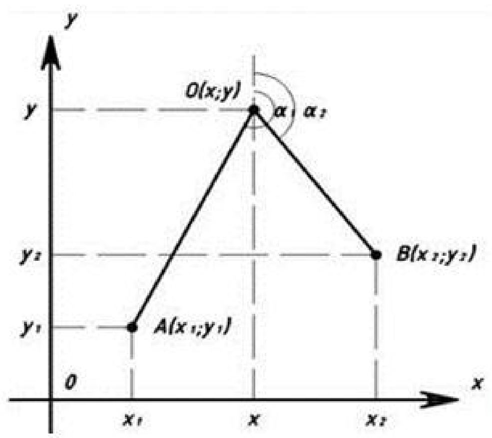

Fig. 11. Location coordinates determination principle

X. THE ALGORITHM FOR DEFINITION THE LOCATION OF THE OBJECT

The coordinates of the location point $0(x; y)$ of a moving object we will define as the intersection of two straight lines. To do this, we will write the equation of a straight line of a common type:

$$y = kx + d,$$

where $k = \text{tg}\alpha$ is the tangent of pitch angle.

When we know the coordinates of the base stations, let's define using (1) the values d_1 and d_2:

$$\begin{aligned} d_1 &= y_1 - \text{tg}\alpha_1 x_1; \\ d_2 &= y_2 - \text{tg}\alpha_2 x_2. \end{aligned} \quad (1)$$

Let's write the system of equations for finding the coordinates of point $0(x; y)$:

$$\begin{cases} y = tg\alpha_1 \times x_1 + d_1; \\ y = tg\alpha_2 \times x_2 + d_2. \end{cases} \quad (2)$$

Let's put to the system (2) coefficients d_1 and d_2:

$$\begin{cases} y = tg\alpha_1 x_1 + d_1 + y_1 - tg\alpha_1 x_1; \\ y = tg\alpha_2 x_2 + d_2 + y_2 - tg\alpha_2 x_2. \end{cases} \quad (3)$$

Solving the system (3), let's express the coordinates of point $0(x; y)$ by intersection of two lines:

$$x = \frac{y_2 - \text{tg}\alpha_2 x_2 - y_1 + \text{tg}\alpha_1 x_1}{\text{tg}\alpha_1 - \text{tg}\alpha_2}, \quad (4)$$

$$y = \text{tg}\alpha_1 \left(\frac{y_2 - \text{tg}\alpha_2 x_2 - y_1 + \text{tg}\alpha_1 x_1}{\text{tg}\alpha_1 - \text{tg}\alpha_2} \right) + y_1 - \text{tg}\alpha_1 x_1. \quad (5)$$

Obtained expressions (4) and (5) are the possible coordinates of a moving object. For their calculations, we need to know coordinates of base stations and azimuth angles on these stations.

CONCLUSIONS

Here it was explained the necessity of development of navigation system on the base of mobile network for positioning of moving objects. There was also represented the overview and the analysis of all the existing methods of positioning in navigation systems, in particular in GSM systems. There also was represented the description of realization methods and performing technology.

Among the main advantages of this method, I should distinguish rather fast capability of defining the coordinates in the city. Main disadvantage – is low accuracy of this method of defining the coordinates, because of a huge amount of buildings in the city that creates interference during the positioning.

The created method is very easy to use, and further development of such methods can cardinally improve the positioning processes in navigation systems. These methods can be especially useful in military, industrial and emergency spheres of development.

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В. М. Синєглазов, С. С. Шильдський. Навігацийні системи на основі систем мобільного зв'язку
Розроблено та розглянуто алгоритм позиціонування на борту рухомого об'єкту із застосуванням інформації про отримання сигналів від базових мобільних станцій. Розроблена система може застосовуватися як ефективний та надійний метод позиціонування.
Ключові слова: алгоритм позиціонування; отримання сигналу; код місцевості; центр аутентифікації.

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В. М. Синеглазов, С. С. Шильдский. Навигационные системы на основе систем мобильной связи
Разработан и рассмотрен алгоритм позиционирования на борту движущегося объекта, используя информацию о направлении получения сигнала от базовых мобильных станций. Разработаная система может использоваться как эффективный и надежный метод позиционирования.
Ключевые слова: алгоритм позиционирования; получение сигнала; код местности; центр аутентификации.

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