Infrastructure of Contemporary Maritime Communication, Navigation and Surveillance (CNS) System

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Abstract: This paper introduces development and implementation of Maritime Satellite Communications, Navigation and Surveillance (CNS) of GPS or GLONASS for enhancement of safety and emergency systems including security and control of vessels, logistic and freight at sea, on inland waters and the security of crew and passengers onboard oceangoing ships, cruisers, boats, rigs and hovercrafts. These improvements include many applications for the better management and operation of vessels and they are needed more than ever because of world merchant fleet expansion. Just the top 20 world ships registers have more than 40,000 units under their national flags. Above all, the biggest problem today is that merchant ships and their crews are targets of the types of crime traditionally associated with the maritime industries, such as piracy, robbery and recently, a target for terrorist attacks. Thus, International Maritime Organization (IMO) and flag states will have a vital role in developing International Ship and Port Security (ISPS). The best way to implement ISPS is to design an Approaching and Port Control System (APCS) by special code augmentation satellite CNS for all ships including tracking and monitoring of all vehicle circulation in and out of the seaport area. The establishment of Maritime CNS is discussed as a part of Global Satellite Augmentation Systems (GSAS) of the US GPS and Russian GLONASS for integration of the existing Regional Satellite Augmentation Systems (RSAS) such as the US WAAS, European EGNOS and Japanese MSAS, and for development new RSAS such as the Russian SDMC, Chinese SNAS, Indian GAGAN and African ASAS. This research has also to include RSAS for Australia and South America, to meet all requirements for GSAS and to complement the services already provided by Differential GPS (DGPS) for Maritime application of the US Coast Guard by development Local Satellite Augmentation System (LSAS) in seaports areas.

Key Words: IMO, ISCS, APCS, GSAS, RSAS, LSAS, GPS, GLONASS, ICAA, WSAS, EGNOS, MSAS, SDCM, SNAS, GAGAN, ASAS, MTAS, MMSS, MCS, MNS, MSS, SESR, RSD, FSPP, OSGC, CMGC

1. Introduction

The current infrastructures of the Global Navigation Satellite System (GNSS) applications are represented by old fundamental solutions for Position, Velocity and Time (PVT) of the satellite navigation and determination systems such as the US Global Position System (GPS) and Russian (former Soviet Union) Global Navigation Satellite System (GLONASS) military requirements, respectively. The GPS and GLONASS are first generation of GNSS-1 infrastructures giving positions to about 30 metres, using simple GPS/GLONASS receivers (Rx) onboard ships or aircraft, and they therefore suffer from certain weaknesses, which make them impossible to be used as the sole means of navigation for ships, particularly for land (road and rail) and aviation applications. In this sense, technically GPS or GLONASS systems used autonomously are incapable of meeting civil maritime, land and especially aeronautical mobile very high requirements for integrity, position availability and determination precision in particular for Traffic Control and Management (TCM) and are insufficient for certain very critical navigation and flight stages **[1, 2, 3].**

Because these two systems are developed to provide navigation particulars of position and speed on the ship's bridges or in the airplane cockpits, only captains of the ships or airplanes know very well their position and speed, but people in Traffic Control Centers (TCC) cannot get in all circumstances their navigation or flight data without service of new CNS facilities. Besides of accuracy of GPS or GLONASS, without new CNS is not possible to provide full TCM in every critical or unusual situation. Also these two GNSS systems are initially developed for military utilization only, and now are also serving for all transport civilian applications worldwide, so many countries and international organizations would never be dependent on or even entrust people's safety to GNSS systems controlled by one or two countries. However, augmented GNSS-1 solutions of GSAS network were recently developed to improve the mentioned deficiencies of current military systems and to meet the present transportation civilian requirements for high-operating Integrity, Continuity, Accuracy and Availability (ICAA).

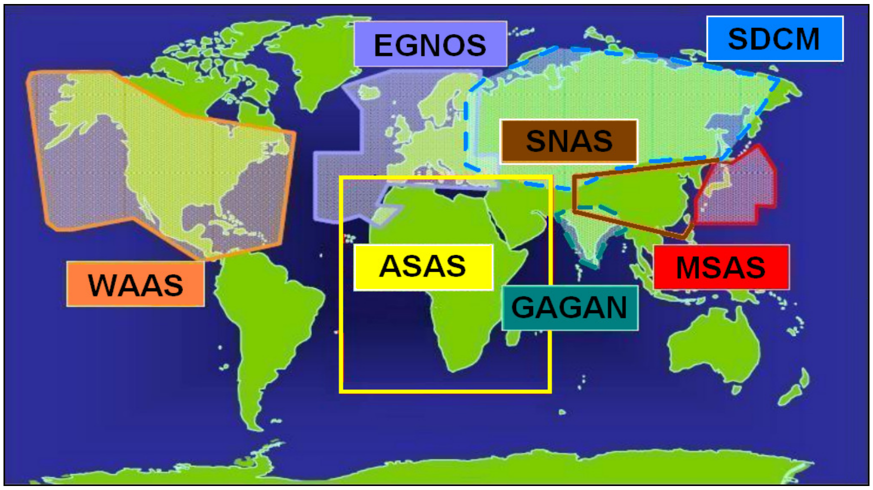

Figure 1. GSAS Network Configuration – Source: Ilcev **[1]**

These new developed and operational CNS solutions are the US Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay System (EGNOS) and Japanese MTSAT Satellite-based Augmentation System (MSAS), and there are able to provide CNS data from mobiles to the TCC via Geostationary Earth Orbit (GEO) satellite constellation.

These three RSAS are integration segments of the GSAS network and parts of the interoperable GNSS-1 architecture of GPS and GLONASS and new GNSS-2 of the European Galileo and Chinese Compass, including Inmarsat CNSO (Civil Navigation Satellite Overlay) and new projects of RSAS infrastructures. The additional four RSAS of GNSS-1 networks in development phase are the Russian System of Differential Correction and Monitoring (SDCM), the Chinese Satellite Navigation Augmentation System (SNAS), Indian GPS/GLONASS and GEOS Augmented Navigation (GAGAN) and African Satellite Augmentation System (ASAS). Only remain something to be done in South America and Australia for establishment of the GSAS infrastructure globally, illustrated in **Figure 1.**

The RSAS solutions are based on the GNSS-1 signals for augmentation, which evolution is known as the GSAS network and which service provides an overlay function and supplementary services. The future ASAS Space Segment will be consisted by existing GEO birds, such as Inmarsat-4 and Artemis or it will implement own satellite constellation, to transmit overlay signals almost identical to those of GPS and GLONASS and provide CNS service. The South African firm IS Marine Radio, as designer of the Project will have overall responsibility for the design and development of the ASAS network with all governments in the region **[1, 4, 5, 6, 7].**

1.1. Current GNSS Applications

The RSAS infrastructures are available globally to enhance current standalone GPS and GLONASS system PVT performances for maritime, land (road and rail) and aeronautical transport applications. Mobile user devices can be configured to make use of internal sensors for added robustness in the presence of jamming, or to aid in vehicle navigation when the satellite signals are blocked in the "urban canyons" of tall city buildings or mountainous environment. In the similar sense, some special transport solutions, such as maritime and especially aeronautical, require far more CNS accuracy and reliability than it can be provided by current military GPS and GLONASS space infrastructures.

Moreover, positioning accuracy can be improved by removing the correlated errors between two or more satellites GPS and/or GLONASS Rx terminals performing range measurements to the same satellites. This type of Rx is in fact Reference Receiver (RR) surveyed in, because its geographical location is precisely well known. In such a manner, one method of achieving common error removal is to take the difference between the RR terminals surveyed position and its electronically derived position at a discrete time point **[8, 9, 10].**

These positions differences represent the error at the measurement time and are denoted as the differential correction, which information may be broadcast via GEO data link to the user receiving equipment. In this case the user GPS or GLONASS augmented Rx can remove the error from its received data. Alternatively, in non-real-time technique GNSS solutions, the differential corrections can be stored along with the user's positional data and will be applied after the data collection period, which is typically used in surveying applications **[7]**.

If the RR or Ground Monitoring Station (GMS) of the mobile users, the mode is usually referred to as local area differential, similar to the US DGPS for Maritime applications. In this way, as the distance increases between the users and the GMS, some ranging errors become decorrelated. This problem can be overcome by installing a network which consist a number of GMS reference sites throughout a large geographic area, such as a region or continent and broadcasting the Differential Corrections (DC) via GEO satellites. In such a way, the new projected ASAS network has to cover entire African Continent and the Middle East region.

Therefore, all GMS sites connected by Terrestrial Telecommunication Networks (TTN) relay collected data to one or more Ground Control Stations (GCS), where DC is performed and satellite signal integrity is checked. Then, the GCS sends the corrections and integrity data to a major Ground Earth Station (GES) for uplink to the GEO satellite. This differential technique is referred to as the wide area differential system, which is implemented by GNSS system known as Wide Augmentation Area (WAA), while another system known, as Local Augmentation Area (LAA) is an implementation of a local area differential **[9]**. The LAA a local area differential solution is an implementation for seaports and airport including for approaching utilizations. The WAA network is an implementation of a wide area differential system for wide area CNS maritime, land and aeronautical applications, such as Inmarsat CNSO and the newly developed Satellite Augmentation WAAS in the USA, the European EGNOS and Japanese MSAS **[1, 7]**.

These three operational systems are part of the worldwide GSAS network and integration segments of the future interoperable GNSS-1 architecture of GPS and GLONASS and GNSS-2 of Galileo and Compass, including CNSO as a part of GNSS offering this service via Inmarsat-3/4 and Artemis spacecraft. The author of this paper for the first time is using more adequate nomenclature GSAS than Satellite-based Augmentation System (SBAS) of ICAO, which has to be adopted as the more common designation in the field of CNS **[7, 10]**. As discussed earlier, the current three RSAS networks in development phase are the Russian SDCM, Chinese SNAS and Indian GAGAN, while African Continent and Middle East have to start at the beginning of 2011 with development ASAS project. In this sense, development of forthcoming RSAS projects in Australia and South America will complete Augmented CNS system worldwide, known as an GSAS Network **[7]**.

Three operational RSAS together with Inmarsat CNSO are interoperable, compatible and each constituted of a network of GPS or GLONASS observation stations and own and/or leased GEO communication satellites. Namely, the Inmarsat CNSO system offers on leasing GNSS payload to the European system EGNOS, which will provide precision to within about 5 metres and is operational from 2009. In fact, it also constitutes the first steps towards forthcoming Galileo, the future European system for civilian global navigation by satellite. The EGNOS system uses leased Inmarsat AOR-E and IOR satellites and ESA ARTEMIS satellite.

Thus, the US-based WAAS is using Inmarsat satellites and Japanese MSAS is using its own multipurpose MTSAT spacecraft, both are operational from 2007 and 2008, respectively. Although the global positioning accuracy system associated with the overlay is a function of numerous technical factors, including the ground network architecture, the expected accuracy for the US Federal Aviation Administration (FAA) WAAS will be in the order of 7.6 m (2 drms, 95%) in the horizontal plane and 7.6 m (95%) in the vertical plane **[4, 5, 11, 12]**.

1.2. New RSAS System Configurations

The RSAS network are designed and implemented as the primary means of satellite CNS for maritime course operations such as ocean crossings, navigation at open and close seas, coastal navigation, channels and passages, approaching to anchorages and ports, and inside of ports, and for land (road and railways) solutions.

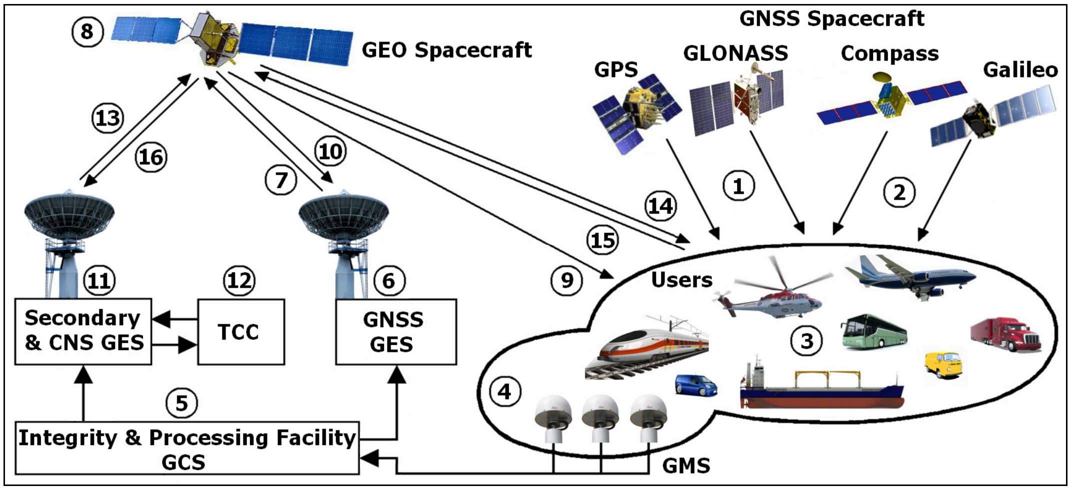

Figure 2. ASAS Network Configuration – Source: Ilcev **[7]**

In this sense, it will also serve for aviation routes in corridors over continents and oceans, control of airports approaching and managing all aircraft and vehicles movements on airports surface **[3].**
It was intended to provide the following services:
1) The transmission of integrity and health information on each GPS or GLONASS satellite in real time to ensure all users do not use faulty satellites for navigation, known as the GNSS Integrity Channel (GIC).
2) The continuous transmission of ranging signals in addition to the GIC service, to supplement GPS, thereby increasing GPS/GLONASS signal availability. Increased signal availability also translates into an increase in Receiver Autonomous Integrity Monitoring (RAIM) availability, which is known as Ranging GIC (RGIC).
3) The transmission of GPS or GLONASS wide area differential corrections has, in addition to the GIC and RGIC services, to increase the accuracy of civil GPS and GLONASS signals. Namely, this feature has been called the Wide Area Differential GNSS (WADGNSS).
The combination of the Inmarsat overlay services and Artemis spacecraft will be referred to as the ASAS network illustrated in **Figure 2.** As observed previous figure, all mobile users **(3)** receive navigation signals **(1)** from GNSS-1 of GPS or GLONASS satellites. In the near future can be used GNSS-2 signals of Galileo and Compass satellites **(2).** These signals are also received by all reference GMS terminals of integrity monitoring networks **(4)** operated by governmental agencies in all countries within Africa and Middle East.
The monitored data are sent to a regional Integrity and Processing Facility of GCS **(5)**, where the data is processed to form the integrity and WADGNSS correction messages, which are then forwarded to the Primary GNSS GES **(6)**. At the GES, the navigation signals are precisely synchronized to a reference time and modulated with the GIC message data and WADGNSS corrections. The signals are sent to a satellite on the C-band uplink **(7)** via GNSS payload located in GEO Inmarsat and Artemis spacecraft **(8)**, the augmented signals are frequency-translated to the mobile user on L1 and new L5-band **(9)** and to the C-band **(10)** used for maintaining the navigation signal timing loop. The timing of the signal is done in a very precise manner in order that the signal will appear as though it was generated onboard the satellite as a GPS ranging signal. The Secondary GNSS GES can be installed in Communication CNS GES **(11)**, as a hot standby in the event of failure at the Primary GNSS GES. The TCC ground terminals **(12)** could send request to all particular mobiles for providing CNS information by Voice or Data, including new Voice, Data and Video over IP (VDVoIP) on C-band uplink **(13)** via Communication payload located in Inmarsat or Artemis spacecraft and on C-band downlink **(14)** to mobile users **(3)**.
The mobile users are able to send augmented CNS data on L-band uplink **(15)** via the same spacecraft and L-band downlink **(16)**. The TCC sites are processing CNS data received from mobile users by Host and displaying on the surveillance screen their current positions very accurate and in the real time **[13]**. Therefore, the ASAS will be used as a primary means of navigation during all phases of traveling for all mobile applications **[1, 7, 10, 13].**

The RSAS space constellation could be formally consisted in the 24 operational GPS and 24 GLONASS satellites and of 2 Inmarsat and 1 Artemis GEO satellites. The GEO satellites downlink the data to the users on the GPS L1 RF with a modulation similar to that used by GPS. Information in the navigational message, when processed by an RSAS Rx, allows the GEO satellites to be used as additional GPS-like satellites, thus increasing the availability of the satellite constellation. At this point, the RSAS signal resembles a GPS signal origination from the Gold Code family of 1023 possible codes (19 signals from PRN 120-138) **[9, 14].**

2. Maritime Transportation Augmentation System (MTAS)

The navigation transponder of GEO payload is a key part of the entire system. Thus, it sends GNSS signals to mobiles in the same way as GPS or GLONASS satellites and improves the ICAA positioning system. Thanks to the large number of mobiles, the GNSS signal is able to incorporate data on GPS spacecraft status and correction factors, greatly improving the reliability and accuracy of the present GPS system, which comes to few tenths of metres. The augmented GPS and GLONASS accuracy will be just a few metres, allowing maritime and land traffic to be controlled solely by satellite, without ground radar or radio beacons facilities. The development of the MTAS was to identify the possible applications for enhancement of Radio and Satellite CNS and safety systems including security and control of vessels, logistic and freight at sea, on inland waters and the security of crew and passengers onboard oceangoing ships, cruisers, boats and hovercrafts. These enhancements include many applications for the better management and operation of vessels and they are needed more than ever because of world merchant fleet expansion.
To complement the GPS channel, communication channels allow bidirectional transmission between ships and GES. The ship sends its position and navigation data to the Port authorities, TTC and to the relevant ship-owner. This enables ship movements to be managed and to enhance safety at sea and to improve operating efficiency. The satellite will forward flexible and safe routing information to ships, as determined by the shore centre, decreasing fuel consumption, reducing sailing times and enhancing the safety and security systems in all sailing stages. The CNS/MTAS mission is divided into three Maritime CNS systems, such as Communication, Navigation and Surveillance. As usual, the MTAS system consists in space and ground infrastructures **[1, 2, 15]**.

2.1. Space Segment

The space segment for MTAS infrastructure and mission, as a part of GSAS configuration, can be the same new designed GEO and/or leased Inmarsat, Japanese MTSAT, European Artemis of ESA or any existing GEO with enough space for GNSS transponder inside of payload. The spacecraft GNSS payload can provide global and spot beam coverage with determined position on about 36,000 km over the equator.
The MTAS spacecraft also can have an innovative communication purpose payload for Maritime Mobile Satellite Service (MMSS), which will be similar to the Inmarsat system of Maritime Satellite Communications (MSC). The heart of the payload is an IF processor that separates all the incoming channels and forwards them to the appropriate beam in both directions: forward (ground-to-ship) and return (ship-to-ground). In fact, global beam covers 1/3 of the Earth between 75^{o} North and South latitudes. Thus, spot beam coverage usually consists in 6 spot beams over determined regions including heavy traffic areas at sea, to meet the demands of increasing maritime transport operations and for enhanced safety and security **[1, 7, 16]**.
The GNSS signal characteristics are generally based on the ICAO Annex 10 (SARP), IMO and Inmarsat SDM and comply with the Radio Regulations and ITU-R Recommendations. This type of spacecraft has two the following types of satellite links related to the maritime Ship Earth Stations (SES) and Ground Earth Stations (GES):
1. Forward GES to Satellite Direction – The GES terminals are located throughout the region coverage and their signals are received by L, Ku or a Ka-band ships antenna. Thanks to the very high Radio Frequency (RF) used, the reflector size of the antennas is quite small, 500 mm for Ku-band, 450 mm for Ka-band and double size for L-band.

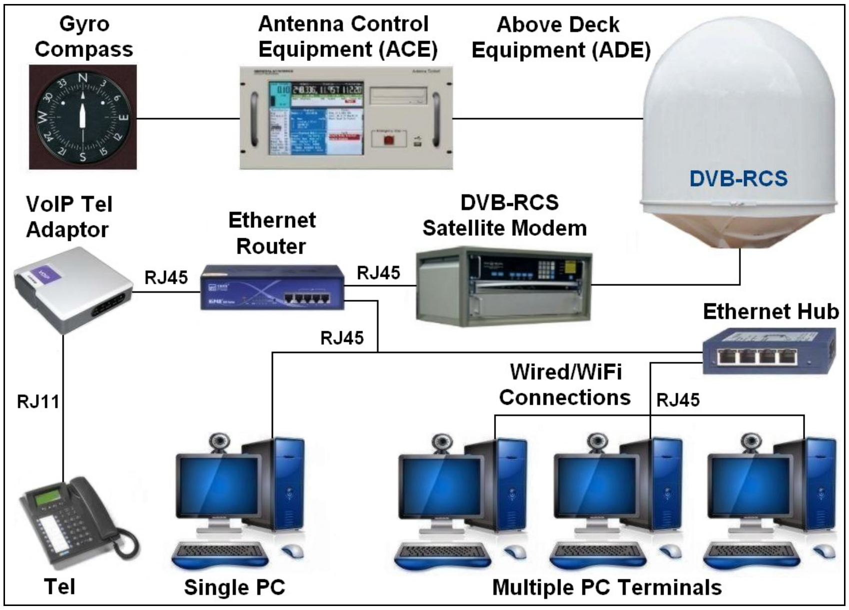

Figure 3. SES or Shipborne DVB-RCS Terminal or SES – Source: Ilcev **[4]**

The reflector onboard mobile is movable via focusing tracking motors automatically correcting Azimuth and Elevation angles. The focusing motors are connected to the Gyrocompass onboard ships, so that it can work with the communications satellite payloads in any of the possible vessel positions in four GEO coverages, see **Figure 3.** The GES uses C-band feeder link and SES uses L-band service link with larger size of antenna than antennas using Ku and Ka-band. The SES standards are using new broadband technique and are capable to provide Broadcast, Multimedia and Internet service for Voice, Data and Video over IP (VDVoIP) and IPTV. Incoming signals are then amplified, converted to IF, filtered and routed within the IF processor where they are then up-converted and transmitted to the SES. Otherwise, the author of this paper proposed this solution in 2000 in his book **[6]** as Maritime Broadband, seven years before Inmarsat offered and promoted its FleetBroadband**.**

2. Return Satellite to GES Direction – The L-band signal received from approaching SES are processed in the same way and retransmitted to GES via Ku and Ka-band GES antennas, although the GES system can also employ Inmarsat C-band transmitter and antenna. The output power of the Ku and Ka-band SES transmitters is just 2W thanks to the high gain satellite antenna. It is also possible to provide station-to-station channels in either the Ku or Ka-band to enable stations working with different spots to communicate with one another. The GNSS channel is also routed to GES on same two bands for calibration purposes **[1, 4, 7, 11]**.

2.2. Ground Segment

The MTAS Ground Segment consists in several GES and Ground Control Terminal (GCT) located in any corresponding positions. Thus, an important feature of these stations is that they have been built to withstand earthquakes, which also required a special antenna design.

1. Ground Earth Stations (GES) – In order to provide continuous service, even during natural disasters, two GES can be implemented at two different locations separated by about 500 km. The MMSS provided by GES is in charge of all communication functions via satellites. With a 13 m antenna diameter GES transmits and receives signals in the Ku, Ka and C-band. A very high EIRP of 85 dBW and a high G/T ratio of 40 dB/K are achieved in the Ku and Ka-band, respectively and ensure very high availability of the feeder link. The L-band terminal similar to the SES is used for the system testing and monitoring. About 300 circuits are available simultaneously in both: transmit and receive directions. It also includes dedicated equipment for testing the satellite performance after launch and for permanent monitoring of the traffic system. Top-level management software is provided to configure the overall system and check its status.

2. Ship Earth Stations (SES) – Special part of the MTAS Ground Segment are SES terminals approaching to the entire region including GNSS. It is similar to the Inmarsat standards containing: ADE (Above Deck Equipment) as an antenna and BDE (Below Deck Equipment) as a transceiver with peripheral equipment using L-band. The BDE Voice, Data and Video (VDV) terminals can be used for ship crew and cabin crew including passenger applications. The SES is a ship-mounted radio capable of communications via spacecraft in the MTAS system, providing VDV and Fax two-way service anywhere inside the satellite footprint.
3. Satellite Control Stations (SCS) – The SCS terminal is usually located in the same building as the GES and utilizes an antenna with the same diameter. This station has to control the satellite throughout its operational life in the Network. Two Radio Frequency (RF) bands can be used: S-band in normal operation and Unified S-band (USB) while the satellite is being transferred to its final orbit, or in the event of an emergency when satellite loses its altitude. Accordingly, in S-band the EIRP is 84 dBW and for security reasons, the EIRP in USB is as high as 104 dBW. An SCS displays the satellite’s status and prepares telecommands to the satellite. Furthermore, the satellite position is measured very accurately (within 10 m) using a trilateral ranging system instead of measuring one signal, which is sent to the satellite then returned to the Earth. On the other hand, the Station sends out two additional signals, which are retransmitted by the satellite to two dedicated ranging stations on the ground, which return the same signals to the SCS via satellite. This technique allows the satellite’s position to be measured in three dimensions. On the other hand, a dynamic spacecraft simulator is also provided to check telecommands.
4. GNSS System – The GNSS system known as the MTAS for maritime applications consists in a large number of GMS, GCS, GES and few Geostationary Ranging Stations (GRS) to implement a wide triangular observation base for GEO satellite ranging. The GMS terminals are very small autonomous sites housed in a shelter of some adequate building with appropriate antenna system and trained staff. Each GMS computes its location using GPS and MTAS communication signals over the coverage area. Any differences between the calculated and real locations are used by the system to correct the satellite data. Data is sent to the GCS via the public network or satellite links, while the GCS collects all the information from each GMS. Complex software is able to calculate accurately the position and internal times of all GPS and MTAS satellites. The GNSS signal, incorporating the status of the GPS spacecraft and corrections, is calculated and sent to the traffic station known as GES for transmission to MTAS satellites **[1, 7, 8, 16]**.

3. Comparison of the Current and New Maritime CNS System

Business or corporate shipping and airways companies have used for several decades HF communication for long-range voice and telex communications during intercontinental sailing and flights. Meanwhile, for short distances mobiles have used the well-known VHF onboard ships and VHF/UHF radio on aircraft. In the similar way, data communications are recently also in use, primarily for travel plan and worldwide weather (WX) and navigation (NX) warning reporting. Apart from data service for cabin crew, cabin voice solutions and passenger telephony have also been developed. Thus, all mobiles today are using traditional electronic and instrument navigations systems and for surveillance facilities they are employing radars.
The Current Communication System between ships and Ship Traffic Control (STC) or Ship Traffic Management (STM) are executed by Radio MF/HF voice and telex and by VHF voice system is shown in **Figure 4 (Above Left)**. The VHF link between ships and Coast Radio Station (CRS) and TCC terminals may have the possibility to be interfered with high mountainous terrain and to provide problems for STC. The HF link may not be established due to lack of available frequencies, high frequency jamming, bad propagation, intermediation, unstable wave conditions and to very bad weather, heavy rain or thunderstorms.
The current Navigation System provides possibilities for recording and processing Radio Direction Information (RDI) and Radio Direction Distance Information (RDDI) between vessels and TCC or STC centre are performed by ground navigation equipment, such as the shore Radar, Racons (Radar Beacon) and Passive Radar Reflectors, integrated with VHF CRS facilities, shown in **Figure 4 (Middle Left)**.

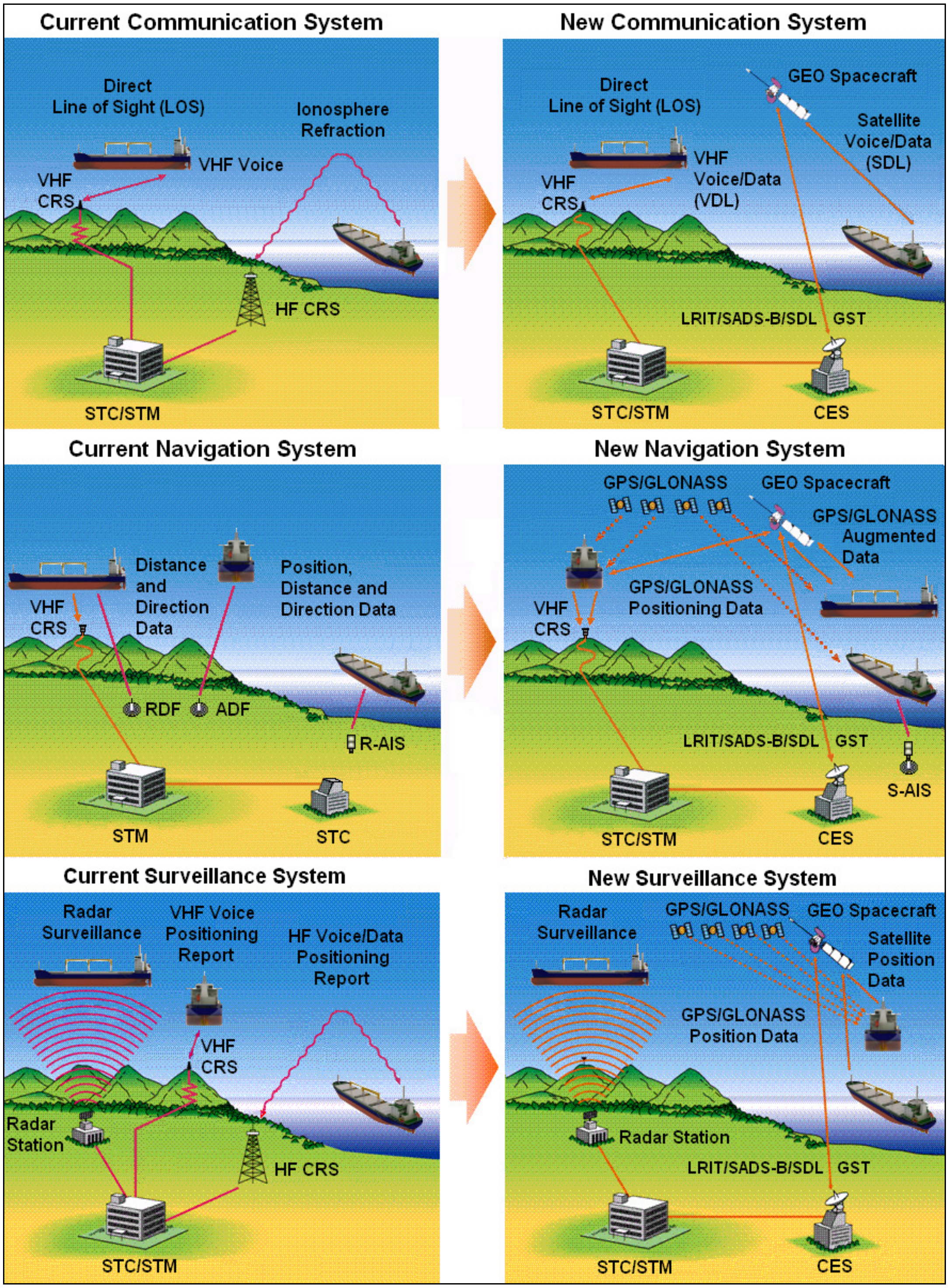

Figure 4. Current and New Maritime CNS/STM System – Source: Ilcev **[1]**

However, this subsystem needs more time for ranging and secure navigation at the deep seas, within the cannels and approachings to the anchorages and ports, using appropriate number of types of radar and other visual and electronic navigational aids.

The Current Surveillance System utilities Radar and VHF Voice Position Reports (VPR) and HF Radio Data/VPR between ships and TCC and STM can be detected by Radar and MF/HF/VHF CRS. This subsystem may have similar propagation problems and limited range or when ships are sailing inside of fiords and behind high mountains Coastal Radar cannot detect them; see the Surveillance Subsystem in **Figure 4 (Below Left).**

The very bad weather conditions, deep clouds and heavy rain could block radar signals totally and on the screen will be blanc picture without any reflected signals, so in this case cannot be visible surrounded obstacles or traffic of ships in the vicinity, and the navigation situation is becoming very critical and dangerous causing collisions and huge disasters **[1, 8, 15]**.
The New Communication System utilizes the communications satellite and it will eliminate the possibility of interference by very high mountains, which communication CNS subsystems is shown in **Figure 4 (Above Right)**. At this point, satellite voice communications, including a data link, augments a range and improves both the quality and capacity of communications. The WX and NX warnings, sailing planning and NAVAREA information may also be directly input to the Navigation Management System (NMS). The New Navigation System shown in **Figure 4 (Middle Right)** is providing improved GPS/GLONASS navigation data, while New Surveillance System shown in Figure 4 (Below Right) is utilizing augmented facilities of GPS or GLONASS signals. Thus, if the navigation course is free of islands or shallow waters, the GPS Navigation Subsystem data provides a direct approaching line and the surveillance information cannot be interfered by mountainous terrain or bad weather conditions. The display on the screen will eliminate misunderstandings between controllers and ship's Masters or Pilots **[2, 4, 6, 17]**.

4. Maritime Mobile Satellite Service (MMSS)

The MMSS functions in frame of the new MTAS infrastructure include the provision of all the mobile maritime communications defined by the IMO, such as new Global Maritime Distress and Safety System (GMDSS), Inmarsat and Cospas-Sarsat systems, including new systems with nomenclatures such as Maritime Commercial Communications (MCC) and Maritime Crew and Passenger Communications (MCPC). In a more general sense, these MSC service solutions could be available for STC and STM providers and maritime operators in all ocean regions through data link service providers. Direct access to the MTAS network could also be possible through the implementation of dedicated GES in other states covered by MTAS spacecraft.
The MTAS system for the SES is interoperable with MSC system of the Inmarsat Space and Ground network. It can be connected directly to the navigation bridge GMDSS operator (Master, duty-deck or radio officer) by VDV, Fax, video, GPS augmentation information and Automatic Dependent Surveillance System (ADSS). The MTAS will not only be capable of handling MTS for ocean going vessels, but will also be offered to the Civil Maritime Community (CMC) in all coastal regions as an infrastructure, which could facilitate the implementation of the future IMO CNS/STM systems.
The MTAS service provides all ocean going vessels with GPS augmentation information to improve safety and security at sea and all navigational performance requirements, namely to find out the response to the demands of ICAA, which are essential to the use of GPS or GLONASS for vessels operation as the sole means of navigation. Using previous not augmented system, ship navigation officers know very well where their ship is in space and time, but offshore STC terminals don't know.
In order to provide all ships and STC with sufficient GPS or GLONASS augmentation information and satellite surveillance, a certain number and location of GMS will be required. At this point, the number and location of GMS required for each state in the region will depend on the requirements for the level of navigation services and reception of GPS signals. The MTAS system needs number of GMS, few GCS and GES for the each region.
The MTAS system as a part of the MMSS infrastructure for the SES terminals is interoperable with MSC system of the Inmarsat or Iridium Space and Ground network for enhanced GMDSS network.
This system can be connected directly to the ships navigation bridge GMDSS operator (Master, duty-deck or radio officer) by VDV, Fax, video, GPS augmentation information and Automatic Dependent Surveillance System (ADSS).
The MTAS will not only be capable of handling STC/STM service for ocean going vessels, but will also be offered to the Civil Maritime Community (CMC) in all coastal regions as an infrastructure, which could facilitate the implementation of the future IMO CNS/MTM systems **[1, 6, 18, 19]**.

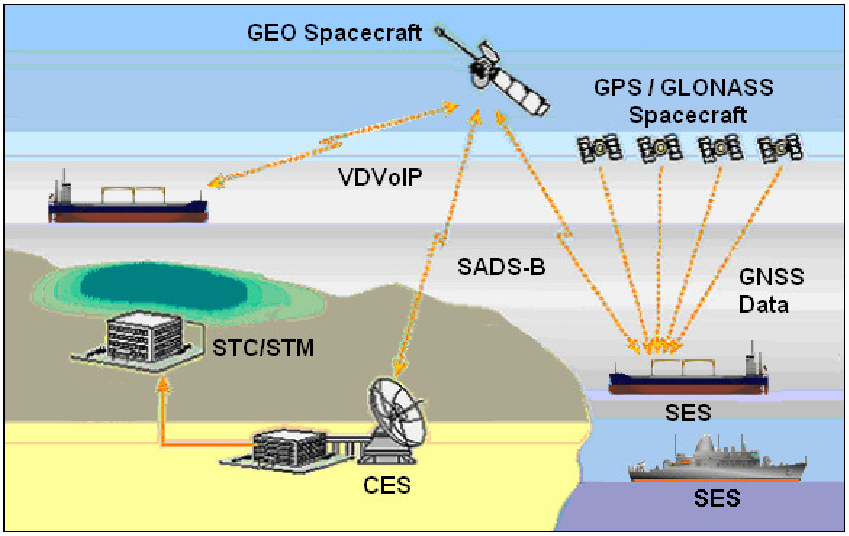

Figure 5. Modern MCS Network – Source: Ilcev **[1]**

4.1. New Maritime Communication Subsystem (MCS)

The current Maritime Radio Communications (MRC) system for general international purposes has been operational over 100 years and recently was replaced by New MCS system to enhance ship-to-shore voice (VDVoIP) and data Satellite Automatic Dependent Surveillance-Broadcast (SADS-B) data traffic for both commercial and safety applications, which MCS architecture is shown in **Figure 5**. In general, the initial development will have been established by using a service of MRC on MF and HF Morse radiotelegraphy, radio telex and radiotelephony (voice) for maritime medium and long distance communications, respectively. The latter progress was in order to promote advanced maritime commercial, safety, approaching and on scene distress communications on VHF voice frequency band. Finally, global DCS MF/HF/VHF Radio subsystem was developed by IMO in frame of GMDSS system an integrated with Inmarsat and Cospas-Sarsat facilities.
Meanwhile, in order to respond to the significant increase in the volume of communications data that has accompanied the large increases in cargo maritime traffic, periodic communications have moved to the satellite communications low, medium and high speed data link and data transmission has become the core type of maritime communications. The media needs to be divided to reflect this change in communications content, which has seen voice (Tel) communications used mainly for irregular safety and security or even for emergency situations in general. A transmission system based on fundaments new GMDSS digital technology (bit-based) needs to be integrated by the MTAS, to introduce wholesale improvements in Satellite CNS ability and to enhance current system for emergency (distress, safety and security).
Gradually, new MMSS VDV and VDVoIP satellite links have come into use and totally may replace old HF and VHF traditional radio (MRC). Because of any emergency and very bad weather conditions ship can be extremely affected, it is necessary to keep them as alternative solutions and to employ again a well-trained Radio Officer onboard every oceangoing ship. However, in normal circumstances and for fast communication impact SES can be used for communications with corresponding GES via any MATS or Inmarsat GEO satellite for maritime commercial, emergency and social purposes **[1, 4, 12, 20]**.

4.2. New Maritime Navigation Subsystem (MNS)

The GPS or GLONASS can be used worldwide to control the positions of vessels and to manage maritime traffic for oceangoing and coastal navigation. They support vessel's navigation well in all routing phases, including approaching to the port and mooring utilities. In fact, they have some performance limitations and they cannot consistently provide the highly precise and quite safe information in the stable manner required for wide-area navigation services.

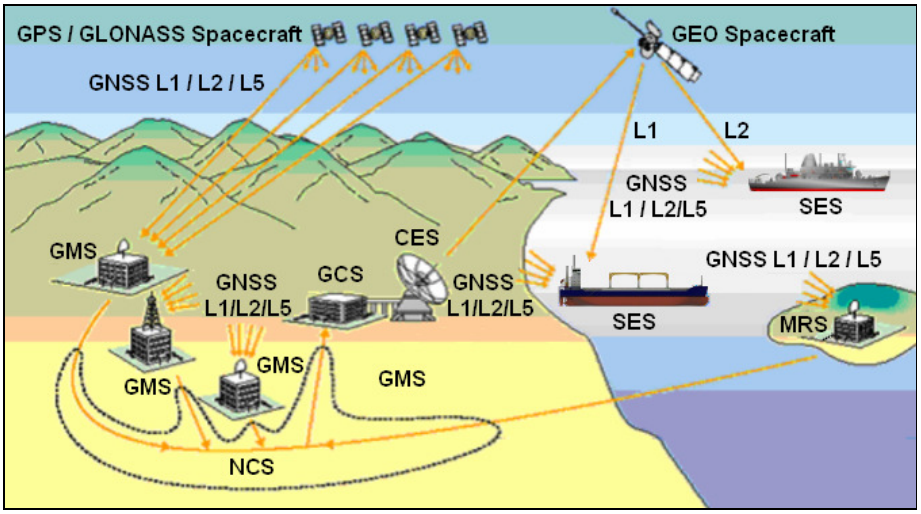

Figure 6. Modern MNS Network – Source: Ilcev **[19]**

To assure safe and efficient sea traffic navigation of civil vessels, GPS and GLONASS performance needs to be augmented with another system that provides ICAA essential elements well for sea navigation. The MTAS augmentation solution for GPS/GLONASS can be integrated with adequate Land Transportation Augmentation System (LTAS) and Aeronautical Transportation Augmentation System (ATAS) into the US WAAS, Japanese MSAS, European EGNOS, Russian SDCM, Chinese SNAS, Indian GAGAN and new systems such as ASAS, Australian and South American RSAS. Once in operation, this new state-of-the-art system will assure full navigation services for vessels in all navigation phases within the oceanwide, coastal, approaching and channel waters through GSAS coverage.

The L1/L2 RF band is nominated for the transmission of signals from GNSS spacecraft in ground and air directions, which can be detected by the GMS, GES and GNSS-1 onboard ship's receivers. Otherwise, the MTAS GNSS satellite transponder uses the L1 RF band to broadcast GNSS augmentation signals in the direction from GES to SES. The L, Ku or Ka-band is used for unlinking GNSS augmentation data from SES via GEO spacecraft to TCC. The whole ground infrastructure and Communication System is controlled by GCS and Network Control System (NCS). The components of the MTAS navigation system (MNS) are illustrated in **Figure 6**. To provide GNSS augmentation information, all ground stations, which monitor GNSS signals, are necessary in addition to MTAS. This special navigation infrastructure, which is composed by MTAS, GPS/GLONASS or GNSS wide-area augmentation system and these ground stations, is called the MTAS network.

The ASAS or any RSAS is integrating modern MCS with GNSSS-1 solutions to provide signals from GPS or GLONASS spacecraft to SES terminals. In opposite way all PVT and other data from GPS or GLONASS receiver terminals onboard ships can be sent by SES terminals manually or automatically to STC/STM via GEO satellites and CES terminals.

The convergence of MSC and Internet technique has opened many opportunities to deliver new multimedia service over hybrid satellite systems to SES terminals. With the need for increased bandwidth capability, the numbers and sophistication of GEO and Non-GEO communication satellites is increasing dramatically **[1, 6, 19, 21, 22]**.

4.3. New Maritime Surveillance Subsystem (MSS)

The current radio surveillance system is mainly supported by VHF CRS. Namely, this system enables display of real-time positions of the nearby approaching ships using radar and VHF voice radio equipment. Due to its limitations, the VHF service being used for domestic sea space, channels and coastal waters cannot be provided over the ocean. Meanwhile, out of radar range and VHF coverage on the oceanic routes, the ship position can be regularly reported by HF radio voice or via data terminals to the HF Coast Radio Stations (CRS).

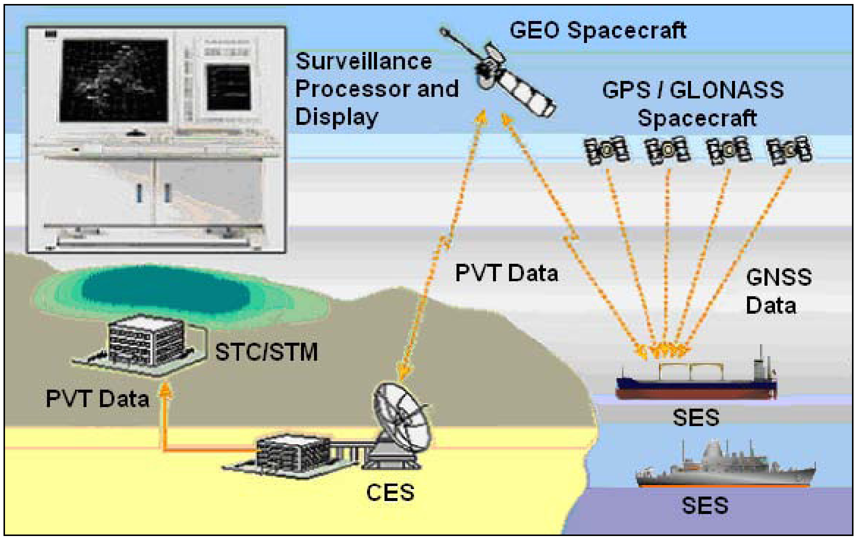

Figure 7. Modern MSS Network – Source: Ilcev **[19]**

Consequently, the advanced Maritime Surveillance Subsystem (MSS) as CNS/STM system utilizes the ADSS data function, which automatically reports all current ships positions measured by GPS or GLONASS service to STC, as illustrated in **Figure 7**. In this way, the approaching vessels receives positioning data from GPS/GLONASS spacecraft or GPS/GLONASS augmented data via GEO satellite transponder, as illustrated in **Figure 2**, and then sends via GES its current position for recording and processing to the STC terminal and displaying on the like radar screen. This service enhances safety, security and control of vessels in ocean and coastal navigation.

The screen display of satellite ADSS looks just like a pseudo-radar coverage picture showing positions of the ships. The new ADSS system will increase safety and security at sea and reduce ships separation improve functions and selection of the optimum route with more economical courses. It will also increase the accuracy of each ship position and reduce the workload of both controller and ship's Master or Pilot, which will improve safety and security. In this sense, ships can be operated in a more efficient manner and furthermore, since the areas where VHF radio does not reach due to the short range, mountainous terrain or bad weather will disappear, small ships, including Pilot boats and helicopters, will be able to obtain any data and safety information on a regular basis. These functions are mandatory to expand the traffic capacity of the entire ocean or coastal regions for all ships and for the optimum navigation and safety route selection under limited space and time restraints **[4, 10]**.

The Wide Area Navigation (WANAV) system is a way of calculating own precise position using the Ship Surveillance Satellite Equipment (SSSE) facilities and other installed onboard ship navigation devices to navigate the desired course and to send this position to TCC. In the case of WANAV routes it has been possible to connect in an almost straight line to any desired point within the area covered by the satellite equipment and service. In any event, setting the WANAV routes has made it possible to ease congestion on the main sea routes and has created double tracks. This system enables more secure, safety and economical sea navigation routes **[1, 7, 19]**.

5. Special Effects of the MTAS System

Special effects of the MTAS system used for secure communications, navigation, ranging, logistics and control of the vessels at sea, in the channels, around the coastal waters and in the port surface ship traffic are Safety Enhancements on Short and Long Ranges, Reduction of Separation Minima, Flexible Sailing Profile Planning and Coastal Movement Guidance and Control.

These effects of the MTAS are very important to improve maritime communication facilities in any phase of sailing, to enable better control of ships, provide flexible and economic trip with optimum routes, to enhance surface guidance and control in port and in any case to improve safety and security at sea and in the ports.

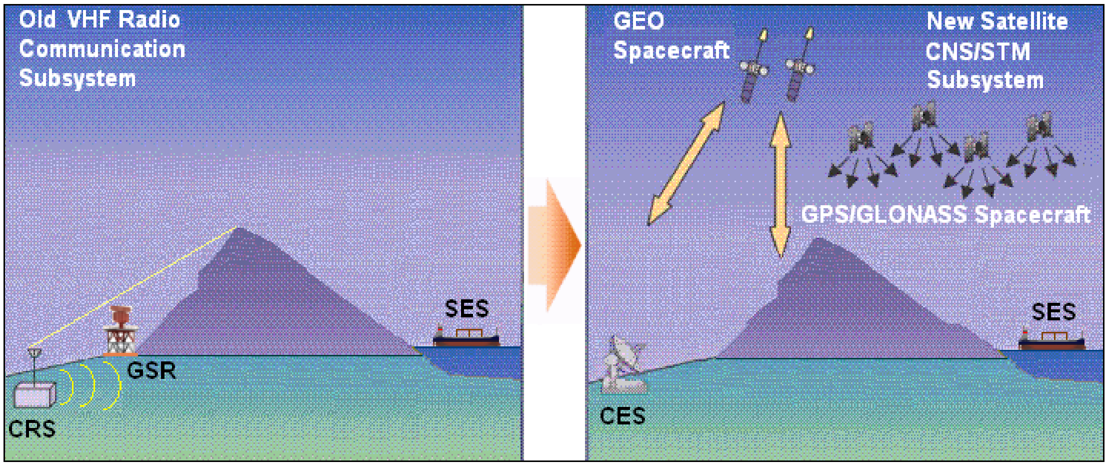

Figure 8. Maritime SESR Subsystem – Source: Ilcev **[19]**

5.1. Safety Enhancements at Short and Long Ranges

A very important effect of the new ASAS system for CNS/STC is Safety Enhancement at Short Ranges (SESR) via VHF CRS illustrated in **Figure 8 (Left)**.

Old radio system for short distances between vessels and CRS is provided by VHF voice or by new DSC VHF voice and data equipment, so the ship's Master or Pilot will have many problems establishing voice bridge radio communications when the ship position is in the shadow of high mountains in coastal waters or channels.

Meanwhile, all vessels sailing in coastal waters, sea passages or fiords and in seaports can receive satellite navigation and communications even at short distances and where there is no navigation and communications coverage due to mountainous terrain, which diagram is shown in **Figure 8 (Right).** This scenario is very important for safety and secure of navigation during bad weather conditions and reduced visibility in channels, approaching and coastal waters, in short to avoid collisions and disasters.

The ASAS infrastructure is also projected to provide Safety Enhancement at Long Rangers (SELR) via HF/HF radio communications shown in **Figure 9 (Left).** The faded HF radio can be replaced by noise-free satellite system depicted in **Figure 9 (Right)**. Thus, many ships out of HF range can provide their augmented or not augmented positioning to STC station or will be able to receive safety and weather information for secure navigation **[1, 4, 19, 22]**.

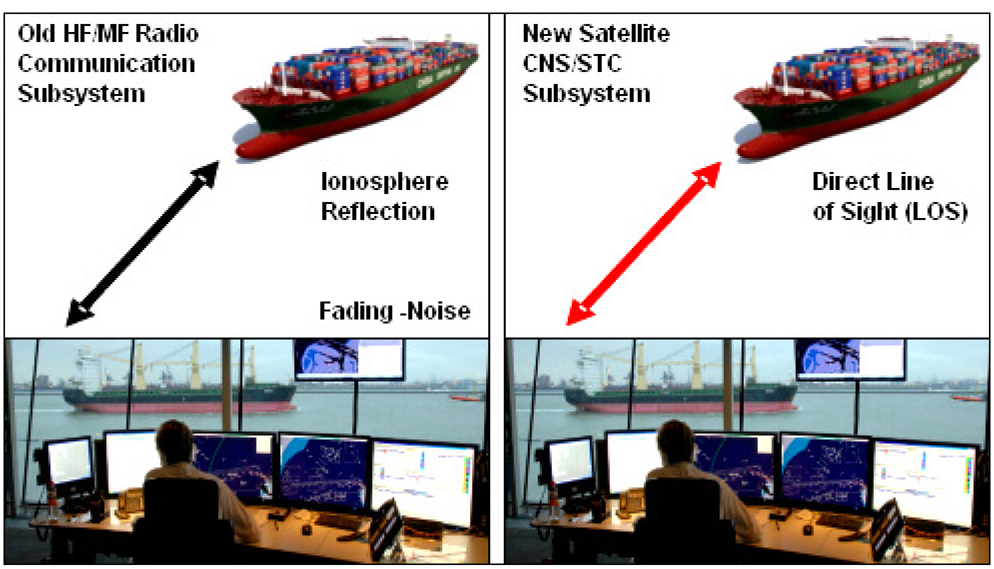

Figure 9. Maritime SELR Subsystem – Source: Ilcev **[1]**

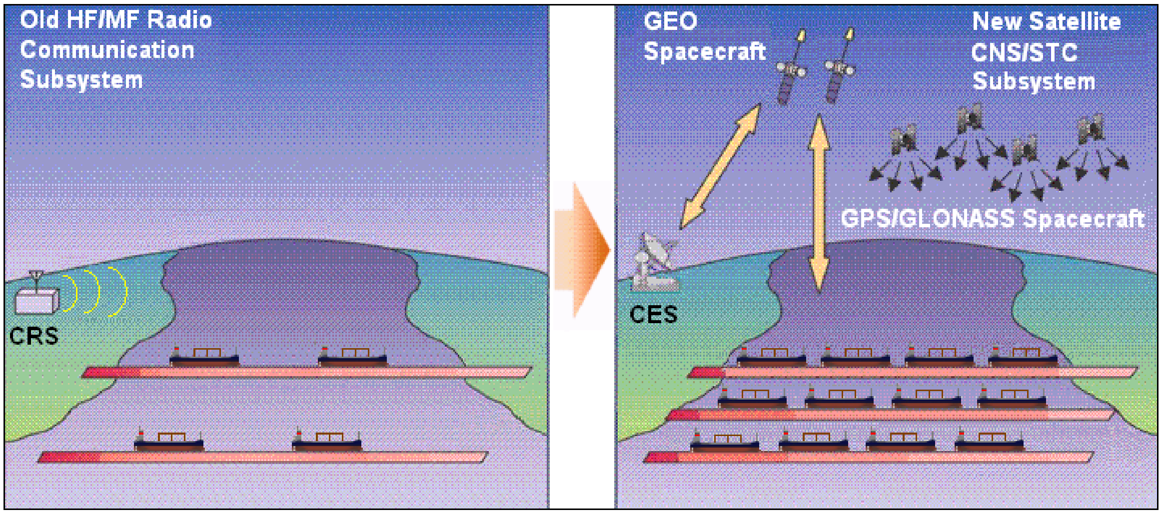

Figure 10. Maritime RSD Subsystem – Source: Ilcev **[19]**

5.2. Reduction of Separation Distance (RSD)

One of the greatly important safety navigation effects deployed by ASAS network is the Reduction of Separation Distance (RSD) between oceangoing ships or other moving object on the sea routes by almost half, as is illustrated in **Figure 10.** The current system has an RSD controlled by conventional VHF or HF Radio system and GSR, which allows only large distances between vessels. However, the new maritime CNS/STC system controls and ranges greater numbers of vessels for the same sea corridors (channels), which enables minimum secure separations, with a doubled capacity for vessels and enhancements of safety and security. Therefore, a significant RSD for sailing ships will be available with the widespread introduction and implementation worldwide of the new ASAS or any RSAS technologies on the CNS system **[1, 19, 23]**.

5.3. Flexible Sailing Profile Planning (FSPP)

The next positive effect of ASAS network is Flexible Sailing Profile Planning (FSPP) of shortest or optimal course, as is shown in **Figure 11.** The old system uses fixed courses of orthodrome (great circle), loxodrome (an imaginary line on the surface of a sphere that crosses all meridians at the same angle) and combined navigation by NavAids. Thus, the fixed course is controlled by the vessel's on-board navigation instruments only, which is a composite and not the shortest possible route from departure to arrival at the destination port. The FSPP allows the selection of the shortest or optimum course between two seaports and several sub points. With thanks to new RSAS technologies on CNS/STC system FSPP will be available for more economic and efficient sailing operations. This means that the ship's engines will use less fuel by selecting the shortest sailing route of new CNS/STC system than by selected the fixed courses of current route composition.

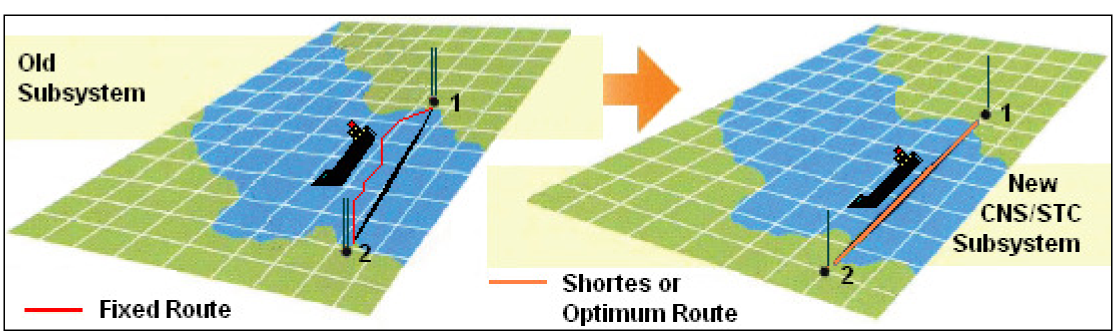

Figure 11. Maritime FSPP Subsystem – Source: Ilcev **[19]**

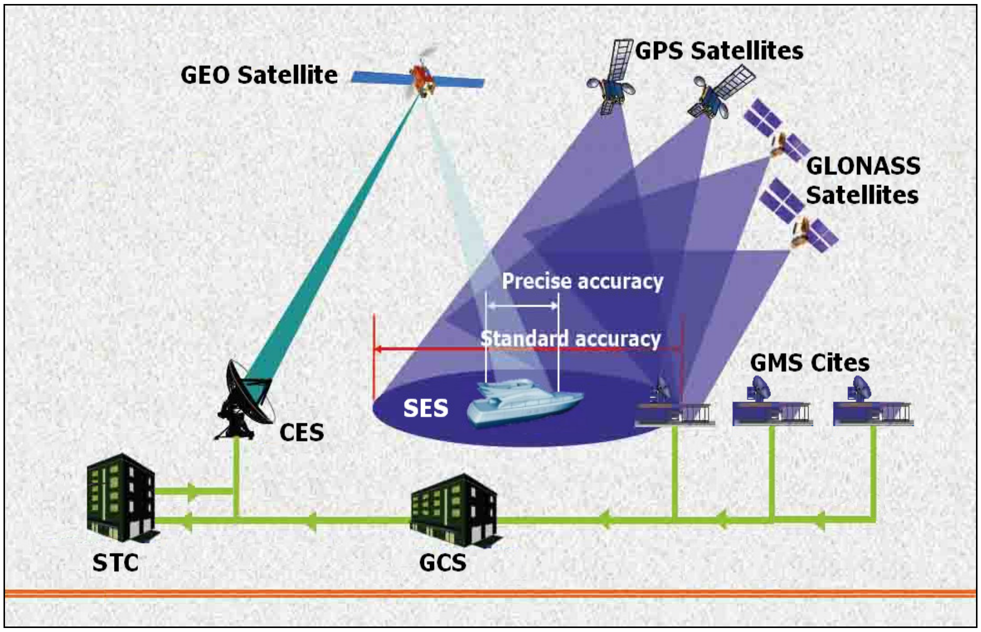

Figure 12. Maritime OSGC Subsystem – Source: Ilcev **[1]**

5.4. Oceanic Sailing Guidance and Control (OSGC)

The Oceanic Sailing Guidance and Control (OSGC) network for communication facilities can use voice, data and video of Inmarsat MMSC system, new SADS-B, SDL, Digital Video Broadcasting-Return Channel via Satellite (DVB-RCS) with Voice, Video, Data over IP (VDVoIP) or MMSC via other GEO satellite constellations to send GNSS-1 data (received from GPS or GLONASS satellites by SES) to CES on L/C, Ku or Ka-band, what depends on the type of GEO spacecraft. In addition, Ground Monitoring Station (GMS) sites are able to receive GNSS signals and forward them to Ground Control Station (GCS) for processing and then via GEO Satellite and CES terminal sends augmented signals to SES by the same L1 or L5-band GNSS-1 frequencies.
The GCS signals can also be sent to maritime STC station for processing and displaying them at radar like display. Then, STC can send to any ship position of near by ships in certain sea area for awareness and enhanced collision avoidance. The scenario of OSGC is illustrated in **Figure 12**, which has to provide more safety and security in navigation across the oceans **[1, 2, 19, 24]**.

5.5. Coastal Movement Guidance and Control (CMGC)

The Local VHF Augmentation System (LVAS) infrastructure is intended to complement the CNS service for local environment of seaport or airports using a single differential correction that accounts for all expected common errors between a local reference and mobile users at sea or in the air. In fact, the LVAS network will broadcast navigation information in a localized volume area of seaports or airports using VHF service of CSN solutions. In addition, this local service can be also covered by any of mentioned RSAS networks developed in Northern Hemisphere or even the future service of ASAS network.
As stated earlier, any hypothetical RSAS or ASAS network will consist a number of GMS (Reference Stations), several GCS (Master Stations) and enough CES (Gateways), which service has to cover entire mobile environment of dedicated region as an integrated part of GSAS. Inside of this coverage the RSAS network will also serve to any other customers at sea, on the ground and in the air users, who needs very precise determinations, tracking and positioning, such as:
1. Maritime (Shipborne CNS, Tracking, Seafloor Mapping and Seismic Surveying);
2. Land (Vehicleborne CNS, Tracking and Transportation Steering and Cranes);
3. Aeronautical (Airborne CNS, Tracking and Mapping);
4. Agricultural (Forestry, Farming and Machine Control and Monitoring);

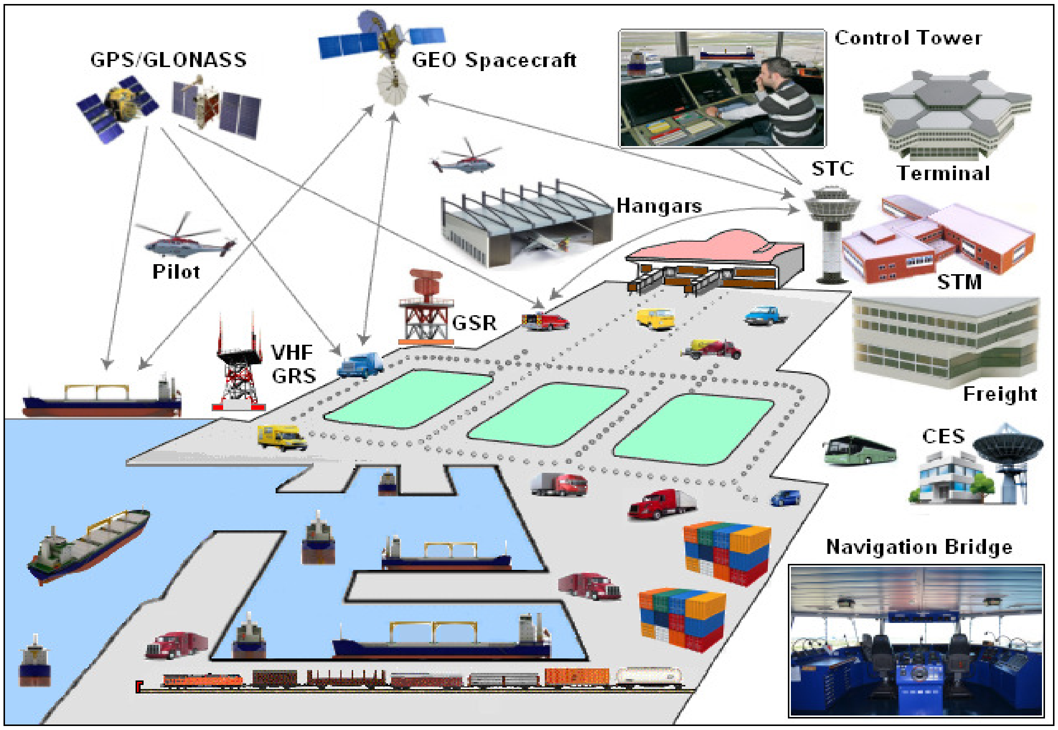

Figure 13. Maritime CMGC Subsystem – Source: Ilcev **[7]**

5. Industrial, Mining and Civil Engineering;
6. Structural Deformations Monitoring;
7. Meteorological, Cadastral and Seismic Surveying; and
8. Government and Military CNS, Tracking (Police, Intelligent services, Firefighting); etc.

In a more general sense, all above applications will be able to assess CNS service inside of any RSAS or ASAS networks coverage directly by installing new Rx equipment known as augmented GPS or GLONASS (GNSS-1) onboard mobiles terminals, and so to use more accurate positioning and determination data. This scenario will be more important for establishment STC or ATC CNS service using augmented GNSS-1 signals from the ships or aircraft, respectively. In this sense, the RSAS or ASAS network can be utilized for seaports known as Coastal Movement Guidance and Control (CMGC) and for airports as Surface Movement Guidance and Control (SMGC).

The CMGC mobile network is a special security, safety, guidance and control system that enables a shore controller at STC centres to guide and monitor all ships movements at sea in coastal navigation, in the cramped channel strips, approaching areas to the anchorage and seaports, which scenario is shown in **Figure 13.** In addition, the CMGC system is managing all movement in harbours, such as ships, land vehicles (Road and railways) in seaport and around the seaport's coastal environment, especially during very bad weather and poor visibility conditions. The controller issues instructions to ship Masters and seaport Pilots with reference to a command surveillance display in a seaport control tower that gives ships position information detected via GEO satellite and by sensors on the ground, which can be VHF Ground Radar Station (GRS) and Ground Surveillance Radars (GSR). On the other hand, ship's captain on the navigation bridge together with harbor Pilot is more comfortable and safe in any situation during maneuvering inside and out of seaports.

The command staff monitor in Control Tower also displays reported position data of approaching coming or departing vessels and all auxiliary land vehicles (road and railways) moving into the port's surface. This position is measured by GNSS signals, using data from GPS/GLONASS and GEO satellite constellation. A controller is also able to show the correct ship course to Masters and seaport Pilots under bad weather conditions and poor visibility or to give information on routes and separation to other adjacent vessels in progress. The following segments of CMGC infrastructure are illustrated in **Figure 13**:

1) GPS or GLONASS GNSS Satellite measures the vessel or seaport vehicle's the exact position.
2) GEO MSC Satellite is integrated with the GPS positioning data network caring both communication and navigation payloads, In addition to complementing the GPS satellite, it also has the feature of communicating data between the ships or vehicles and the ground facilities, pinpointing the mobile's exact position.
3) Control Tower is the centre for monitoring the traffic situation on the channel strips, approaching areas, in the port and around the port's coastal surface. The location of each vessel and ground vehicle is displayed on the command monitor of the port control tower. The controller performs sea-controlled distance guidance and movements for the vessels and ground-controlled distance vehicles and directions based on this data.
4) Light Guidance System (LGS) is managed by the controller who gives green light or red light guidance whether the ship should proceed or not by pilot in port, respectively.
5) Radar Ground Station (RGS) is a part of previous system for STC of ship movement in the channels, approaching areas, in port and around the port's coastal environment.
6) Very High Frequency (VHF) is Coast Radio Station (CRS) is a part of RCS and VHF or Digital Selective Call (DSC) VHF Radio communications system.
7) Coast Earth Station (CES) is a main part of satellite communications system between GES terminals and shore telecommunication facilities via GEO satellite constellation.
8) Pilot is small boat or helicopter carrying the special trained man known as a Pilot, who has safely to proceed arrival vessel in port, departure vessel out of port to anchorage or to manage vessels sailing through the channels and rivers.
9) Bridge Instrument onboard each vessel displays the ship's position and course during all stages of navigation at open sea or inside of seaports **[1, 2, 7, 12, 25]**.

6. Conclusion

The CNS has been set up to identify the possible applications for global radio and satellite CNS, safety and security and control of aircraft, freight and passengers and SAR service in accordance with IMO and ICAO regulations and recommendations. The new satellite CNS using GEO satellites with Communication and GNSS payloads for STC/STM is designed to assist navigation both sailing at open sea and approaching to the anchorages and seaports. The potential benefits will assist STC to cope with increased maritime traffic and to improve safety and reducing the infrastructures needed at shore. The Communication payloads usually at present employ transponders working on RF of L/C, Ku and recently on Ka-bands for DVB-RCS scenario. Because that Ku-band is experiencing some transmission problems and is not so cost effective, there is proposal that Ka-band will substitute Ku-band even in mobile applications including maritime and aviation.

When planning maritime routes and berthing schedules at busy seaports, it is essential to ensure that ships are always at safe distance from each other and that they are passing some critical channels safely. The trouble is that it is not always possible to figure out where the ships are, especially during very bad weather conditions. It is necessary to reduce the margins of critical navigation and increase the safety of ships in each sea and passage corridors. The new CNS GNSS-1 networks of MTAS and forthcoming European Galileo and Chinese Compass GNSS-2 will provide a guaranteed service with sufficient accuracy to allow ship's masters and pilots including STC to indicate a current position and safety margins reliably and precisely enough to make substantial efficiency sailing. The GNSS helps masters to navigate safely, especially in poor weather conditions and dense fog, in which sailing using CNS via RSAS system or DGPS is reliable. Any seaports are unlikely to invest in this system, but they can use CNS of global or local augmented system or when Galileo and Compass become operational, the need for a differential antenna will reduce costs. Galileo and Compass will also need implementation of CNS via RSAS, so their guaranteed service and use of dual frequencies will increase accuracy and reliability to such an extent that vessels will be able to use safely their navigational data for guidance including their on-board technology alone.

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