

**SYSTEM AND METHOD FOR WIDESPREAD LOW COST ORBITAL SATELLITE
ACCESS**

by

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CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Application Serial Number 13/757,062 filed on February 1, 2013 and US Application Serial Numbers 13/961,384, and 13/961,875 both filed on August 7, 2013. The contents of the three applications are herein incorporated by reference.

FIELD OF INVENTION

[0002] The present invention relates to a system and process for implementing high-volume, low-cost, distributed access and control of select satellite operations. In particular, the present invention relates to providing a launch and operations architecture for orbital satellites that permits widespread distribution of satellite access services, including but not limited to satellite images, sensor data and video, at a cost and pricing structure that greatly expands the population of potential user and uses. Such satellite access services may be further leveraged with common technologies to provide widespread access to other satellite-based services normally out of reach at the consumer level. Leveraged services can include, but is not limited to, the measurement of radio occultation through the atmosphere to determine atmospheric parameters useful in the atmospheric sciences and long-range location tracking of vehicles operating within a geographic area.

BACKGROUND

[0003] Space in many ways is truly the final frontier. This is particularly true for those searching for new markets and business opportunities in select commercial operations. Space is not only one of the last truly new markets, but one of the most difficult to commercially exploit as the road to successful commercial space based enterprises is littered with failed endeavors and enterprises. While access and indeed travel to space is now many decades old, there are but a few systematic approaches to commercial operations in space. Indeed, beyond telecommunications there are very limited commercial efforts in space.

[0004] The past growth of satellite use in space has followed a path that actually retards the exploitation of this market. In particular, satellite technology has focused on developing large payloads and expensive launch equipment designed to last long periods of times – over a decade in some instances. This is based in part on the cost of building and launching a satellite which is easily in the millions of dollars and thus must be amortized over many years of life. This however creates a serious barrier to commercial exploitation as most satellites are based on computer and telecommunication technologies that are changing rapidly – and this rate of change is accelerating. A satellite launched five years ago is using technology that may be three generations out of date, leaving a platform that is quickly becoming obsolete.

[0005] Further, the substantial financial and technological resources required of conventional satellite systems remains to be a significant barrier to entry for expanded applications in space. Satellite-based sensor platforms provide a uniquely advantageous perspective for the measurement of data across a large geographic area. Weather and climate study, and vehicle surveillance are both applications with a high impact on society that greatly benefit from the vantage point provided by satellites.

Radio Occultation Measurement Through the Atmosphere

[0006] Ranging from vacation planning to military tactics, few things have as much of an impact on our lives as the weather. Weather and climate matters factor crucially into many major business, economic, government, military, and individual decisions. Notwithstanding this critical role, weather conditions remain stubbornly difficult to predict with accuracy.

[0007] Many researchers, in addressing climate prediction, see the problem in terms of insufficient real time data regarding the huge and complex fluid dynamic systems that comprises our atmosphere. Recent advances in computing technology now allow for the processing of vast amounts of data, and this provides for a better understanding of atmospheric conditions. However, there still exist significant weaknesses in the existing systems for capturing atmospheric data – critical data regarding atmospheric conditions that is otherwise critical for implementing the weather models that permit accurate predictions. In other words, we have very capable computer systems that process what data we have, but we need more and better data – indeed data collected very quickly or even in real time – to implement the processing that will give better predictions.

[0008] As an electromagnetic wave passes from space through a medium such as a planet's atmosphere, it is refracted and the phase and amplitude are modulated. The degree of this modulation is known as the refractivity of the atmosphere. If the refractivity for a portion of the atmosphere is determined, the atmospheric properties for that portion can be calculated or estimated. These relationships allow for determination of such atmospheric properties, such as air pressure, temperature, water vapor pressure, ionosphere frequency and electron density temperature, pressure, air density, and water content.

[0009] Radio Occultation (RO) is a technique for determining atmospheric properties by observing how a radio wave behaves as it passes through an atmosphere. A radio receiver is positioned to receive the occulted radio wave and the degree of refraction and modulation are measured. From this, the refractivity is derived and atmospheric properties can be determined. Using this technique, a high degree of precision in the derived properties over a large vertical atmospheric section can be obtained. Furthermore, at longer radio wavelengths, cloud cover has little to no effect on the measurements, which provides tremendous advantage over existing atmospheric observation methods.

[0010] Existing weather satellite systems, such as NASA's Geostationary Operational Environmental Satellite (GOES) system, provide imaging data on cloud tops, but cannot routinely profile an entire atmospheric column. Using RO, atmospheric data along a relatively large vertical resolution can provide key insight into the three dimensional state of the atmosphere, which is crucial to climatology study.

[0011] A Global Navigation Satellite System (GNSS), such as GPS, provides excellent radio signal sources for RO study because they are a large network of existing satellites transmitting a reliable signal of a known quality at regular intervals. The precise location of the sources of GNSS signals relative to the Earth—an important part of RO measurements—are also known for any time of the day. Additionally, the large number of satellites provides many sounding opportunities for a single receiver satellite as it orbits, allowing the receiver satellite to take RO measurements across many "slices" of the atmosphere as it orbits and different occulted GNSS signals come within view.

[0012] A number of different GNSS systems provide signal sources suitable for RO study. The United States' Global Positioning System (GPS) is well known and provides global

coverage. Russia's Global Navigation Satellite System (GLONASS) also provides global coverage, but has been through periods of unreliability. The European Union's Galileo system is currently in development, but will provide global coverage with 35 satellites once operational. India's Regional Navigational Satellite System (IRNSS) and China's BeiDou Satellite Navigation System (BDS or Compass) are regional systems, but nevertheless provide suitable signals from which RO measurements can be taken.

[0013] There are existing missions to study GPS RO, most recently with the joint U.S./Taiwan FORMOSAT-3/COSMIC mission (COSMIC). Launched in 2006, the COSMIC project consists of six approximately 70kg Low Earth Orbit (LEO) satellites each carrying GPS receivers and ionospheric photometer. GPS RO observations from COSMIC and previous missions have already improved weather predictions at many national forecast centers around the world. However, the COSMIC satellites are approaching the end of their operational lifetimes, while follow-on systems have encountered delays and funding issues, and are insufficient to meet the current and future demands of weather forecasting, climate monitoring and space weather prediction.

[0014] This highlights a major disadvantage of past and existing GPS RO systems. While relatively inexpensive when compared to traditional weather satellites, these systems still require institutional- or governmental- level funding for their development, launch and maintenance. The custom, non-standard satellite platforms inevitably lead to a higher cost system that is also expensive to replace. Aging satellites rapidly degrade in the harsh environment of space. The technology aboard these satellites is also limited to the state of the art at the time that they were launched. The hardware of a satellite fleet cannot be upgraded and quickly becomes obsolete.

[0015] Higher cost satellite systems rely on fewer satellites. Having fewer receivers in orbit limits the number of global soundings, or RO observations, that are made within a given time period—a severe disadvantage when measuring a highly dynamic weather pattern, such as a hurricane. Fewer satellites also means lower geographic coverage as each satellite can only take RO measurements across a single slice of the atmosphere at one time.

[0016] Existing GPS RO satellites communicate directly with ground stations, which requires line of sight between the satellite and ground station. Non-geosynchronous orbiting satellites are within line of sight of a ground station for limited periods of time, which may result

in delays in the delivery of a data package. This introduces further decreases in temporal resolution.

Vehicle Surveillance

[0017] For centuries, ocean transport has represented a substantial portion of economic activity and a major trade conduit. Throughout its history, sea-based transport and commerce has suffered from the inability to accurately track shipments and vessels involved in transport. Even today, with a world comprised of substantial real-time tracking of nearly every aspect of our world economy, ocean transport remains stubbornly difficult to track for substantial portions of vessel time and journey. This creates significant issues due to the dangerous cargos in transit, the illegal contraband, including human captives, and the use and/or exposure to global terrorism and abuse. A continuing problem with pirates further exposes ocean transport to dangerous threats in certain regions of the world.

[0018] Today, most large vessels include automatic beacons that periodically broadcast/announce certain information about each vessel using select frequencies. Known as the Automatic Identification System (AIS), its use was mandated under the United Nations SOLAS convention for all international vessels over 300 tons, cargo vessels over 500 tons and passenger ships of all sizes. The AIS system was originally implemented for communication of critical information about ships navigating coastal waters. The information is used by coastal authorities to coordinate, manage and track maritime traffic near the coast.

[0019] AIS transceivers are installed onboard selected vessels and are programmed to automatically broadcast a message containing data on a ship's identity, speed, heading and navigational status every 2-10 seconds. The AIS transceivers broadcast the message in the VHF band, but because they were implemented for the purposes of ship to shore communications, their range is typically limited, and in some instances limited to about 74 km.

[0020] While not intended for space based tracking, several proposals have been made that would employ satellite receivers to collect AIS transmissions for tracking purposes. See in particular, Høye et al., "Spaced based AIS for global maritime traffic monitoring," *Acta Astronautica* (2008) 62, 240-245, the contents are hereby incorporated as if restated in full. The foregoing reference offers some suggested alterations to a spaced based receiver for AIS tracking

(S-AIS), but does not address all of the current issues in developing consistent tracking using AIS alone. S-AIS takes advantage of the 1000 km vertical range of ship-borne AIS transmissions, well within range of a satellite in low earth orbit. Moving the AIS receivers to a satellite platform allows observational coverage over a much larger area as compared to land- or sea- based receiver stations.

[0021] The wide field of view and high coverage also presents the problem of collision between AIS messages. AIS transceivers on each ship shares the same broadcast frequency with transceivers on other ships within the same broadcast area using a form of Self-Organized Time-Division Multiple-Access (SOTDMA). The time divisions are split and reserved by ships within an organized area. The organized area coincides with the ship-to-ship broadcast range of the AIS transceivers (approx. 20 nautical mile radius). S-AIS, however, is capable of detecting AIS signals emanating from multiple “organized areas”, resulting in collisions between time divisions in adjacent areas.

[0022] It is possible to increase the probability of detection by a single satellite by limiting the receiver satellite’s field of view and/or increasing the observation time over a given area. However, limiting the field of view cripples one of the primary advantages of space based AIS observation—broad observation capabilities. It also would increase the time required for a receiver satellite to observe an area since it must perform more scans to cover an area that would require fewer scans with a larger field of view. Increasing the observation time to parse out the AIS signals has the same effect, because a satellite can only be tasked with observing one area at a time. Introducing these delays early on in the data gathering process could result in further and possibly critical delays in the response system.

SUMMARY

[0023] It is therefore an object of the present invention to provide a platform for operating a commercial satellite access service that is both affordable and valuable to a wide audience of users.

[0024] It is also an object of the present invention to provide a commercial satellite access service to multiple users, for example by subscription, via a web based interface that permits limited but direct control over select satellite operations.

[0025] It is also an object of the present invention to provide a commercial satellite access service to multiple users, for example by subscription, via a web based interface that permits access to satellite telemetry data and sensor readings, including visual and multi-spectral images and video.

[0026] It is a further object of the present invention to provide a market pricing clearinghouse for allocating limited access time and for distributing the use of satellite- and other spaced-based platforms.

[0027] It is yet another object of the present invention to provide a satellite access protocol based on the launch of relatively inexpensive satellites having a relatively short expected useful lifespan, so that over time, successive generations of technology are placed in sequential launches to provide an evolving and advancing technological platform during the extended operation of the system.

[0028] It is still another object of the present invention to provide a protocol for managing access to multiple concurrently orbiting satellites to support applications that implement operations that require use of more than a single satellite at one time.

[0029] It is another object of the present invention to provide a ground based server that is connected to a multi-access network and in communication with one or more satellites so that users on the network can interact with the satellite(s) and in particular, instrumentation located on board the satellite(s).

[0030] It is still another object of this invention to provide a reliable, flexible and efficient space-based data collection network through a large constellation of small satellites capable of communicating data and/or commands between each other and multiple ground stations.

[0031] It is another object of this invention to provide a highly reliable and scalable satellite network by utilizing inexpensive, replaceable satellite units that do not require meaningful hardware maintenance after being placed into orbit. Redundancy is built into the system by adding more satellites than minimally required for the mission task.

[0032] It is another object of this invention to provide a highly flexible data collection network through the use of a frequently updated fleet of satellites. Frequent hardware revisions can take advantage of performance gains in commonly available components and to respond to

evolving mission requirements and further refinements in operating theory.

[0033] It is another object of the present invention to provide a flexible, satellite-based monitoring platform that can adapt to changing needs and exploit performance gains in receiver and camera technology.

[0034] It is another object of the present invention to provide a ground-based marketplace to facilitate reservation of satellite access time in an open architecture system. Optionally, the system will permit the auction of satellite access time slots for high value events such as photographic access to the Super Bowl; or select access to on-board instruments during rare space events, such as solar events, celestial events (for example, eclipses), asteroid events, etc.

[0035] It is still a further object of the present invention to provide an open source platform to allow users to develop programs and applications that are based on selected standards and to facilitate upload and operation of these applications onboard an orbiting satellite or satellite constellation for implementing one or more functions thereon.

[0036] It is still a further object of the present invention to provide an open source platform to allow users to develop programs and applications that utilize satellite telemetry or sensor data, including images and video, and process this data remotely from the satellite; for example, in a cloud-based computing system, mobile device, or any other computing system. Optionally, such programs may be distributed and/or sold to other satellite users in a clearinghouse or online store.

[0037] Many of the above and other objects of the present invention are realized in an illustrative multi-faceted, computer implemented commercial satellite access enterprise. This enterprise may include a satellite launch sequence protocol that provides the scheduled launching of small, relatively inexpensive satellite payloads each comprising computer, sensor, camera and communication modules of state-of-the-art design. Use of state-of-the-art components in the satellite design insures that the ultimate capabilities of the active array of satellites in orbit at any one time allow for user access to current or relatively current technology.

[0038] In a further aspect of the present invention, the satellite includes a programmable computer connected to an array of sensors and peripheral devices. The onboard microprocessor is designed to allow for operation of one or more applications designed by users and implemented in space in accordance with user selected objectives; for example, a user

application may assist the user in conducting experiments using the onboard sensors, and record data for transmission back to the user. Further examples include one or more user implemented programs that (i) task the satellite(s) to track and record weather and climate related data or (ii) operate to collect data and images that allow insight into the economic activity of a region or country, such as the current state of its agriculture industry.

[0039] In another aspect of the present invention, the administrative system monitors key components to the launch payload and updates the parts database so that the system architecture is an evolving design incorporating new and advanced parts as they are released from the suppliers. As the satellite manufacturing cycle progresses, each new vehicle's assembled parts will include many of the latest components.

[0040] In one embodiment of the present invention, the administrative system may coordinate the utilization of different parts or components on different satellites during operations. For example, the administrative system may allow a user running an experiment requiring component x and component y to use the latest component x located on satellite 1 in conjunction with the latest component y located on satellite 2.

[0041] In yet another aspect of the present invention, the administrative system maintains near continuous communications with orbiting satellites allowing for monitoring of on-board systems and for sending control signals and for receiving data from these on-board systems. Preferably these communications are handled through a dedicated link under the direct supervisory control of the administrative system. Alternatively, communications may be leased from one or more contract satellite link operations to support some or all of these satellite communications.

[0042] It is another object of this invention to provide a flexible, upgradeable satellite network for taking high-resolution RO measurements through the atmosphere for purposes that include weather and atmospheric analysis and prediction.

[0043] It is yet another object of this invention to provide RO measurements of the atmosphere over select regions of the globe through the use of a large constellation of small satellites.

[0044] It is still another object of this invention to provide RO measurements of the

atmosphere over all or at least a large portion of the globe through the use of a large constellation of small satellites. Reliable RO measurements are achievable from approximately 1km above the surface or lower through the ionosphere.

[0045] It is a further object of this invention to provide rapid response or near real time RO measurement collection from multiple viewing angles of a selected portion of the atmosphere through the use of a large constellation of small satellites making multiple RO readings from GNSS satellite signals

[0046] It is another object of this invention to provide high resolution and error-corrected RO measurements by using multiple RO measurements from multiple GNSS signals across different frequencies.

[0047] It is still another object of the present invention to provide a network of multiple low cost satellites in low earth orbit equipped with radio receivers tuned to select GNSS signals and further including additional sensors such as optical detectors, cameras and the like to create discrete readings of RO, image and other atmospheric properties that can be integrated to form a predictive tool regarding atmospheric changes.

[0048] The above and other objects of the present invention may be realized in an illustrative non-limiting example thereof comprising a constellation of radio receiver equipped satellites that are programmed to collect RO data from an existing network of GNSS. This constellation includes communication links to one or more earth stations for data downloads and for the receipt of new instructions or changes to programming. In various alternate arrangements and preferred embodiments, the system of multiple satellites includes data transmission between individual satellites for data qualifying parsing, assembling and/or distributed processing. In a preferred arrangement, satellite life is limited so obsolete satellites are quickly replaced with newer version that includes updated hardware and programming. In a preferred arrangement, multiple ground stations are deployed in strategically useful locations to increase direct communication windows for each satellite in the constellation.

[0049] In accordance with the varying features of the present invention, the constellation of satellites is preferably at least 10 individual operating vehicles. In a more preferred arrangement, at least 30 to 50 satellites form a working constellation. In the most preferred arrangement, the

constellation includes between 75 and 100 satellites in communication with multiple ground stations and with each other. The preferred system includes optical sensors and cameras to create imaging data for integration with RO in processing algorithms.

[0050] Another object of the present invention is to provide a platform of space-based, selectively tuned or adjustable receivers capable of capturing AIS or similar signals for use in tracking and monitoring vehicle movements.

[0051] Another object of the present invention is to provide a large constellation of small satellites that communicate with one or more ground base stations to provide network-based support and access to ship movements as determined by the satellites.

[0052] It is a further object of the present invention to provide a plurality of satellites orbiting the earth to capture AIS signals from ocean traversing vessels so that these vessels can be continuously monitored during transit.

[0053] Yet another object of the present invention is to provide a constellation of satellites in low earth orbit, positioned to receive identifying signals from one or more aircraft for purposes of tracking and monitoring aircraft movement. In a particular example, the United States will soon require the majority of aircraft operating within its airspace to be equipped with some form of Automatic Dependent Surveillance-Broadcast (ADS-B) technology. The US ADS-B requirement is currently slated to come into effect by January 1, 2020. In the EU airspace, planes with a weight above 5,700 kilograms (13,000 lb) or a maximum cruising speed of over 250 knots will be required to carry ADS-B and is currently slated to phase in between 2015 and 2017.

[0054] Still a further object of the present invention is to provide a constellation of satellites with the capability of capturing images of ships, airplanes or other vehicles and their movements and to process these images in conjunction with signals collected from the moving vehicles to enhance overall tracking of a large volume of vehicles by the space based tracking satellites.

[0055] It is another object of the present invention to provide a constellation of satellites equipped to receive AIS signals and to capture images of select regions of ocean and to integrally process associated data to discern pirate and/or disabled ship locations.

[0056] The above and other objects of the present invention are realized in an illustrative

embodiment that operates with a deployed network of satellites configured to communicate with one or more ground stations. Individual satellites are positioned in low earth orbits of 200-1000 km above the surface and complete their orbits in approximately 90 minutes. Typically, the satellites in the network will each include memory and processors for implementing programming on-board. One or more satellites in the network are equipped with an optical camera and a receiver for detecting radio transmissions from the ocean vessels and/or aircraft. In some embodiments, more than one receiver will reside on the satellite; in some embodiments, the satellite is stabilized in orientation, but may be re-positioned based on internally generated computer commands or ground-based instructions.

[0057] Operation is enhanced by increasing the number of satellites in the network and/or by increasing the number of ground stations in communication with the network. In some embodiments, data will be routed between satellites before transmission is made to one or more ground stations; in some embodiments, a packet communication protocol, similar to well-known FTP protocols for file transfers, may be used so that multiple ground stations sequentially or concurrently can communicate with one or more satellites in the network. Communication between satellites allows for the transfer of data from satellites to ground stations that are either out of range or outside the line of sight of the satellite.

FIGURES OF DRAWINGS

[0058] This invention is described with particularity in the appended claims. The above and further aspects of this invention may be better understood by referring to the following description in conjunction with the accompanying drawings, in which like numerals indicate like structural elements and features in various figures. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention.

[0059] The drawing figures depict one or more implementations in accord with the present teachings, by way of example only, not by way of limitation. In the figures, like reference numerals refer to the same or similar elements.

[0060] Figure 1 is a schematic diagram depicting the salient features of a illustrative satellite in accordance with the present invention.

[0061] Figure 2 is a second launch vehicle in accordance with the present invention.

- [0062] Figure 3 is a functional block diagram of an illustrative arrangement used to implement the present invention.
- [0063] Figure 4 is a further block diagram of the SAT/SYS server as used in the preferred embodiment of the present invention.
- [0064] Figure 5 is a functional block diagram of an illustrated ground control station.
- [0065] Figure 6 illustrates the RO signal based on atmospheric conditions;
- [0066] Figure 7 depicts GNSS and the constellation in orbit around the earth;
- [0067] Figure 8 depicts an illustrative constellation arrangement in orbit;
- [0068] Figure 9 depicts global placement of an illustrative network of ground stations;
- [0069] Figure 10 depicts a temperature profile for a storm system;
- [0070] Figure 11 depicts a functional block diagram for the data flow; and
- [0071] Figure 12 is a flow chart for the system.
- [0072] Figure 13 illustrates components of the present system.
- [0073] Figure 14 depicts a constellation of earth satellites in low altitude orbits.
- [0074] Figure 15 depicts a network of ground stations for use with multiple satellites.
- [0075] Figure 16 is a representative grid depicting 8 ships with AIS; one without AIS.
- [0076] Figure 17 is a flow chart diagram of the programming logic for the present system.
- [0077] Figure 18 is a flow chart diagram of more programming logic for the present system.

DETAILED DESCRIPTION

Satellite Constellation and Ground Station Network

[0078] The present invention is directed to, *inter alia*, an infrastructure and operational protocol that permits widespread access to space based satellite operations. There are three main aspects of the present invention from a systems standpoint. First, the satellite or satellite array that is in operation after launch into LEO. The satellite, in one embodiment, is based on an industry standard, developed in 2001 by Stanford University and California Polytechnic Institute.

The standard is called CubeSat and described in the document “CubeSat Design Specification.”¹ The size and sophistication of the satellite is such that it fits the overall design and objectives of the operative platform used to support it. In this illustration, the size of the satellite is relatively small, in general not exceeding 10 cm x 10 cm x 30 cm and 10 kg of mass, and the design includes around 25 separate sensors connected to and in communication with the central processing unit of the satellite. These sensors include a plurality of frequency specific monitors such as UV (Ultraviolet) and IR (infrared); other sensors are for remote detection of surface temperature; spectroscopy and one or more accelerometers; other onboard tools include camera/vision systems for still and video capture.

[0079] **Figure 1** provides a simplified illustration of a compatible satellite for the foregoing system. Beginning with framing structure 180, the satellite includes a framework for housing the various subassemblies. Five separate solar panels 170 are used to provide the exterior facing walls that define the interior of the satellite; and positioned to continually expose one or more of the surfaces to solar energy during operation. These panels convert solar emissions into electrical power and are connected to power module 120 comprising energy storage and power control circuits. The power module 120, in addition to storing the solar energy, drives and powers all the operative systems within the confines of the satellite.

[0080] Continuing with **Figure 1**, the satellite further comprises ultra high frequency dipole antenna (UHF) forming an array of four separate antenna rods 110. The antenna array is connected to a UHF Transceiver 30, configured to manage and implement all incoming and outgoing communications to the satellite. To complete the assembly, the satellite further includes a flight control computer 160 that manages aspects of flight including deployment and orientation. A spectrometer module 140 is positioned next to the flight control computer, and a final payload 150 is included. The payload is often mission specific and can be altered between launches depending on the current needs/offers to the market.

[0081] The payload captures a further, preferred embodiment of the invention. In particular, the payload will change with each launch, embracing an increasingly sophisticated collection of sensors and computer processing power. In addition to advancing the technology in each successive launch, the payload may vary among launches depending on and directed to different

¹ Available at http://www.cubesat.org/images/developers/cds_rev12.pdf

missions. For example, the sensors included for a launch may be custom to the orbital path for the satellite(s), with polar orbits equipped differently than equator orbits. Another example involves supporting processing/operations that employ two or more satellites concurrently. This may occur for an application that needs concurrent readings from two perspectives – such as two photos of a storm. To support this, it may be that one payload is the “master” and a second (and perhaps third) are “slaves.” Alternatively, the “master” may reside on the ground control station, and each satellite is a “slave.”

[0082] The computer platform in the payload includes one or more microprocessors for implementing user and administrator in-orbit-configurable logic governing programs. This includes in a preferred arrangement, onboard resident programs for implementing a host of permanent functions that are expected to be useful and used for the life of the satellite (typically one year) as well as programs uploaded by users and/or administrators while the satellite(s) is(are) in orbit. These programs govern the operation of the onboard systems in the satellite(s) including all communications, sensor management, diagnostics, maintenance, memory management and select operating system features and functions. Included within this software package design is an open source platform that permits implementation of applications optionally designed by third party users and a user community of the satellite(s). Platform resources may be open source or proprietary depending on the nature of the business model being pursued.

[0083] The microprocessor is further connected to or integrated with application memory for storing programs that can be uploaded to the satellite via the communication link discussed in more detail below. Depending on the operational approach and application, the platform, structure and syntax for said programs will vary from very open source (e.g. Arduino IDE) to more closed systems (e.g. the Apple iOS system) that ensure safe operation. In any case however, the structure of the platform is such that it allows for easy and widespread innovation in the global development and user community.

[0084] As noted earlier, the satellite includes a portfolio of sensors and imaging devices (camera or video). The technology for these components is rapidly advancing and individual hardware will become relatively obsolete within a couple of years. As new generations of satellites are prepared for launch, they will be equipped with state-of-the-art sensors and support software (applications and operating systems) that is also evolving to accommodate the more

modern components. For example, camera resolution and performance may double every six to twelve months. As the satellite design progresses to include state-of-the-art camera designs, the software must also be updated so as to support applications that implement camera operations. Software upgrades, in certain embodiments, can be done remotely while the satellite is in orbit. In certain embodiments, one or more satellites will be replaced with an updated satellite every 6-24 months. In preferred embodiments, one or more satellites will be replaced with an updated satellite every 12-18 months.

[0085] A second satellite is depicted in **Figure 2**. In this figure, the satellite is presented in more detail but includes many features in common with **Figure 1**. Moving from left to right, the arrangement includes a main telescope 202 and an array of solar panels 234. Next, an S-band transmitter 204 begins the instrument stack. Continuing GPS patch antenna 206 and S-band patch antenna 208 are vertically placed in the satellite.

[0086] Turning now to the right hand side of the **Figure 2**, the linear stack includes flight control computer 210 and UHF transceiver 212. This is followed by the power supply 214 and ADCS module 216. The right hand surface of the satellite includes antenna array 218, supporting UHF communications. Continued in structure 220 are the individual boards forming the payload computer 222. Continuing along the lower edge, sensor package 224, optical spectrometer 226 and secondary battery 228 are arranged in series. Finally, this stack is topped by the GPS receiver 230 and wide-angle camera 232.

[0087] Turning now to **Figure 3**, the operative system design for the preferred embodiment is provided in functional or block diagram form. Space based hardware consists of one or more orbiting satellites corresponding in general terms to the design provided in **Figure 1**. As reflected in **Figure 3**, two satellites are orbiting, each with a communication link via UHF transceiver, to a ground station. These satellites are marked 310 and 320 respectively. The remaining hardware resides on the earth, including a ground UHF transceiver station 330. Depending on the complexity sought and the number of satellites in orbit, additional ground based communication stations may be used, and different communication protocols other than UHF may be employed.

[0088] Continuing with **Figure 3**, the ground based communication station 330 is linked to a system operations server 340. The SAT/SYS operation server provides the operative computer

platform controlling access to and communications from the satellites. Typically, but not shown in the diagram, is the supporting database (conventional, e.g., Oracle, or custom) and other server/network systems (Apache) required to implement the business operations of the service. In addition, SAT/SYS Server is programmed to manage and implement the business operations supporting the satellite operations.

[0089] The operative features of the preferred embodiment of SAT/SYS Server 340 are presented in more detail in **Figure 4**, *infra*. The SAT/SYS Server 340 is connected to the Internet to allow for conventional access to the Web in accordance with the well-known communication protocols of the Web (e.g., TCP/IP). This communication extends to a community of service subscribers, indicated in the diagram as Users 1, 2, and 3 each with links to the SAT/SYS Server via the Internet. For ease of exposition, these users are separately and respectively marked as User 350, User 360 and User 370. Finally, an institutional server 380 is depicted reflecting a broader based subscriber, such as a school, that connects via the Internet but internally manages access – such as by an intranet.

[0090] In yet another aspect of the present invention, the system spatially and temporally synchronizes data and images collected from one or many satellites and provides for an easy access interface for users to said synchronized data. The synchronization involves a synchronization protocol and algorithm to permit fast and accurate data collection and storage in a database. For example, a constellation of 20 satellites can record 20 times as often data from one spot on earth (higher temporal resolution) or simultaneously record measurements at 20 locations on earth (higher spatial resolution). In this multi-faceted arrangement, the data collected is collected individually from each source (satellites) but stored with them and time and location (and orientation) data so as to provide spatial and temporal synchronization in a manner that retains the full value of the collected information.

[0091] The operative web portal for the satellite service will include a number of features to assist in distributing satellite access time. Typically, the system will be subscription based, where users will sign up, with appropriate security safeguards and privacy software in place. A public access portal may be included for browsing and to permit marketing efforts for the system administrator to build demand. In the subscription only area, web pages will provide multiple levels of system access. For the users actually allotted time to a satellite, the web portal will

provide, for example, a window into the current operation of the satellite, including tracking information, and select output from sensors as well as the ability to upload their own application or code to task all or part of the satellite and payload functions. For the users which have purchased or received access to all or parts of the data collected, their access will allow them to receive and potentially download data from the spatially and temporally synchronized database.

[0092] In one arrangement, the system supports two levels of access. The first or entry level is general telemetry or operating data decoupled from any particular test or analysis. This would include position, speed, temperature and other environmental/demographic data that is streamed or sent in data dumps (batch mode) from the satellite. For example, a landing screen display may include real-time images sent from one or more of the orbiting satellites and/or graphs of current measurements or readings. The second tier of access is more custom and involves the implementation of a user developed protocol or algorithm (via controlling software or firmware application). This second form of access is also supported on the web portal, but may have greater restrictions, based on the commercial nature of the study.

[0093] For example, a user may develop an open source storm tracking program that operates onboard the satellite for a select window of time. The program receives inputs from ground control regarding a storm that is forming and/or moving across the Atlantic towards Bermuda. Once the target directional data is uploaded, the program operates the onboard camera systems and other sensors to collect images and temperature data for the storm being tracked. As the information is being collected, a second ground based application is receiving and interpreting the data and preparing output formats for user review of the test results. A second tier subscription user may be able to upload and run this tracking program on the satellite, and receive access to the related data. In one embodiment, the programs designed to run on the satellite, such as the tracking program, may be sold on and purchased from a clearinghouse or online application store. In another embodiment, a user might get access to not only the spatially and temporally synchronized raw-data set but also some further analytics on top of the raw-data. For example, in the above sketched scenario, the user might get access to the raw images tracking the storm but also regularly (and potentially in real-time) updated prediction of the future track of the storm and expected landfall, estimated damages caused, economic impact, etc.

[0094] The foregoing arrangement discusses a user-prepared program that conforms to select

Open Source requirements for this application. In addition to user-designed applications, the system includes a library of “canned” applications developed by the system administrator. In addition, a user community supplements this library, offering programs that can operate alone to implement one or more experiments of general user interest, or act as building blocks to build more sophisticated and/or special purpose programs. For example, as users build their own applications, these can be added to the library for later use by others under terms to be administered by the system administrator. In one arrangement, the library of applications can be converted into a marketplace, where tested applications may be sold to current and potential users of satellite access time. Applications may be sold only upon approval of the system administrator based on stored criteria for commercial release.

[0095] As demand grows for satellite test/access time slots, a further aspect of the illustrative system is an auction site for time slots using bid/ask spreads to develop market pricing for satellite access. Certain time slots may be more valuable due to certain space, atmospheric or ground events. For example, a major event such as a large weather pattern, storm, volcano or tsunami will create exceptional short term demand for time slots and orbital paths that bring the event within the reach of the satellite sensors. Appropriate tools for pricing these slots and allowing purchasers to resell are provided on the SAT/SYS Server.

[0096] As discussed above, a major market for satellite access time exists within the science departments and the science curriculum of most schools and universities - particularly in the grade 7-12 age groups and for undergrad programs. Platform access time and programming for targeted testing is packaged and made available to science and educational groups spanning these demographics, e.g., by web access on the SAT/SYS Server through an education-themed portal. Using this approach allows for expanded satellite access for a relatively small investment. For this market, the system is enhanced through educational videos, tutorials and discussion forums to increase the familiarity of the potential users with the satellite payload options and relevant science, math, technology and engineering subjects. Lastly, this might be further augmented with local and global competition to further drive engagement and innovation by the target market audience.

[0097] Additional major markets for satellite images and data collected by the above described constellation of satellites with rapidly improving components are in the weather,

climate, agriculture and disaster monitoring and disaster recovery industries. In particular spatially and temporally synchronized data and images with optional add-on analytics on top of the raw-data are of high value with many potential uses and customers.

[0098] Similarly, spatially and temporally synchronized satellite collected data and images are of significant value for the financial services industry (asset managers, banks, insurance). This data is used in assessing the type and amount of local or global economic activity and thus supports investment decision-making.

[0099] The foregoing arrangements for the SAT/SYS Server 130 of **Figure 3** can be found in the functional block diagram of **Figure 4**. In particular, the Server includes an Interface 410 that creates the working environment for web users connected by the Internet. System data, user account data, satellite data and other digital information is stored in the database 430. Continuing along the bottom row, communications control to and from the orbiting satellite, including any real time feed or current imaging for display on the landing page of the web site is managed by the Comm Controls 440. Overall operations are governed by the Operations module 460 including both ground and orbiting commands.

[00100] Continuing with **Figure 4**, the application library is depicted by block 420 and provides user access to one or more programs that may be used in conjunction with experiments or testing during satellite access time. Block 450 depicts the auction or trading site for access time allocations and transfers. The education module is shown at block 470 and includes various education packages for user review. Block 480 provides the governing controls for site access including subscription management, security and privacy.

[00101] Satellite communication and control is delivered by ground station resources embraced by block 330 of **Figure 3**. This arrangement is described with more detail in **Figure 5** and includes both the Ground Station Control Box 510 and the Ground Station Computer 560. The Control Box is moveably mounted and includes a Motor Microprocessor and Motor Controller. Incoming control signals to router are directed to the Motor Microprocessor. These control signals are translated to a control output signal and directed to the Motor Controller for operations of Elevation Motor 540 and Azimuth Motor 550.

[00102] Communication is controlled by SDR connected to the router. Processing on the RF

board results in output signals to the Transmit Amp and Tuner for figuring band adjustment. Ground Antenna 530 receives the adjusted low noise signal for the Amp 520 controlled by the LNA controller. Communication to and from the satellites are sent and collected by Antenna 530.

[00103] A portion or the entirety of the constellation of satellites described above may be configured and tasked for specific data collection missions that take exploit the widespread sensor platform provided by a large constellation of satellites.

Radio Occultation Application

[00104] In one embodiment, a network of more than one satellites as described above is configured and tasked for collecting RO data. In this embodiment, each satellite within the constellation (“constellation satellite”) is equipped with receiver hardware capable of receiving signals from one or more GNSS in current use and now orbiting the planet. As new GNSS are placed into service, use of these new radio signal sources will be incorporated into newly launched satellites or programmed into existing satellites. In a preferred embodiment the receiver hardware is designed for a particular GNSS signal for higher computational efficiency and lower power consumption. In another embodiment, a software GNSS receiver provides the satellite with adaptive signal processing capabilities at the cost of higher processing and power consumption.

[00105] For the sake of simplicity, the GPS system and its components and features are specifically referred to hereinafter, but it is understood in the art that signals from any GNSS system (e.g. GLOSNASS) may be used in RO measurements and the present invention may be configured to utilize the signals from any one or more GNSS system.

[00106] **Figure 6** depicts the generation of an occultation signal measurable by the constellation satellite. In this arrangement, the GPS transmitter delivers a signal having known properties. A low earth orbit (LEO) satellite includes one or more signal receivers tuned to the transmitted signal – a signal that follows a known path through the atmosphere. The received signal is distorted (occulted) by the atmosphere, and the resulting occultation (RO) can be measured. A single constellation satellite is capable of taking RO measurements. Each additional satellite in the constellation increases temporal resolution and coverage of the system

as a whole, and provides more opportunity for RO data generation over select portions of the atmosphere. In addition, as more satellites are added, a constellation is created that supports multiple data points within a single atmospheric region and faster delivery of data for processing by intersatellite communication and the benefits it provides as described below. A preferred embodiment comprises 50-100 satellites to achieve a near real time temporal resolution in select regions of the atmosphere.

[00107] **Figure 7** provides a schematic of both the GNSS arrangement in orbit around the earth, and the complementary satellite constellation, placed in low earth orbit for receiving GPS signals from the GNSS to develop RO data.

[00108] **Figure 8** depicts multiple orbits of the constellation satellites, and multiple earth based ground stations forming a communication network for collecting RO data. The constellation satellites are capable of attitude control through a combination of magnetorquers and/or reaction wheels. Orientation may be determined through a combination of one or more on-board magnetometer, sun sensors, gyroscopes and/or accelerometers. The constellation satellites are further configured to determine current location and velocity with respect to the Earth through the on-board GNSS receiver.

[00109] The constellation satellites may also include one or more on-board digital cameras. The cameras provide additional data on weather systems that is combined with RO measurements. In one embodiment, constellation satellites are equipped with a standard digital camera or smartphone camera system to capture images within the visible spectrum. In another embodiment, constellation satellites are equipped with a multispectral or hyperspectral digital camera system to capture images over a wide range of the electromagnetic spectrum. Wide spectrum images are useful for capturing data past the upper cloud layer. The high replacement rate of the constellation satellite system allows for advances and cost reductions in camera sensors to be exploited.

[00110] **Figure 9** provides a regional diagram for multiple ground stations and possible communication coverage for RO data collection. The constellation satellites are configured to transmit data and communicate with other satellites in the constellation as well as with ground stations. In a preferred embodiment, a telecommunications link between constellation satellites and ground stations is established on one or more UHF and/or SHF radio bands. In another

embodiment, the constellation satellites are equipped with software defined radio (SDR) communication systems that allow for telecommunication links to be established through a wide spectrum of radio frequencies and provide the system with the flexibility to adjust according to mission needs.

[00111] In a preferred embodiment, data is transferred between constellation satellites and ground stations digitally according to well-known network protocols, such as the File Transfer Protocol (FTP), or a similar system. In other embodiments, the network protocol utilized is secured using a standard such as SSL/TLS, or another similar security standard. Packet delivery of messages/data permits single data streams to be broken into segments and transmitted to multiple receivers/ground stations. The originating single message is then reconstituted on the ground at a central server.

[00112] The constellation satellites and ground stations are configured such that intersatellite and satellite to ground station communications compensate for Doppler shift in the transmitted signals due to relative velocities. Doppler compensation techniques are well known in the digital communications arts. In a preferred embodiment, phase-locked loop (PLL) and/or frequency-locked loop demodulation algorithms are applied by the receiver to compensate for Doppler.

[00113] The intersatellite communications capability allows for the satellite constellation to form an ad hoc wireless data network with each satellite acting as a node and the network formed in a variety of topologies for the transmission of data according to the needs of the mission and the distribution of the satellites. Each constellation satellite may be programmed and configured to link to other constellation satellites within range and forward data sent by those satellites. The topology and data routing can then be determined dynamically according to the connectivity and operational status of the satellite-nodes.

[00114] This flexible data routing provides the invention with the advantage of near real-time communications with the ground based network. For example, because a link between any constellation satellite and the ground requires line of sight, there may be times when an individual satellite is not within communications range of a ground station and cannot transmit its data payload. The constellation satellite must then wait until the next ground station comes within range to send its payload. These individual delays can accumulate to unacceptable levels across the network. The present system allows for the out-of-range constellation satellite to send

its data payload to the ground network via any other connected constellation satellite.

[00115] The large number of satellites in the constellation and flexible network capabilities provides the system with many advantages over current systems. The malfunction of individual satellite-nodes in a large constellation would have a negligible effect on the overall network throughput. Similarly, the satellite network could route around any non-operational ground station. As discussed above, the dynamic routing capability also allows for near real time transmission of acquired data to the ground network.

[00116] The ground station network is configured to transmit data to one or more servers (“ground servers”) through the Internet or other suitable data transmission system. For example, a ground station may be connected to the same local area network as a ground server, in which case a more suitable transmission method would be through the local area network.

GPS Signal Structure

[00117] Every GPS satellite transmits their navigation signals on two frequencies: 1575.42 MHz (“L1”) and 1227.60 MHz (“L2”). The L1 and L2 signals are shared across the GPS satellite network using a code division multiple access (CDMA) technique. The navigation signals transmitted by each satellite in the GPS system are comprised of a carrier wave of constant phase and amplitude, phase modulated with a Navigation Data Modulation (NDM) code. The navigation message is transmitted at a rate of 50 bits per second with each complete message taking 750 seconds (12 1/2 minutes) to complete. The message structure has a basic format of a 1500-bit-long frame made up of five subframes, each subframe being 300 bits (6 seconds) long. Subframes 4 and 5 are subcommutated 25 times each, so that a complete data message requires the transmission of 25 full frames. Each subframe consists of ten words, each 30 bits long. Thus, with 300 bits in a subframe times 5 subframes in a frame times 25 frames in a message, each message is 37,500 bits long. At a transmission rate of 50 bps, this gives 750 seconds to transmit an entire almanac message. Each 30-second frame begins precisely on the minute or half-minute as indicated by the atomic clock on each satellite.

[00118] The first subframe of each frame encodes the week number and the time within the week, as well as the data about the health of the satellite. The second and the third subframes contain the ephemeris – the precise orbit for the satellite. The fourth and fifth subframes contain

the almanac, which contains coarse orbit and status information for up to 32 satellites in the constellation as well as data related to error correction. Thus, in order to obtain an accurate satellite location from this transmitted message the receiver must demodulate the message from each satellite it includes in its solution for 18 to 30 seconds. In order to collect all the transmitted almanacs the receiver must demodulate the message for 732 to 750 seconds or 12 1/2 minutes.

[00119] The ephemeris is updated every 2 hours and is generally valid for 4 hours, with provisions for updates every 6 hours or longer in non-nominal conditions. The almanac is updated typically every 24 hours. Additionally, data for a few weeks following is uploaded in case of transmission updates that delay data upload.

Radio Occultation Determination

[00120] Each constellation satellite in the constellation is configured to receive and track occulted and unocculted GPS signals. The location of each constellation satellite is determined from unocculted GPS signals using well-known GPS locating techniques. The location of the GPS satellites is estimated from their known orbits and time and/or decoded from the GPS navigation message within the received GPS signals.

[00121] For RO measurement, a constellation satellite tracks a “target” occulted GPS signal on both the L1 and L2 frequencies as it occults through a portion of the atmosphere. The constellation satellite may be configured to track any and all occulted GPS signals it receives or specific occulted GPS signals that pass through a portion of the atmosphere that is over an area of interest (e.g. a developing hurricane system). In a preferred embodiment, open-loop tracking methods are applied by the constellation satellite processor to track the target GPS signal as it occults through the atmosphere.

[00122] The RO measurement techniques employed by the constellation satellites are provided in detail in Kuo et al., “Inversion and Error Estimation of GPS Radio Occultation Data,” J. Meteorological Soc. of Japan (2004) 82:1B, 507—531; Cucurull, “Global Positioning System (GPS) Radio Occultation (RO) Data Assimilation,” presentation, National Oceanic and Atmospheric Administration & Joint Center for Satellite Data Assimilation, DA Colloquium (July 2009); “Radio Occultation,” University Corporation for Atmospheric Research (available at: http://www.cosmic.ucar.edu/related_papers/RO_COMET_Final.ppt). The contents of these

articles are incorporated by reference herein.

[00123] In sum, raw measurement of a GPS signal by a constellation satellite receiver is processed to filter out any changes in the raw GPS signal that are not caused by atmospheric Doppler contributions, including geometric delays, clock errors and relativistic effects on the phase. The Doppler shift of the filtered signal with respect to the known properties of the raw GPS signal is then calculated and attributed to atmospheric effects. Using the known velocities of the GPS satellite and the constellation satellite receiver, and assuming spherical symmetry of the Earth and its atmosphere, the bending angle of the GPS signal as it is refracted by the atmosphere is derived. Because the ionosphere has a dispersive effect on radio waves, GPS signals of different frequencies (i.e. L1 and L2) are refracted along slightly different bending angles. The bending angle of both the L1 and L2 signals are calculated separately. The bending angle is inverted through an Abel inversion to produce the index of refraction at the tangent point of the bent signal path. This is computed at the tangent points of both the L1 and L2 signals, which, due to the dispersive effect of the ionosphere, are at different altitudes. Refractivity is a simple conversion from the index of refraction.

[00124] Example

For a system of 50 satellites, RO signals are tracked across a 150 mile diameter storm off the coast of Florida using US GPS satellite signals; at intervals of 0.5 seconds, RO data is developed by 17 in field of view RO satellites from 7 different GPS sources and an a RO pressure/airspeed velocity map is constructed spanning 13,000 ft of altitude across the diameter of the storm; optical images from 3 RO satellites create a 3D map of the outer cloud surface; the resulting combined digital picture “signature” is compared to a library of past storms and tracks – based on a best fit, the storm track is projected.

[00125] As the system tracks additional stations and other weather events, the stored data will grow and longer term trends will become available through proper application of select statistical assessments.

[00126] The above process provides data related to a single “snapshot” of the occultation. The process is repeated as the GPS satellite “sets” under or “rises” over the horizon with respect to the receiver constellation satellite, providing a refractivity profile along a vertical column of

the atmosphere. This data can be used to derive atmospheric properties depending on the altitude of the measurement. At microwave wavelengths, such as that of the GPS signals, refractivity, N , as a product of atmospheric properties can be expressed as:

$$[00127] \quad N = \left[77.6 \frac{P}{T} \right] + \left[3.73 * 10^5 \frac{P_w}{T^2} \right] - \left[40.3 * 10^6 \frac{n_e}{f^2} + O\left(\frac{1}{f^3}\right) \right] + [1.4 * W_w + 0.6 * W_i]$$

[00128] where P is the total pressure (in mb), T is the temperature (in K), P_w is the water vapor pressure (in mb), n_e is the electron density (in m^{-3}), W_w is the liquid water content (in gr/m^3) and W_i is the ice content (in gr/m^3). Different aspects of the equation weigh in more heavily at different parts of the atmosphere. In the lower “wet” portion of the atmosphere (below ~6 km), the P , T and P_w terms dominate. In the “dry” portion of the atmosphere (~6 km to ~70 km), the P and T terms dominate. In the ionosphere (above ~70 km), the ionosphere portion (third bracketed portion of the above equation) dominates. Furthermore, the different frequencies (e.g. L1 and L2) react very differently with the ionosphere allowing to invert the above equation, to determine and then to remove the ionosphere contribution. The scattering terms (last bracketed portion of the above equation) are negligible because the GPS RO measurements are nearly unaffected by clouds.

[00129] **Figure 10** illustrates select atmospheric conditions within a storm system of interest. In a preferred embodiment, each constellation satellite takes RO measurements from any GPS satellite whose occulted signal path passes within the constellation satellite’s range of detection, and completes its processing tasks to determine the atmospheric properties of a portion of the atmosphere. The satellite transmits a data package to the ground station network through the satellite data network described above, or directly to a ground station. The data package consists of at least the atmospheric properties and geolocation data, but can also include additional information, such as the receiver satellite identification, receiver satellite status (geolocation data, health, sensor calibration data, orientation, and velocity), time and date of the RO measurement or any portion of the measured GPS signal.

[00130] In another embodiment, RO measurement, processing, and data transmission tasks are shared between more than one constellation satellites. This configuration may be useful when satellites are partially malfunctioning, or to share processing capabilities across low power satellites. It also allows for tasks to be assigned to satellites more efficiently. For example, one

satellite may be in a location where many RO measurements can be taken, but another satellite is in a poor location for taking RO measurements. In this situation, the first satellite's processing power can be devoted to taking RO measurements, while the second satellite's processor can be tasked with calculating atmospheric parameters.

[00131] In yet another embodiment, processing tasks are shared between the satellite constellation and the ground servers. In this configuration, the constellation satellite sends a minimized data package comprising of at least the RO measurements and the servers calculate the atmospheric properties. The remaining parameters may be interpolated by the ground servers from previously obtained data. This takes advantage of the processing capabilities of the servers and also preserves the data processing resources of the satellites. It also allows for more advanced algorithms to be applied by the servers that may factor in data from other sources to provide a more accurate weather solution.

[00132] The ground servers collect and compile the atmospheric data into a comprehensive data map that is updated on a near real time basis.

[00133] **Figure 11** depicts a functional block diagram for an illustrative system arrangement. Starting with block 600, the GNSS transmits signals of known properties – collected by the receivers on-board the low earth orbit satellites forming the collection constellation, block 610. The properties of the GNSS are distributed for subsequent uses, block 650 (not shown). The RO data developed by the constellation, block 610 is delivered to the ground network block 620; in addition, programming and orientation instructions are delivered to the constellation by the ground network to permit proper tracking of select atmospheric conditions. Finally, ground operations include both database management and data processing, block 630; with resulting atmospheric conditions and predictions delivered to a display/distribution system block 640.

[00134] **Figure 12** depicts an illustrative logic programming arrangement. Starting at block 700, system operation logically begins with RO data collections triggered by either an event, block 710 or by User Command, block 750. An event may be by automated threshold tracking, for example an atmospheric anomaly, such as a hurricane image identified by constellation image/camera operations, a “yes” to test 710 initiating RO data collection. Once activated, a collection algorithm develops RO data for the region of interest. This algorithm can provide instructions to target satellite operation so that GNSS “paths” of interest are populated (by for

example, satellite orientation) and select reception by the constellation, block 730, with data collected at block 740 and deposited into the database.

[00135] Continuing with **Figure 12**, regional studies are also triggered by USER COMMAND, test 750. If selected, the system determines the profile of RO collection with GNSS and constellation combinations to create the properly oriented paths for study, block 770. Once oriented, the data is collected and delivered to the database for subsequent analysis, 780. Because the constellation collects image data for the same atmospheric regions of interest, processing of RO is done with the image data. Illustrative uses for the image data include resolving ambiguities created by the RO data as to individual data and/or ultimate conclusions regarding conditions within the region.

Space-based Ship Tracking

[00136] In another embodiment, a network of more than one satellites as described above is configured and tasked for tracking the location of ships or other vehicles. Under this embodiment, the constellation satellites may include one or more on-board digital camera systems. In a preferred embodiment, one or more constellation satellites are equipped with a high definition digital camera or similar system to capture images within the visible spectrum. In another embodiment, one or more constellation satellites are equipped with a multispectral or hyperspectral digital camera system to capture images over a wide range of the electromagnetic spectrum. In another embodiment, one or more constellation satellites are equipped with a narrow spectrum camera system optimized for capturing images from a task-optimized spectrum band. For example, an IR camera could capture images through the upper cloud layer and detect heat signatures emanating from a ship, which could enhance the ship detection capabilities as described below. The high replacement rate of the constellation satellite system allows for future advances and cost reductions in camera sensors to be exploited.

[00137] Each satellite within the constellation in the present invention (“constellation satellite”) is equipped with receiver hardware capable of receiving signals from one or more GNSS systems. In a preferred embodiment the receiver hardware is designed for a particular GNSS system for higher computational efficiency and lower power consumption. In another embodiment, a software GNSS receiver provides the satellite with adaptive signal processing

capabilities at the cost of higher processing and power consumption.

[00138] One or more constellation satellite is capable of detecting AIS signals. Either a dedicate AIS signal sensor and processor is utilized, or a software defined radio (SDR) system that is configurable to receive and process AIS signals is installed. In a preferred embodiment, a high-gain or other type of directional antenna is used by one or more constellation satellites for detecting AIS signals for higher sensitivity and to provide control over the observed area. A phased array configuration, which utilizes smaller antennas installed on multiple satellites, may be used for further directional control of the observed area and even higher signal gains. Phased arrays, when capable of beam forming, provide the further benefit of allowing directional control over the observed area without the need for physically orienting the satellite platform. In another embodiment, a low-gain antenna is used by one or more constellation satellites to detect AIS signals over a larger observable area. In yet another embodiment, a combination of high-gain and low-gain antennas are used in concert to provide a broad view of detected AIS signals and to lock on to a specific AIS signal or group of AIS signals.

[00139] Each additional satellite in the constellation increases temporal resolution and coverage of the system as a whole, and provides more opportunity for intersatellite communication and the benefits it provides as described below. It is preferred to use 10 or more satellites for supporting global ship based tracking and monitoring. It is preferred to use 50-100 satellites in the network – forming a constellation of receivers – for increasing reliability and performance of the network. While fewer than 10 satellites may be deployed in accordance with the present invention, time windows between tracking events will range between 2-6 hrs. For a network of 50 satellites the temporal range for monitoring select regions of ocean comprising shipping traffic drops to 2-10 minutes.

[00140] The constellation satellites are capable of attitude control through a combination of magnetorquers and/or reaction wheels. Orientation may be determined through a combination of one or more on-board magnetometers, sun sensors, gyroscopes and/or accelerometers. The constellation satellites are further configured to determine its location and velocity with respect to the Earth through the on-board GNSS receiver. In a preferred embodiment, a satellite's orientation control is used to direct one or more of the on-board sensors towards an area of interest. In another embodiment, the orientation capabilities are used to orient the satellite's on-

board communication antennas for optimal transmission.

[00141] The constellation satellites are configured to transmit data and communicate with other satellites in the constellation as well as with ground stations. In a preferred embodiment, a telecommunications link between constellation satellites and ground stations is established on one or more UHF and/or SHF radio bands. In another embodiment, the constellation satellites are equipped with software defined radio (SDR) communication systems that allow for telecommunication links to be established through a wide spectrum of radio frequencies and provide the system with the flexibility to adjust according to mission needs.

[00142] In a preferred embodiment, data is transferred between constellation satellites and ground stations digitally according to well-known network protocols, such as the File Transfer Protocol (FTP), or a similar system. In other embodiments, the network protocol utilized is secured using a standard such as SSL/TLS, or another similar security standard.

[00143] The constellation satellites and ground stations are configured such that intersatellite and satellite to ground station communications are compensated for any Doppler shift in the transmitted signals due to relative velocities. Doppler compensation techniques are well known in the digital communications arts. In a preferred embodiment, phase-locked loop (PLL) and/or frequency-locked loop demodulation algorithms are applied by the receiver to compensate for Doppler shifts.

[00144] The intersatellite communications capability allows for the satellite constellation to form an ad hoc wireless data network with each satellite acting as a node and the network formed in a variety of topologies for the transmission of data according to the needs of the mission and the distribution of the satellites. Each constellation satellite may be programmed and configured to link to other constellation satellites within range and forward data sent by those satellites. The topology and data routing can then be determined dynamically according to the connectivity and operational status of the satellite-nodes.

[00145] This flexible data routing provides the invention with the advantage of near real-time communications with the ground based network. For example, because a link between any constellation satellite and the ground requires line of sight, there may be times when an individual satellite is not within communications range of a ground station and cannot transmit

its data payload. The constellation satellite must then wait until the next ground station comes within range to send its payload. These individual delays can accumulate to unacceptable levels across the network. The present system allows for the out-of-range constellation satellite to send its data payload to the ground network via any other connected constellation satellite.

[00146] The large number of satellites in the constellation and flexible network capabilities provides the system with many advantages over current systems. The malfunction of individual satellite-nodes in a large constellation would have a negligible effect on the overall network throughput. Similarly, the satellite network could route around any non-operational ground station. As discussed above, the dynamic routing capability also allows for near real time transmission of acquired data to the ground network.

[00147] The ground station network is configured to transmit data to one or more servers (“ground servers”) through the Internet or other suitable data transmission system. For example, a ground station may be connected to the same local area network as a ground server, in which case a more suitable transmission method would be through the local area network.

AIS Signal Reception

[00148] Ship-borne AIS signals are broadcast over the same VHF channel using a TDMA technique that takes advantage of the limited horizontal range of AIS transmitters. Time slots are divided between ships within an organized area. As conventionally used, interference between ships transmitting from adjacent areas on the same time slot is not an issue because the standard horizontal range of the AIS signal does not reach beyond the range of the organized area.

[00149] **Figure 13** illustrates an example of the system using a single satellite. **Figures 14** and **15** illustrate the constellation satellites and their ground stations. The example of **Figure 13** is “multiplied” over the many satellites and additional functionality can be realized using the constellation. **Figure 13** illustrates a satellite receiving AIS signals from both ships and stationary navigational markers. Further illustrated are the standard AIS receiving ground stations. However, as discussed herein, the present examples can operate far from shore in international waters. Using the constellation satellites, large sections of the Earth’s navigable waters can be efficiently monitored. **Figure 13** also illustrates the monitoring of aircraft, and that example is discussed below.

[00150] For space-based AIS observation, an AIS receiver covers a much larger area than the AIS signal structure was designed to operate within. A standard AIS receiver operating on an orbiting satellite platform can receive competing AIS signals from many organized areas within its field of view. AIS signals operating on the same TDMA time slot, but from different areas can interfere with each other when received by the receiver and reduce the likelihood that either signal can be successfully detected and tracked. Any increase in the number of ships in the observed area further reduces this probability. At an altitude of 1000 km, with an operating field of view to the horizon (~3630 nautical mile sweep), a standard AIS receiver may receive up to 6200 ship signals simultaneously.

[00151] In a further example, the constellation satellites can be placed in much lower orbits, below the 1000 km altitude. At an altitude of 500 km, for example, the satellites only cover $\frac{1}{4}$ of the area covered by the same satellites at a 1000 km. This should result in only $\frac{1}{4}$ off the ships in the observed area, or up to 1550 ship signals. This aids in speeding up the processing for the de-collision of the signals. A second benefit to a lower orbit, is that the constellation satellites are automatically de-orbiting within a few years of launch (i.e. falling out of the sky and burning up in the atmosphere). This allows for easy replacement and upgrade cycles, for example, as one satellite de-orbits, another can take its place and not compete for the outdated satellite in its orbital path.

[00152] If a large number of AIS sensors are utilized to cover an area, it is possible to increase the probability of detection by limiting each receiver satellite's field of view, but still provide high coverage and data updates. This overcomes the shortcomings of previous attempts at an S-AIS system. The large constellation of satellites described above provide an optimal platform for a high coverage S-AIS system that is frequently updated at near real time rates. By limited the field of view of the AIS antenna for each constellation satellite, the number of TDMA organized areas observed by the AIS sensor is controlled. In one embodiment, the field of view is controlled by adjusting the antenna reception characteristics. This may be accomplished by selecting an antenna with the desired reception profile or, in the case of a phased array, shaping the reception beam. In another embodiment, the field of view is controlled by reorienting the satellite.

[00153] The use of a constellation of satellites that are properly programmed provides several

elegant solutions to the collision issue. AIS transmissions can be tracked by multiple concurrent satellites and organized by signal strength to filter overlapping AIS packets. Once the system associates a particular signal/strength to a particular vessel within the grid under review, second and later passes by other satellites provides embellishing data allowing increasing confidence by the system as to each tracked AIS/vessel. As more satellites receive the same AIS, de-collision processing results in a very high level of accuracy regarding signal fidelity.

[00154] In addition, the ground based network can post-process the data for select AIS signals after multiple reads from separate constellation satellites. This can be done very rapidly and all de-collisioning accomplished using sophisticated best fit algorithms on large data sets. As the overall processing power of individual satellites increases over time, these will become more articulate in assessing and de-collisioning AIS signals in orbit – and near real time. Again, these solutions are largely possible due to the constellation approach coupled with the ground based station network.

Image capture

[00155] Using the one or more installed camera systems, the satellite constellation network can also provide near real time imagery data over the entire globe. The large constellation provides mission operators with a high degree of flexibility in how images are captured. For example, to increase the frequency of image update, many satellites may be instructed to capture and transmit images of the same area as their orbits take them within capture range. To increase coverage, the satellites may be instead instructed to capture images of all areas. All captured images can then be compiled to produce a live global map.

[00156] Images may be geolocated using the location and orientation data of the satellite. Multiple images and data can be compared and error corrected to increase geolocation accuracy. In one embodiment, image recognition algorithms are used to identify landmark features in captured images to further enhance the geolocation accuracy.

[00157] Imaging and AIS reception tasks can be accomplished by the same satellite or shared between more than one satellite.

[00158] Image recognition algorithms may be applied to the captured images to identify ships and other objects in the observed area. The geolocation of the identified ships and objects can

then be determined using the image geolocation data. Multiple geolocation determinations can be used to correct for error and increase accuracy. This accuracy can be improved, in an example, if the constellation satellites also carry GPS receivers. Knowing the exact time in the orbit and the location and orientation of the satellite, and thus the location of the image, helps with points of reference between the image and AIS data sets.

[00159] Successive images may be captured with corresponding image and ship/object location determinations. In one embodiment, information on the speed and heading of a ship or object is derived from the changes in the determined locations of the ship or object between images. Using this method, any changes in the shape and size of an object can also be derived. This may be useful for observing natural phenomena, such as the recession of the polar ice caps or the movement of glaciers. It may also allow for the detection and tracking of oil spills.

Comparisons between data

[00160] Data from AIS messages received by the satellite system can be compared to data derived from the captured images. In one embodiment, the location information provided by ships in an observed area is compared to the geolocation determinations for all identified ships in the same area. In another embodiment, additional information provided by ships, such as speed, heading, ship size, ship type, are compared with the same types of data determined from the captured images.

[00161] Comparing the AIS and image data also can provide information regarding vessels lacking or deliberately disabling their AIS beacon. Typically vessels will turn off or disable their AIS beacon if they are being used for illegal purposes. Pirates typically do not have or emit AIS data to avoid detection as they operate in their area of influence. **Figure 16** illustrates 9 ships in a review grid. Eight vessels are identified by their AIS data, and that is represented in this image by the triangular marker. However, image data reveals that there are nine vessels in the grid. The comparison matches the AIS data to image data to determine the one vessel not transmitting AIS data. This vessel is likely engaged in legally questionable activities and both the surrounding vessels and/or authorities in the area can be notified.

[00162] In some recent examples, Iranian oil tankers were ordered to switch off their AIS transponders by their government to order to make oil shipments counter to certain sanctions

imposed against the country. A North Korean freighter was attempting to smuggle weapons into the country, and it had its AIS beacon turned off. The above vessels are tracked or captured by other means, but the present invention can simplify the process, altering authorities almost as soon as the vessels enter international waters.

[00163] Piracy is also an issue, with pirates from certain African nations hijacking freighters, tankers, and even cruise ships. Pirates do not use AIS beacons but can then be readily identified using the image comparison. Given that certain geographical areas are more prone to piracy, additional or expanded coverage by the constellation can be warranted. In line with piracy, the poaching of fishing zones is also an issue. Illegal fishing boats will also turn off their AIS beacon when entering certain fishing areas to mask their poaching. Again, the comparison of optical and AIS data can identify these illegal actors.

[00164] Turning to determining the differences between the AIS data and image data, the geolocation data derived from the captured images will not have perfect accuracy. Some tolerance must be incorporated to account for error. Thus, the system receives the AIS data from a vessel and begins to de-collision the signal to identify the individual vessels in the grid. The image data is also processed, either on the same satellite or on other constellation satellites. As noted, the geolocation of the vessels in the image are generated and compared to the AIS data. Factors to be considered for the comparison are the location, speed and heading of each vessel as well as the relative size of the vessel, all of which can be determined from both sets of data.

Other Features

[00165] Processing tasks may be shared between satellites and ground servers for more efficient use of system resources.

[00166] A large constellation of satellites provides a ship tracking system with comprehensive coverage as well as the capability for duplicative coverage by more than one constellation satellite of a given area at the same time. An embodiment that leverages this capability captures images of an area from multiple angles (i.e. from multiple satellites aimed at the same area) and combines these to form a multi-dimensional view of the space that enhances the image-based ship detection abilities of the system. In another embodiment, images are taken from the same area from the same angle by one or more satellites. Using resolution enhancement, or “super

resolution” algorithms, relatively low resolution images can be combined to produce a high resolution image thereby improving the ship image recognition accuracy. The use of lower resolution images also reduces the bandwidth required to transmit the image data through the satellite constellation network and to the ground station. It also allows for the use of lower cost camera sensors.

[00167] The AIS tracking satellite system may also be adapted for tracking Automatic dependent surveillance-broadcast (ADS-B) signals transmitted by aircraft. ADS-B makes an aircraft visible in realtime by transmitting position and velocity data every second. The system relies on two components—a high-integrity GPS navigation source and a datalink (ADS-B unit). ADS-B data links can operate at 1090 MHz or at 978 MHz. Again, while the aircraft are over international waters they are typically outside the range of land based receivers. However, the constellation satellites cover a majority of the Earth’s surface and can constantly monitor aircrafts from take-off until landing wherever they fly.

[00168] Trains can also be monitored. Currently, rail cars may be equipped with radio frequency identification (RFID) tags such as Automatic Equipment Identification (AEI) tags that can be read by a tag reader positioned at known locations within the rail system and configured to recognize and report when an AEI tagged railcar passes. Accordingly, a location and a time of passage of the rail car can be reported to track the last reported locations of the tagged rail cars. Other sensors can be used to transmit data regarding the condition of the train cars, including an accelerometer for detecting movement of the rail car, a temperature sensor, a pressure sensor, a door position sensor, a cargo identification sensor, and a cargo seal condition sensor.

[00169] However, prior art AEI system can only provide location information of the rail car at the time when the car passes the reader. At any other position, the exact location of the car is unknown. In addition, another issue with AEI tagged cars is power to the transmitters. The transmitters are typically battery powered, or powered by the reading station. This limits their transmission time and length of information transmitted.

[00170] Instead, with the constellation satellites, the train cars can be monitored in real time. The constellation satellites can receive the intermittent messages sent by the transmitters as they pass reading stations. However, the train cars can be further tracked using the image data while the cars are between reading stations. Since the rail lines have defined paths, correlation

between the AEI data and the image data can be performed faster, as it is unlikely other trains are present on the same tracks within specified distances. In addition, images from the constellation satellites can monitor activity on the rail tracks and determine if an object is stationary on the tracks for an extended period of time, separating it from typical vehicle and person traffic. If a stationary object is detected on the tracks, information can be passed to the train crew or dispatcher to slow the train to avoid collisions.

[00171] Additional advantages can be in the reading stations. Currently they need to be linked to a system to power, read and transmit the AEI data. However, if the constellation satellites are reading the AEI data, the reading stations can be made “dumber” and are then only required to power the AEI tag. Thus the AEI stations can be made less expensively and positioned in areas where there is power, but low data transmission access.

[00172] Also note that the technology behind the train car tracking is also the technology supporting most automated road toll collection systems. The present invention can be expanded to also track commercial vehicles with toll collection devices or other transponder technologies. Thus, the present invention can be used to literally track goods or containers from their source to their destination regardless if the goods are shipped via truck, rail, ship, or air.

[00173] Further examples are also described below, based on the above examples. One example is system for tracking vehicles wherein each vehicle transmits an identifying signal. As noted above, that signal can be an Automatic Identification System (AIS) signal, an Automatic Dependent Surveillance-Broadcast (ADS-B) signal or an Automatic Equipment Identification (AEI) signal. The system can include a first transmission link to the constellation of low earth orbit satellites. As noted, each satellite can be equipped with a radio receiver tuned to select transmission frequencies associated with the signals of the vehicles. The frequencies of the AIS, ADS-B, and AEI signals are known in the art. A second transmission link to a network of ground stations can be included. The ground stations can be in communication with one or more constellation satellites, see **Figure 15**. The second transmission link can deliver data collected by the satellites regarding the vehicle transmissions.

[00174] A computer processor at either the ground stations, or on board one or more of the constellation satellites receives input from at least one of first and second transmission links. The processor is programmed to acquire and track vehicle position in near real time based on

identifying signals transmitted by said vehicle. Further, it resolves collisions (i.e. de-collisions) between multiple sampled signals based on multiple receiver inputs. There is also an output device to deliver tracking data and warnings relating thereto to one or more system administrators or vessel operators.

[00175] The constellation satellites can include an image capture device taking image data of a region associated with the vehicles (e.g. an ocean grid). See, **Figure 16**. The image data can be processed by the processor to determine one or more vehicles from the image data (e.g. locate the ships on the open water) and that can be correlated with the identifying signals to determine each vehicle in the image with their respective signals. This process can assist in identifying rogue vehicles, which are vehicles determined in the image data but do not have a respective identifying signal. See, **Figure 16**.

[00176] In an example for tracking ocean vessels, there can be a data link to the constellation of low earth orbit satellites that collect the data of AIS transmissions for select vessels within defined grid coordinates. That data link or a separate data link to the constellation of low earth orbit satellites can collect image data for the grid corresponding to the AIS data. A computer processor can implement a tracking algorithm that applies the AIS data and the image data to develop a tracking model for ships associated with said AIS data within the grid and ships identified by image data within the grid. It can then have an output system reporting on anomalies between image and AIS data, including warning signals for vessels lacking AIS data.

[00177] The computer processor further implements the tracking algorithm to identify rogue ships, which are the ships identified by the image data but are lacking AIS data.

[00178] An example of a method to tracking vehicles that emit an identifying signal is illustrated in **Figure 17**. Here, the system receives, by at least one of a constellation of low earth orbit satellites, at least one the identifying signals from the vehicles (Step 1700). The constellation of low earth orbit satellites also collect image data of a region in which the vehicles are traveling (Step 1702). A position of at least one of the vehicles can be acquired in near real time based on the identifying signals transmitted by the vehicle (Step 1704) and tracking at least one of the vehicles using the position data (Step 1706). At least one of the identifying signals, the image data, or the position data, is transmitted to at least one ground station (Step 1708). The ground station can then output at least the position data to an operator of the vehicle and/or a

system administrator (Step 1710). In a yet further example, the acquiring step can also resolve collisions between multiple received signals from multiple vehicles (Step 1705).

[00179] Another example of the method is illustrated in **Figure 18** and can include steps of analyzing the image data to identify a majority of the vehicles in the region. (Step 1800). Then matching the identification signal and image data identity for a majority of the vehicles in the region (Step 1802). This can allow for determining if a rogue vehicle is in the region by identifying vehicles in the image data that do not have the identification signal (Step 1804).

[00180] As noted above, the identifying signal can be one of an Automatic Identification System (AIS) signal, an Automatic Dependent Surveillance-Broadcast (ADS-B) signal or an Automatic Equipment Identification (AEI) signal, or any other transponder type signal.

[00181] Certain implementations of the disclosed technology are described above with reference to block and flow diagrams of systems and methods and/or computer program products according to example implementations of the disclosed technology. It will be understood that one or more blocks of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, respectively, can be implemented by computer-executable program instructions. Likewise, some blocks of the block diagrams and flow diagrams may not necessarily need to be performed in the order presented, or may not necessarily need to be performed at all, according to some implementations of the disclosed technology.

[00182] These computer-executable program instructions may be loaded onto a general-purpose computer, a special-purpose computer, a processor, or other programmable data processing apparatus to produce a particular machine, such that the instructions that execute on the computer, processor, or other programmable data processing apparatus create means for implementing one or more functions specified in the flow diagram block or blocks. These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instruction means that implement one or more functions specified in the flow diagram block or blocks.

[00183] Implementations of the disclosed technology may provide for a computer program

product, comprising a computer-usable medium having a computer-readable program code or program instructions embodied therein, said computer-readable program code adapted to be executed to implement one or more functions specified in the flow diagram block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational elements or steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions that execute on the computer or other programmable apparatus provide elements or steps for implementing the functions specified in the flow diagram block or blocks.

[00184] Accordingly, blocks of the block diagrams and flow diagrams support combinations of means for performing the specified functions, combinations of elements or steps for performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, can be implemented by special-purpose, hardware-based computer systems that perform the specified functions, elements or steps, or combinations of special-purpose hardware and computer instructions.

[00185] While certain implementations of the disclosed technology have been described in connection with what is presently considered to be the most practical and various implementations, it is to be understood that the disclosed technology is not to be limited to the disclosed implementations, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

[00186] This written description uses examples to disclose certain implementations of the disclosed technology, including the best mode, and also to enable any person skilled in the art to practice certain implementations of the disclosed technology, including making and using any devices or systems and performing any incorporated methods. The patentable scope of certain implementations of the disclosed technology is defined in the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from

the literal language of the claims.

[00187] Certain implementations of the disclosed technology are described above with reference to block and flow diagrams of systems and methods and/or computer program products according to example implementations of the disclosed technology. It will be understood that one or more blocks of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, respectively, can be implemented by computer-executable program instructions. Likewise, some blocks of the block diagrams and flow diagrams may not necessarily need to be performed in the order presented, or may not necessarily need to be performed at all, according to some implementations of the disclosed technology.

[00188] These computer-executable program instructions may be loaded onto a general-purpose computer, a special-purpose computer, a processor, or other programmable data processing apparatus to produce a particular machine, such that the instructions that execute on the computer, processor, or other programmable data processing apparatus create means for implementing one or more functions specified in the flow diagram block or blocks. These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instruction means that implement one or more functions specified in the flow diagram block or blocks.

[00189] Implementations of the disclosed technology may provide for a computer program product, comprising a computer-usable medium having a computer-readable program code or program instructions embodied therein, said computer-readable program code adapted to be executed to implement one or more functions specified in the flow diagram block or blocks. The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational elements or steps to be performed on the computer or other programmable apparatus to produce a computer-implemented process such that the instructions that execute on the computer or other programmable apparatus provide elements or steps for implementing the functions specified in the flow diagram block or blocks.

[00190] Accordingly, blocks of the block diagrams and flow diagrams support combinations of means for performing the specified functions, combinations of elements or steps for

performing the specified functions and program instruction means for performing the specified functions. It will also be understood that each block of the block diagrams and flow diagrams, and combinations of blocks in the block diagrams and flow diagrams, can be implemented by special-purpose, hardware-based computer systems that perform the specified functions, elements or steps, or combinations of special-purpose hardware and computer instructions.

[00191] While certain implementations of the disclosed technology have been described in connection with what is presently considered to be the most practical and various implementations, it is to be understood that the disclosed technology is not to be limited to the disclosed implementations, but on the contrary, is intended to cover various modifications and equivalent arrangements included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

[00192] This written description uses examples to disclose certain implementations of the disclosed technology, including the best mode, and also to enable any person skilled in the art to practice certain implementations of the disclosed technology, including making and using any devices or systems and performing any incorporated methods. The patentable scope of certain implementations of the disclosed technology is defined in the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

[00193] Persons skilled in the art will recognize that the foregoing discussion is for illustration and does not by itself limit the claims. In particular, skilled artisans will recognize that there are current and future variations of the above arrangements that are consistent with the invention, and that the proper scope of the invention is provided by the following individual claims unencumbered by the discussion of these illustrative examples provided above.

CLAIMS

What is claimed is:

1. A computer system operable by a user, comprising:

a communication portal accessible by one or more system users for providing information to said users regarding (i) access times for one or more in-orbit satellites; (ii) one or more sensors available for data collection on said one or more satellites; (iii) ability to upload applications to one or more user-programmable microprocessors on said one or more satellites; and (iii) data from said one or more satellites;

a non-transitory computer-readable storage medium configured to store (i) data collected from said one or more satellites and (ii) information regarding reserving access times for said one or more satellites; and

a computer display connected by said portal to a remote satellite operations server to permit viewing and managing, over the internet, satellite operations in accordance with user selected parameters.

2. The system of claim 1 wherein said data from said one or more satellites is spatially and temporally synchronized for ground based storage.

3. The system of claim 1 wherein said computer system includes tablets, smartphones and laptop computers.

4. The system of claim 1 wherein the communication portal is internet based and configured to allow said users to adjust the parameters of one or more sensors on said satellite through access with said operations server.

5. The system of claim 1 wherein the communication portal is configured to allow said users to run said one or more applications for managing satellite operations on said one or more satellites.

6. The system of claim 1 wherein said users may register with a satellite system administrator over the communication portal for access time to said satellite.

7. The system of claim 6 wherein said registration includes paying for a subscription to access at least a portion of the communication portal.
8. The system of claim 1 wherein said access time is auctioned to said users on a clearinghouse server that permits bidding for said access time.
9. The system of claim 1 wherein increments of said access time are sold for a price, wherein said price is adjusted based on external events or user demand.
10. The system of claim 1 wherein access to at least part of the data is sold for a fee.
11. The system of claim 1 wherein said processor is further programmed to apply analytics to said data.
12. The system of claim 1 wherein one or more of said satellites is replaced by an updated satellite every 6 to 24 months.
13. A non-transitory computer-readable storage medium containing a program for use in a space-based orbiting satellite that, when said program is delivered to said satellite executed on a data-processor, causes a satellite data-processor to:
 - control one or more satellite-based sensors and systems;
 - collect data generated by said satellite-based sensors for a select period of time based on internet-distributed program time frame access rights to said satellite-based sensors; and wherein said program is delivered to said satellite based on said access rights.
14. The non-transitory computer-readable storage medium of claim 13, wherein said access rights to said satellite-based sensors are provided to one or more users for a fee and said sensors operate to collect spectrum based (IR to UV) electromagnetic data, images and/or video.
15. A satellite internet access support system comprising:
 - a computer server programmed to permit USER access to a satellite programmed for internet-controlled access to generated data, wherein said data is supplied based on USER internet request to said system administrator; and

said satellite is replaced by an updated satellite every 6 to 24 months.

16. The system of claim 15, wherein said USER access to said satellite is provided for a fee.

17. A non-transitory computer-readable storage medium containing data created by a program-controlled space-based satellite sensor, said data comprising:

video, picture, temperature or telemetry data created by said satellite sensor, wherein said sensor is program-controlled and said program is USER selected by Internet access, and further wherein access to said satellite is distributed to a community of USER subscribers, via internet access, for select and defined periods of time.

18. The non-transitory computer-readable storage medium of claim 17, wherein said access to said satellite is provided to said subscribers for a fee.

19. A computer-implemented method for creating and collecting data from plural short life satellites, comprising:

a. receiving at said satellites instructions for operating one or more computer, telescope or sensor on said satellites;

b. processing said requests or said satellites and collecting data from said telescope and sensors based on said requests.

c. transmitting said data to one or more ground stations for distribution to one or more system users, where said system users enter said requests through an Internet-based portal for access to a select window of time for said satellites and said satellites are replaced every 6-24 months.

20. The computer-implemented method of claim 19, wherein said access to said select window of time is provided for a fee.

21. A computer based method comprising:

accessing, via a multi-node, user connected computer network, a communication portal, wherein said communication portal is connected to a server and provides information regarding (i) a request for access from one or more users to access one or more sensors available for data

collection on one or more satellites; and (ii) a request to upload applications to one or more user-programmable microprocessors on said one or more satellites;

confirming the authenticity of the request, based on stored access rights information;

transmitting, via the multi-node computer network, based on said request for access time instructions for implementing said request;

storing, in a non-transitory computer-readable storage medium, information regarding data collected from the one or more satellites based on said request; and

distributing to said user information regarding data collected from said satellites.

22. The method of claim 21, further comprising the step of transmitting one or more applications for use in managing satellite operations in accordance with user selected parameters.

23. The method of claim 21, further comprising the step of confirming payment of a fee for said access to the one or more satellites.

24. A system for determining atmospheric conditions, comprising:

a transmission link to a plurality of satellite-based radio transmitters from one or more Global Navigation Satellite Systems (GNSS), wherein the transmitters transmit radio signals and said signals comprise data reflecting occultation of GNSS based radio signals collected from multiple paths by a constellation of satellites placed in low earth orbit;

a computer linked database storing said data; and

a computer processor implementing a occultation analysis algorithm to ascertain atmospheric conditions for use in identifying weather conditions associated with said occultation data.

25. The system of claim 24, wherein the constellation includes at least 50 satellites in low earth orbit.

26. The system of claim 25, wherein the constellation communicates with said transmission link via a network of ground stations.

27. The system of claim 26, wherein the ground stations communicate with said computer linked database to provide recently collected occultation data.
28. The system of claim 24, further comprising a display system to deliver details regarding atmospheric conditions to one or more users by network communications.
29. The system of claim 28, wherein the display system further comprises graphical representation of atmospheric trends or conditions.
30. A method for assessing atmospheric conditions comprising:
collecting RO data from a plurality of satellites based on a Global Navigation Satellite System (GNSS) signal tracking;
collecting image data regarding a region of atmosphere of interest;
storing in computer memory RO and image data; and
processing RO and image data to ascertain properties about select regions of atmosphere.
31. The method of claim 30, wherein said plurality of satellites includes at least 50 satellites placed in low earth orbit.
32. The method of claim 30 wherein said image data is generated by one or more of said plurality of satellites.
33. The method of claim 30 wherein said RO data is developed from GNSS signals using multiple paths through a common region of atmosphere.
34. The method of claim 30 wherein said RO data is collected using a plurality of low priced, low life expectancy satellites equipped with receivers for multiple GNSS signals.
35. The method of claim 34 wherein the collection satellites form a constellation linked to internet communications by plural ground stations.

36. A database and associated processor platform in communication with a plurality of low earth orbit satellites, said platform comprises:

a. A communication link to said satellites assessing and recalling satellite data on atmospheric occulted signals;

b. A database storing said data with time, Global Navigation Satellite System (GNSS) and location information regarding each occulted signal;

c. A computer processor programmed with one or more occultation analysis algorithms i-communication with said database for implementing said algorithm and rendering projections based on atmospheric conductors determined by said algorithm; and

d. System output link to deliver projections to one or more network affiliates platform

37. The platform of claim 36 further comprising an inter-satellite communication link to pass data without instructions between orbiting satellites

38. The platform of claim 36 further comprising creating image data generated by satellite based cameras and receiving said image data at said platform for analysis in conjunction with said occultation data.

39. The platform of claim 36 when said image data is generated by USER communication.

40. A system for tracking vehicles wherein each vehicle transmits an identifying signal, the system comprising:

a. a first transmission link to a constellation of low earth orbit satellites, wherein each satellite is equipped with a radio receiver tuned to select transmission frequencies associated with the signals of said vehicles;

b. a second transmission link to a network of separately located ground stations in communication with said constellation of satellites wherein the transmission link delivers data collected from said vehicle transmissions;

c. a computer processor receiving input from said first and second transmission links and programmed to:

acquire and track vehicle position in near real time based on identifying signals transmitted by said vehicle; and

resolve collisions between multiple sampled signals based on multiple receiver inputs; and

d. an output device to deliver tracking data and warnings relating thereto to one or more system administrators.

41. The system of claim 40, further comprising:

an image capture device equipped on one or more of the satellites taking image data of a region associated with said vehicles;

wherein the image data is transmitted over the second transmission link;

wherein the computer processor is further programmed to:

determine one or more of said vehicles from the image data; and

correlating the one or more of said vehicles with their respective identifying signals.

42. The system of claim 41, wherein the computer processor is further programmed to identify rogue vehicles, which are vehicles determined in the image data but do not have a respective identifying signal.

43. The system of claim 40, wherein the identifying signal is at least one of an Automatic Identification System (AIS) signal, an Automatic Dependent Surveillance-Broadcast (ADS-B) signal or an Automatic Equipment Identification (AEI) signal.

44. The system of claim 40, wherein the output device deliver tracking data and warnings relating thereto to operators of one or more of said vehicles.

45. A system for tracking ocean vessels comprising

a. a data link to a constellation of low earth orbit satellites collecting data of AIS transmissions for select vessels within defined grid coordinates;

b. a data link to a constellation of low earth orbit satellites collecting image data for said grid corresponding to said AIS data;

c. a computer processor implementing a tracking algorithm that applies said AIS data and said image data to develop a tracking model for vessels associated with said AIS data within the grid and vessels identified by said image data within the grid; and

d. an output system reporting on anomalies between image and AIS data, including warning signals for vessels lacking AIS data.

46. The system of claim 45, wherein the computer processor further implements the tracking algorithm to identify rogue ships, which are vessels identified by the image data but are lacking AIS data.

47. A method of tracking vehicles emitting an identifying signal, comprising the steps of:

receiving by at least one of a constellation of low earth orbit satellites, at least one the identifying signals from the vehicles;

collecting image data of a region in which the vehicles are traveling by at least one of the constellation of low earth orbit satellites;

acquiring a position of at least one of the vehicles in near real time based on the identifying signals transmitted by the vehicle and tracking at least one of the vehicles using the position data;

transmitting at least one of the identifying signals, the image data, or the position data, to at least one of a network of separately located ground stations in communication with said constellation of satellites; and

outputting, by a ground station, at least the position data to at least one of an operator of the vehicle or a system administrator.

48. The method of claim 47, wherein the acquiring step further comprises the step of resolving collisions between multiple received signals from multiple vehicles.

49. The method of claim 47, further comprising the steps of:

analyzing the image data to identify a majority of the vehicles in the region;

matching the identification signal and image data identity for a majority of the vehicles in the region; and

determining if a rogue vehicle is in the region by identifying vehicles in the image data that do not have the identification signal.

50. The method of claim 47, wherein the identifying signal is at least one of an Automatic Identification System (AIS) signal, an Automatic Dependent Surveillance-Broadcast (ADS-B) signal or an Automatic Equipment Identification (AEI) signal.