Chapter 2
Requirements for Description of GRFS Systems

2.1 Overview

Requirements for description of Geolocation of RF Signals (GRFS) systems offer an overview of the best practices, classifications, visual interpretation, very important detailed descriptive ingredients, and innovative techniques in the art and science of GRFS over the last 20 years. In Chap. 1 we gave a very brief description of the GRFS systems which consisted only of the description from the local coordinate point of view into: (1) indoors, (2) urban, (3) suburban, (4) global, and (5) satellite. In this chapter, in addition to local coordinate environment description, we are going to add the global coordinate environment description which consists of: (1) water, (2) ground, (3) air, and (4) space descriptions. As we are going to see further in this chapter, there are 39 typical principle system illustration case studies for GRFS systems: (1) four correspond to requirements for description of indoor GRFS systems in Sect. 2.3; (2) eight correspond to requirements for description of urban GRFS systems in Sect. 2.4; (3) nine correspond to requirements for description of suburban GRFS systems in Sect. 2.5; (4) nine correspond to requirements for description of global GRFS systems in Sect. 2.6; and (5) nine correspond to requirements for description of satellite GRFS systems. It covers all research and development aspects including key block diagrams, and practical principle typical descriptions in the frequency band from 100 MHz to 60 GHz (or even 66 GHz). Dr. Progri reveals the research and development process by demonstrating how to understand and explain GRFS' most typical system deployment from basic diagrams to the final principle simulation examples (in Chaps. 4 and 6) and make recommendations for the future final products for research and development of GRFS. Starting with an introduction in Sect. 2.2 where an overview of the requirements for description of GRFS systems is given in both local and global coordinates, the chapter progressively examines various signal bands – such as VLF, LF, MF, HF, VHF, UHF, L, S, C, X, Ku, and, K and the corresponding geolocation requirements per band and per application – to achieve required performance objectives of up to 0° precision. Next follows a step-by-step approach on requirements for description of GRFS techniques and makes suggestions on the best state-of-the-art geolocation designs as well as advanced features found in signal

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generator instruments in Chap. 3. Chapter 4 also suggests the best mathematical techniques employed for GRFS at 100 MHz to 18 GHz or even 60 GHz. Some typical principle simulation examples taken from these system description requirements are discussed in a great detail during the second part of the book, which offers invaluable insights, all-in-one source, for the beginner, the experienced, expert analysts, and professionals.

2.2 Introduction

An illustration of requirements for description of GRFS systems are given in Fig. 2.1.

The motivation behind the requirements for description of GRFS systems is that "the use of cryptographic solutions, however, is insufficient to prevent attacks in wireless networks" [56]. Therefore, the identification, differentiation, design, development, deployment, integration, etc., of GRFS systems to identify all the threats coming from RF sources is imperative to the US National Defense Security, to the public safety, to search and rescue operations, to combat mission from around the world, etc.

First, as depicted in Fig. 2.1, we need to come up with a definition and explanation of what a local environment reference is. A local environment reference indicates the local environment range in which a GRFS system is analyzed, deployed, simulated

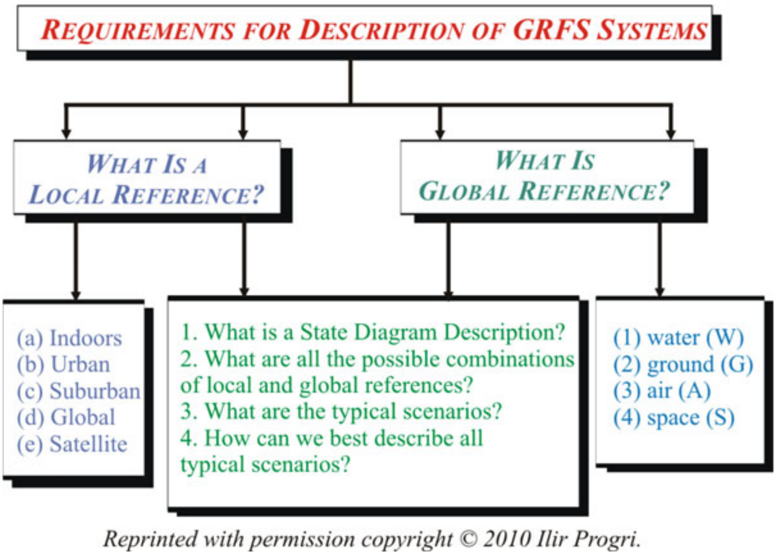

Fig. 2.1 An illustration of requirements of geolocation of RF signals (GRFS) system. Reprinted with permission copyright © 2010 Ilir Progri

etc., which as we have mentioned in Chap. 1 (Fig. 1.6) contains five segments: (1) indoor; (2) urban; (3) suburban; (4) global; (5) satellite.

Second, as depicted in Fig. 2.1, we need to come up with a definition and explanation of what a global reference is. A global reference indicates the global environment range in which a GRFS system is analyzed, deployed, simulated, etc., contains four segments: (1) water (W); (2) ground (G), (3) air (A); (4) space (S).

Third, as depicted in Fig. 2.1, we need to come up with a definition and explanation of what a state diagram is. A state diagram is one in which the global reference is indicated as a state and the local reference represents one aspect of the state diagram, which is indicated with an arc or a state transition path. The visualization and interpretation of the state diagram is obvious in the following sections.

Fourth, what are all the possible combinations of all state transitions in one diagram? The number of combinations of all the state transitions can be determined from the following equation:

$$\begin{aligned} N_C = C_4^1 + C_4^2 + C_4^3 + C_4^4 &= \frac{4}{1} + \frac{4\times 3}{1\times 2} + \frac{4\times 3\times 2}{1\times 2\times 3} + \frac{4\times 3\times 2\times 1}{1\times 2\times 3\times 4} \\ &= 4 + 6 + 4 + 1 = 15. \end{aligned} \tag{2.1.1}$$

So, it appears that there are 15 possible state transition path combinations for each local reference segment. Since we have five local reference segments, there should be up to 75 total number of possible state transition path combinations. We are going to see in much greater detail in the following section that in fact the number of combinations of state transitions paths corresponding to the typical scenarios is only 39.

Fifth, we are going to determine based on the information published in the literature what each typical case study looks like and we are going to make recommendations on what the prospects for future research and development in each case study are.

Sixth, how can we best describe all typical case studies? The main purpose of this chapter and this book is to research, investigate, and make recommendations on navigation, communications, and geolocation properties, requirements, and capabilities of several candidate radio frequency (RF) signals in the entire frequency band of 100 MHz to 66 GHz of all typical state transition case studies of outdoor and indoor environments that we consider next.

This chapter is organized as follows based on the information obtained from [1–138]. First, we are going to research, investigate, and propose the navigation, communications, and geolocation requirements, and capabilities of indoor GRFS systems in Sect. 2.3. Second, we are going to discuss, research, investigate, and make recommendations on the navigation, communications, and geolocation requirements, and capabilities of urban GRFS systems in Sect. 2.4. Third, we are going to discuss, research, investigate, and make recommendations on the navigation, communications, and geolocation requirements, and capabilities of suburban GRFS systems in Sect. 2.5. Fourth, we are going to discuss, research, investigate, and make recommendations on the navigation, communications, and geolocation requirements, and capabilities of global GRFS systems in Sect. 2.6. Fifth, we are going to discuss, research, investigate, and make recommendations on the navigation, communications, and geolocation requirements, and capabilities of satellite GRFS systems in Sect. 2.7. Section 2.8 concludes this chapter.

2.3 Requirements for Description of Indoor GRFS Systems

In this section we are discussing, researching, investigating, and making recommendations on requirements for description of indoor GRFS systems, which have an effective range up to 100 m in any global environment. The state transition path diagram for all indoor GRFS systems is described in Fig. 2.2.

Within 100 m, it is virtually impossible to have any kind of transition path from, let us say, indoor ground environments to indoor water, or air, or space, which is the reason why we have assumed that within 100 m we are either on the ground, in the air, in the water, or in space.

The electronics of GRFS systems working on the ground might be very different from the electronics of GRFS systems working in the air and from those working in space and from those working in the water due to differences in gravity, aerodynamics, dynamics, radiation, temperature, pressure, electric permittivity, magnetic permeability, etc.; however, in this section, as far as we are concerned, the basic principles of GRFS systems remain the same.

This section is organized as follows: first, we describe the requirements for description of indoor ground GRFS systems in Sect. 2.3.1. Second, we discuss the requirements for description of air GRFS systems in Sect. 2.3.2. Third, we consider the requirements for description of space GRFS systems in Sect. 2.3.3. And finally, we consider the requirements for description of water GRFS systems in Sect. 2.3.4.

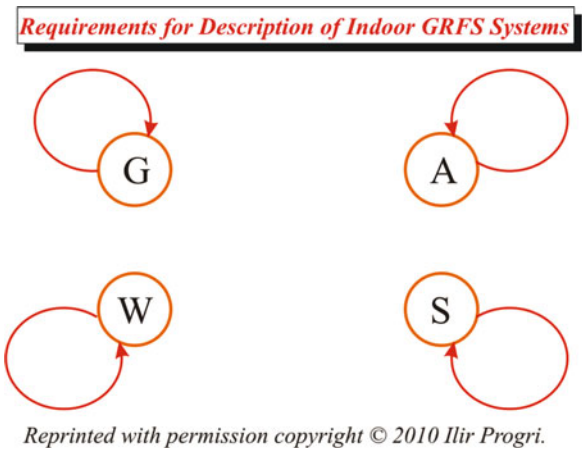

Fig. 2.2 An illustration of the state diagram of requirements for description of indoor GRFS systems. Reprinted with permission copyright © 2010 Ilir Progri

2.3.1 Requirements for Description of Indoor Ground GRFS Systems

For the complete discussion on indoor geolocation systems, the reader should refer to [1] and also to Dr. Progri's upcoming book on *Indoor Geolocation Systems: Theory and Applications*. However, as we have pointed out in Chap. 1, the description of GRFS systems is entirely different from the description of indoor geolocation systems. GRFS systems deal primarily with how to locate RF sources in an indoor environment based on where the user is located; that is, having the user (or GRFS receiver) as the center of the local coordinate system. Indoor geolocation systems deal mainly with locating a user inside based on previously positioned (or known or calculated trajectories of) transmitters (satellites, pseudolites or other positioning sensors).

In the general case, a GRFS system should be able to locate both indoor positioning transmitters and RF sources such as cordless phones, mobile phones, Wi-Fi access points (Worldwide Interoperability for Microwave Access (WiMAX) femtocells [43, 46]), HomeRF, Bluetooth, WLAN, light sensors, medical device sensors [15], wireless personal area network (WPAN) technologies in medical environments to support high efficiency medical care delivery anywhere and anytime [18], WiMedia UWB access point [16], motion sensors, temperature (heat or cold) sensors, smoke (or fire) sensors, seismic sensors, wind sensors, power outage sensor, either fiber, or landline disconnection (or loss of communication) sensor, etc.) A security system with *self-calibrating* and *self-* (or *internal*, *functional*) *awareness* capability might be very costly today for all homeowners but it might be a necessity for a good number of government facilities, commercial warehouses, retail stores, high class hotels, etc. So, RF sensors will become more and more useful in the future not only to tell us where an object is located but also about the condition (or *internal functional information*) of devices, humans, subsystems, etc. A GRFS system will become a necessary *secondary* (or *diagnostic*) system to locate, monitor, survey, weight, communicate, etc., location, health, status, condition of the primary everyday electric, power, communications, radiation, safety, transportation, etc., systems including humans (Fig. 2.3).

Some practical application examples of indoor ground GRFS systems may include body area networks that will support wireless communications of sensors positioned on a body or other objects [24].

Another example of indoor ground GRFS systems may be a "Human behavior inspired cognitive radio network design" which are supposed to be sensing their operating environment with little or no prior information and learning to adapt their behavior accordingly [36].

Another example of indoor ground GRFS systems is the "Millimeter-wave soldier-to-soldier communications for covert battlefield operations" to enable infantry soldiers of tomorrow – one of the most technologically advanced modern warfare has ever construed by creating the ability to provide information superiority at the

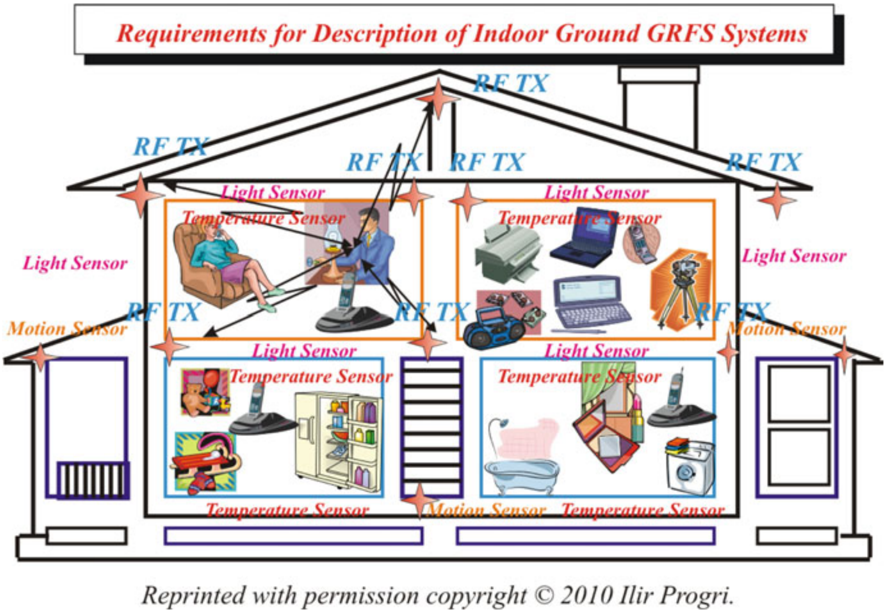

Fig. 2.3 An illustration of the requirements for description of indoor ground GRFS systems. Reprinted with permission copyright © 2010 Ilir Progri

operational edge of military networks by equipping the dismounted soldier with advanced visual, voice, and data communications [45] or UAVs, and mobile APs [49]. Chapter 4 contains a much greater discussion of this scenario and also provides detailed principle simulation examples on indoor ground GRFS systems.

So, GRFS systems should be able to locate malfunctions or areas of concern in the primary systems and hopefully increase the accuracy repair and the probability of safety of life for any primary system. Moreover, when integrated with indoor geolocation systems, geospatial database, and/or Geographic Information Systems (GIS), and maps, GRFS systems should provide the safest, the shortest, and the best route in case of severe emergency. This requirement is even more critical for the next GRFS systems, which function in the air, in space, and in deep water.

2.3.2 Requirements for Description of Indoor Air GRFS Systems

For the most part, there are many secondary systems in military airplanes, helicopters, or even in commercial airplanes that can quickly and accurately identify faults in the primary systems. However, there are still many improvements that we can make to the existing indoor environments to further enhance the capability of the secondary RF systems. There is a simple explanation why GRFS systems are a much better solution than secondary systems built into the primary system.

Aeronautical communications can be subdivided into two main areas: (1) the safety critical air traffic control (ATC)/air traffic management (ATM) communication which also covers airline communications (AOC, AAC); (2) and the commercial aeronautical passenger communication (APC) [51]. Currently, safety critical communications is mainly based on voice communication using Double-Sideband Amplitude Modulation (DSB-AM) which is over 50-year-old communications technique which uses the available spectrum very inefficiently [51].

There is no surprise that an intruder might corrupt the primary system built on a 50-year-old communications technique; it will be almost impossible for an intruder to corrupt (jam or cause to miss-function) spatially located sensors working independently within an airplane or an indoor environment. Although it will be perhaps the hardest system to design, it will provide for sure the highest level of security, safety, and functionality. (For example, if we were to envision an air system that will read your DNA as you board the plane, that will be something that will make almost impossible for an intruder to board on the plane.) Now, we may not want that level of security on board of every commercial airplane but we will certainly want that level of security for the US Air Force plane that boards the President and the Vice President of the United States of America and maybe other high officials of the Pentagon (or Department of Defense (DoD)) or NATO countries.

Figure 2.4 provides an overview on the requirements for description of indoor air GRFS systems which contains a passenger airplane on the top and also a very small UAV (Shadow-200 UAV $13' \times 10' \times 2.94'$) with three transmitter antennae and four receiver antennae. For example small UAVs can be utilized for a number of case studies. We could use the small UAVs for a number of intelligence gathering missions or a number of other tactical air missions [52]. The Prestigious Defense Science Board of the US DoD performed a study in 2004 that recommended: "UAV and Uninhabited Combat Aerial Vehicle (UCAV) become an integral part of the US force structure, and not an additional asset," and that "UAV and UCAV be allowed unencumbered access to the UN National Airspace System (NAS) outside of restricted areas here in the US and around the world" [55]. A UAV is a low-cost nonpiloted airplane designed to operate in D-cube (Dangerous-Dirty-Dull) situations and although many UAVs exist today; however, with the advent of the commercial UAV's civil applications, the class of mini/macro UAVs is emerging as a valid option in a commercial scenario [52].

Many studies conducted by the Defense Science Board, the office of Science and technology, Government Accountability Office, and the Congressional Research Service Library of Congress have emphasized that soon there will be a significant number of UAVs (600 UAVs were manufactured in the US alone in 2006) operating side-by-side with manned civil aircraft in the Federal Aviation Administration (FAA)'s NAS, in which many UAVs will perform many of the

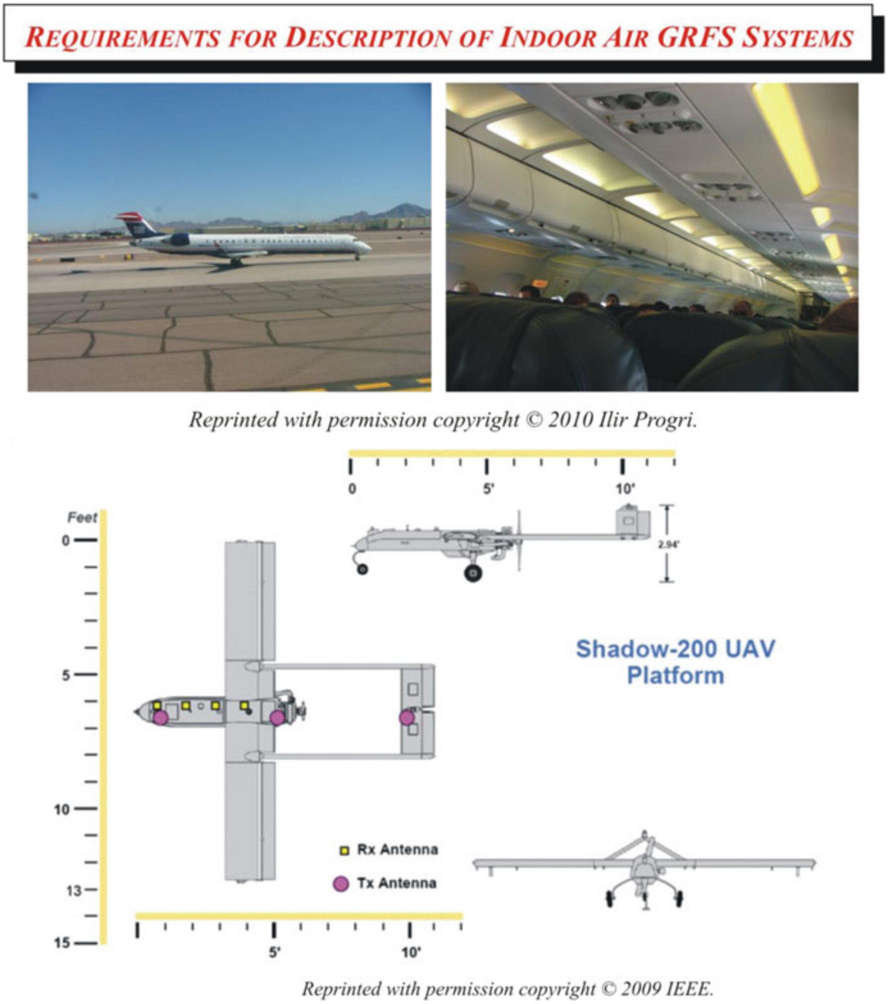

Fig. 2.4 An illustration of the requirements for description of indoor air GRFS systems. Reprinted with permission copyright © 2009 Blum, R.S., Haimovich, A.M., Li, J., *IEEE*; copyright © 2010 Ilir Progri

D-cube civilian missions [55]. Many of the safety certification operations of UAVs in US NAS which includes safety requirements, design, development process, verification, and operational procedures in the planned operational environment are discussed extensively in [55]. There safety requirements are good for the reader to know if a potential client will take the challenge to incorporate the GRFS systems principles of operations in a real-world UAV operational system design.

Further descriptions are provided later in the other air GRFS systems.

2.3.3 Requirements for Description of Indoor Space GRFS Systems

Similarly, for the most part there are many secondary systems in space shuttles or space stations that can quickly and accurately identify faults in space shuttle primary systems. However, there are still many improvements that we can make to the existing indoor environments to further enhance the capability of the secondary RF systems. There is a simple explanation why GRFS systems are a much better solution than secondary systems built into the primary system. In space there are different gravity requirements, different space and signal density, and displacement requirements. People and objects may be floating all the time. Therefore, indoor space GRFS systems should be able to locate astronauts, floating objects, faults in lines, or panels that have RF Bluetooth built in (see Fig. 2.5) [107].

Constellation is a human spaceflight program whose goals are gaining experience in operating away from Earth's environment, developing technologies to expand the space frontier, and conducting fundamental science [107].

Constellation was developed through the Exploration Systems Architecture Study, which determined how National Administration Space Agency (NASA) would pursue the goals laid out in the Vision for Space Exploration and the NASA Authorization Act of 2005 [107]. The reader can further understand how NASA's Exploration Systems Architecture Study is further incorporated into this chapter and other GRFS systems are discussed [107] further in this chapter.

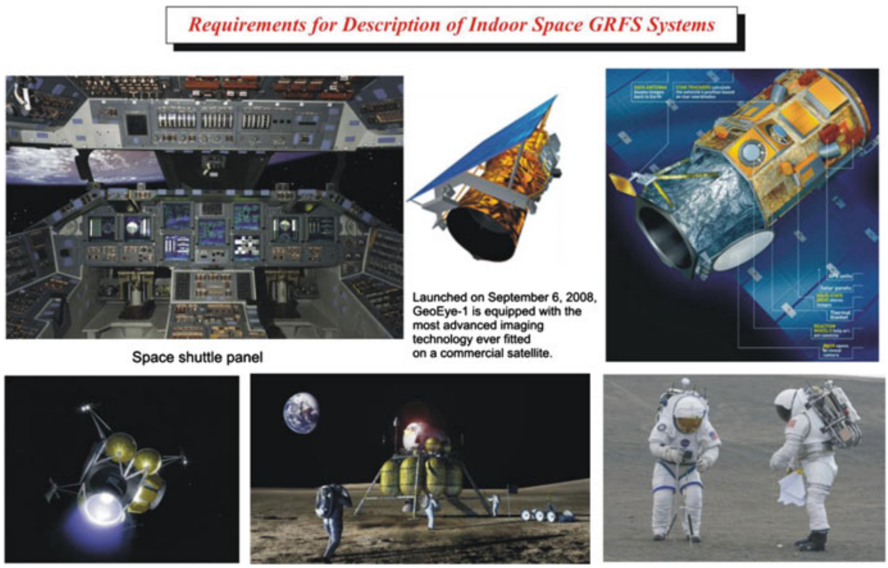

Fig. 2.5 An illustration of the requirements for description of indoor space GRFS systems. Images courtesy of National Administration Space Agency (NASA)

2.3.4 Requirements for Description of Indoor Water GRFS Systems

Similarly, for the most part there are many secondary systems in the military and civilian ships, submarines, or space stations that can quickly and accurately identify faults in the military and civilian ships, submarines, or naval vehicles on primary systems. However, there are still many improvements that we can make to the existing indoor environments to further enhance the capability of the secondary RF systems in the military and civilian ships, submarines, or naval vessels.

There is a simple explanation why GRFS systems are a much better solution than secondary systems built into the primary system. In water there are different water pressure requirements, different environment conductivity, permeability, and permittivity requirements. Therefore, indoor water GRFS systems should be able to locate, differentiate, discriminate, and geolocate navy personnel, objects, and faults in lines or panels that have RF Bluetooth built-in as an illustration.

Underwater wireless communications can enable many military applications such as oceanographic data collection, scientific ocean sampling, pollution and environmental monitoring, climate recording, offshore exploration, disaster prevention, assisted navigation, distributed tactical surveillance, and mine reconnaissance [38]. Some of these applications can be supported by underwater acoustic sensor networks (UW-ASNs) which consists of devices with sensing, processing, and communication capabilities that are deployed to perform collaborative monitoring tasks that can be utilized by this Navy destroyer shown in Fig. 2.6 [38].

Fig. 2.6 An illustration of the requirements for description of indoor water GRFS systems. Reprinted with permission copyright © 2009 Griffiths, H., Willis, N., and *IEEE*

2.4 Requirements for Description of Urban GRFS Systems

Urban GRFS systems are defined as GRFS systems in which the urban range of the area of operations is from 100 m up to 10 km on the ground, in the air, in space, or in or on water.

The electronics of GRFS systems working on the ground might be very different from the electronics of GRFS systems working in the air and from those working in space and from those working in the water due to differences in gravity, aerodynamics, dynamics, radiation, temperature, pressure, electric permittivity or magnetic permeability, etc.; however, in this section, as far as we are concerned the basic principles of GRFS systems remain the same.

There are eight urban GRFS systems that we are going to analyze, research, investigate, and make recommendations in this section as depicted in Fig. 2.7. First, we have the requirements for description of urban ground GRFS systems discussed in Sect. 2.4.1. Second, we present the requirements for description of urban air GRFS systems in Sect. 2.4.2. Third, we depict the requirements for description of urban water GRFS systems in Sect. 2.4.3. Fourth, we analyze the requirements for description of urban space GRFS systems in Sect. 2.4.4. Fifth, we discuss requirements for description of the urban ground-to-air (air-to-ground) GRFS systems in Sect. 2.4.5. Sixth, we provide requirements for description of urban ground-to-water (water-to-ground) GRFS systems in Sect. 2.4.6. Seventh, we present the requirements for description of urban air-to-water (water-to-air) GRFS systems in Sect. 2.4.7. Eight and finally, we depict the requirements for description of urban air-to-space (space-to-air) GRFS systems in Sect. 2.4.8.

There are many urban GRFS system that are discussed extensively in this section. One illustration is the Public Safety and Disaster Recovery (PSDR) which extensively relies on Professional Mobile Radio (PMR) communications systems to conduct their daily tactical and emergency operations [12].

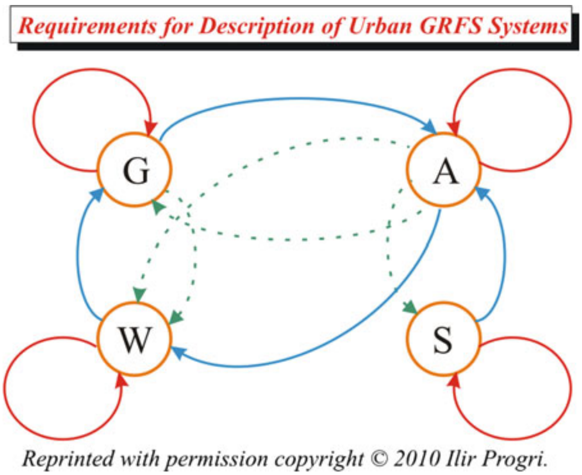

Fig. 2.7 An illustration of the finite state transition diagram of requirements for description of urban GRFS systems. Reprinted with permission copyright © 2010 Ilir Progri

Another example is the wireless broadband (WiBro) system for broadband wireless internet services providing high-speed portable internet access anywhere, anytime at low cost and high data rates [17].

2.4.1 Requirements for Description of Urban Ground GRFS Systems

After indoor ground, urban ground GRFS systems are the most common systems (as depicted in Fig. 2.8) in all or most metropolitan areas, big and small cities, in residential, commercial, or government facilities, in sports arena, university campuses, factories, hotels, etc. In these environments, the multipath distribution is as severe as in indoor ground GRFS systems. Chapter 3 discusses in great detail the kinds of signals that are employed in these environments. The applications range from everyday wireless local area networks, IEEE 802.11, IEEE 802.15, IEEE 802.16, and IEEE 802.20 Wi-Fi, WiMAX [33, 34], 3G WCDMA Mobile Networks [14],

Fig. 2.8 An illustration of the requirements for description of urban ground GRFS systems. Reprinted with permission copyright © 2010 Ilir Progri

FM Radio, Digital TV (DTV), Satellite TV, Low-enforcement networks, and radars to emergency networks such as mobile responder communication networks for public safety [13], the wireless broadband (WiBro) system for broadband wireless internet services [17], and WLAN technologies in medical environments to support high efficiency medical care delivery anywhere and anytime [18]. Another example is the integration of WiMAX with Wi-Fi for optimal pricing and bandwidth sharing using IEEE 802.16e/IEEE 802.11e standards [23, 33, 34] or an evolved cellular system architecture incorporating relay stations [41] or WiMAX femtocells [43].

There are also several proprietary and standard solutions for wireless point-to-point or point-to-multipoint or multipoint-to-point or multipoint-to-multipoint, which include vehicular, hospital, industrial, residential, commercial, etc., application [24, 28] or Universal Telecommunications Mobile Systems (UTMS) case study discussed "On femto deployment architectures and microcell offloading benefits in joint macro-femto deployments" in for cell ranged between 100 m and 10 km were calculated (see urban ground GRFS system from downtown Boston, Fig. 2.8) [46].

Other examples might include wireless relays for broadband access such as fixed, nomadic, or mobile relay stations based on IEEE 802.16e and 802.16j [29]. There are several advantages of wireless relays for broadband access such as: (1) no backhauling required, resulting in lower capital expenditures (CAPEX), and operation expenditures (OPEX); (2) flexibility in locating nodes; (3) within a cell, relays can enlarge the coverage area and increase the capacity of the cell boarders; (4) offer decreased transmit power and interference; (5) fast network rollout, indoor–outdoor service, and macro diversity by way of cooperative relaying [29]. There are also some disadvantages such as increased use of radio resources (in the time domain) and increased number of multiple transceivers in out-of-band relaying (in the frequency domain), additional delays [29].

2.4.2 Requirements for Description of Urban Air GRFS Systems

Urban air GRFS systems have to ensure that in the range of 100 m to 10 km the Air Force aircraft, Navy Aircraft, or Army Helicopter has intelligence about every single RF signal threat in the environment (see Fig. 2.9) [71]. Threats will be interference signals from enemy aircraft radars, enemy aircraft jammers, enemy missiles, etc.

Chapters 4 and 6 provide discussion of these case studies in great detail.

2.4.3 Requirements for Description of Urban Water GRFS Systems

An example of an urban water GRFS system is the design and implementation of a solution for the provision of converged tower and facility management services

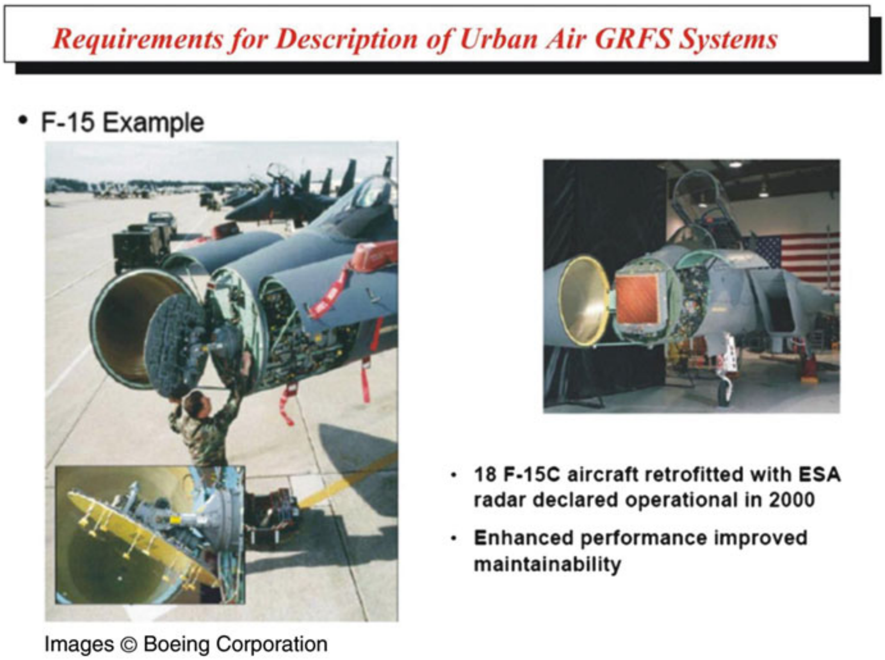

Fig. 2.9 An illustration of the requirements for description of urban air GRFS systems. Reprinted with permission copyright © 2000 Boeing Corp.; copyright © 2009 Williams, J., and *IEEE*

over satellite IP for Greek helicopters [32]. Helicopters generally operate at altitudes of 1,200 m according to rules that apply to instrument flight route and visual flight route (VFR) within the ATC areas, outside of which helicopters are only allowed to operate according to VFR rules [32]. There are also many commercial, recreations, touristic urban water GRFS system that will have the same signal specifications and be able to respond to disaster and safety of life in almost the same way as the urban ground GRFS system in Sect. 2.4.1 in the range of 100 m to 10 km such as the Sydney opera house or many boats sailing in the Sydney's harbor as illustrated in Fig. 2.10.

2.4.4 Requirements for Description of Urban Space GRFS Systems

Urban space GRFS systems constitute the space stations' environment in the 100 m to 10 km as depicted in Fig. 2.11. There is not much going on for urban space GRFS system unless there is a mission to repair the space station or when there is a mission to navigate, rendezvous, and dock a space shuttle in the space station.

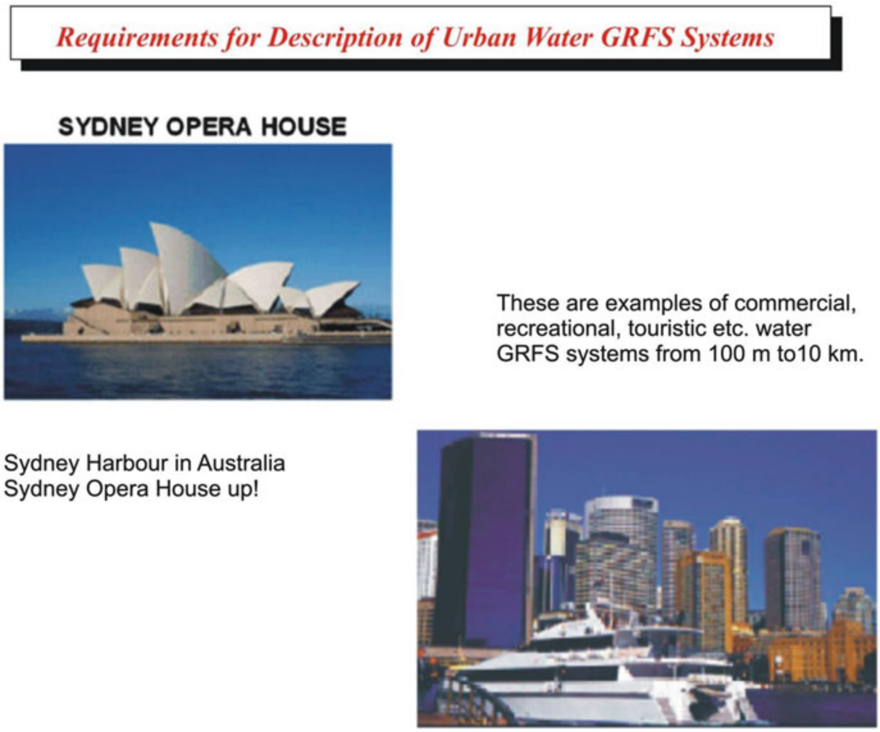

Fig. 2.10 An illustration of the requirements for description of urban water GRFS systems. Reprinted with permission copyright © 2009 Brookner, E., and *IEEE*

For example the Lunar outpost, as shown on in Fig. 2.11, will be an inhabited facility on the surface of the Moon which NASA currently proposes to construct over the 5 years between 2019 and 2024. The United States Congress has directed that the U.S. portion, "shall be designated the Neil A. Armstrong Lunar Outpost" [107].

2.4.5 Requirements for Description of Urban Ground-to-Air (Air-to-Ground) GRFS Systems

Urban ground-to-air (air-to-ground) GRFS systems are perhaps the most common forms of close combat of infantry ground forces supported by aircraft, helicopter, short-range air missile, etc. This is an environment that certain UAVs might be the most suitable means of close combat intelligence gathering as shown in Fig. 2.12. In the example illustrated in the figure, a UAV identifies a vehicle mounted rocket launcher, other portable RF transmitter, and FM radio stations and communications towers. The two greatest concerns are interference and interoperability.

Fig. 2.11 An illustration of the requirements for description of urban space GRFS systems (SATCOMS IRIDIUM). Images courtesy of NASA

Silent Sentry is a passive sensor that uses emissions from indigenous transmitters as its RF sources. Silent Sentry 3 is tailored for FM radio, but can be extended to other waveforms. Line-of-sight is necessary between receiver/transmitters and aircraft/missiles. A direct reference signal is also necessary at the receiver but line-of-sight is not required. Reflected RF energy is collected at the receiver and compared with the original reference signal to provide detection and tracking information. Track data can be sent to the Silent Sentry track display or to a sensor fusion or command and control system (e.g., via Silent Sentry Byte Stream, OTH-Gold, Link 16, Asterix . . .) [70].

Other examples might include "Intelligent sensing and classification in Ad Hoc networks: a case study" such as denial of service (DoS) through intelligent jamming of the most critical packet types of flows in an Ad Hoc network [57].

This is only a very small piece of the network centric warfare (NCW) to enable ground and airborne vehicle-based on-the-move (OTM) and on-the-halt (OTH) network centric connectivity [30]. Urban ground GRFS systems can be used for numerous monitoring, tracking, surveillance, search and rescue operations from the public safety and disaster monitoring of the scales that we have seen in September 11, 2001, in Katrina, etc.

Perhaps the most important example is the improved situational awareness of the military aircraft in both the battlespace and civil airspace which is discussed here in great detail. For the military air communications, navigation, and surveillance

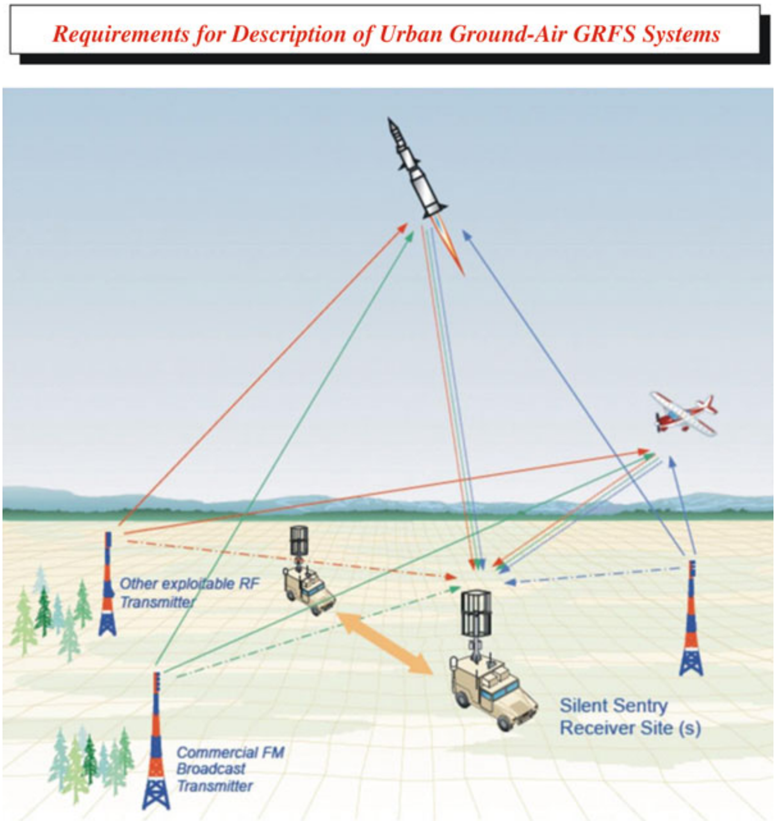

Fig. 2.12 An illustration of the requirements for description of urban ground-to-air (or air-to-ground) GRFS systems. Reprinted with permission copyright © 2009 Griffiths, H., Willis, N., and *IEEE*

(CNS) problems as presented in [58] the interoperability appeared to be a problem. Military aircraft must transition from ground-based navigation aids (VOR/TACAN) to area navigation in performance-based airspace (RNP RNAV) and transition from secondary RADAR surveillance to Automatic Dependent Surveillance Broadcast (ADS-B).

The 1,090 MHz transponder upgrade was proposed to promote safety, facilitate civil interoperability, improve situational awareness, and greatly improve both military and civil air traffic surveillance [58].

With Global Positioning Systems (GPS) installed, the most accurate locating information for each military aircraft will be the self-generated position displayed in that aircraft which was not available to the air traffic controller in 2003. To broadcast this information to the air traffic controller requires installation of a standard data link and a common reference; then, a line-of-site broadcast of the accurate GPS-based *aircraft self-reports* (ADS-B) is possible. These self-reports of aircraft identity WGS-84 geodetic position (Lat-Long-Alt) and velocity vector will be transmitted up to twice a second to the air traffic controller. Aircraft within line-of-sight can use these transmissions to automatically produce a *cockpit display of traffic information* (CDTI) [58].

If all civil and military air traffic participated, ADS-B network will result in an improved situational awareness and aviation safety. The same processing power, modular software, and cockpit displays used for RNP RNAV will be used for ADS-B and CDTI. In 2003, three different data links were considered for ADS-B but only the Mode S 1,090 MHz Extended Squitter was installed. Improved situational awareness from both the RNP RNAV and the ADS-B with considerable military utility is anticipated within the battlespace as well as within civil airspace [58].

2.4.6 Requirements for Description of Urban Ground-to-Water (Water-to-Ground) GRFS Systems

For distances in excess of 100 m, which is the case for Urban Ground-to-Water (Water-to-Ground) GRFS Systems, wireless signal transmission is also crucial to remotely control instruments in ocean observatories to enable coordination of swarms of autonomous underwater vehicles (AUVs), robots, environment (in and around ports), or docking stations (see Fig. 2.13), which play an important role of mobile nodes in future ocean observation networks by virtue of their flexibility and reconfigurability [38].

2.4.7 Requirements for Description of Urban Air-to-Water (Water-to-Air) GRFS Systems

Urban air-to-water (water-to-air) GRFS systems could be very similar to the urban ground-to-air (air-to-ground) GRFS systems but could also be very different from the latter. For urban air-to-water (water-to-air) GRFS systems, the multipath should be less severe than the multipath for ground-to-air (air-to-ground) GRFS systems.

Figure 2.14 illustrates an urban air-to-water (water-to-air) GRFS system in Sydney Harbor (including the Sydney Opera House) that is monitored by the Australian Wegetail Airborne Radar Surveillance System.

Australia has, and is, supporting a significant set of phased array development activities spanning more than 50 years including a wide range of civil and military applications, which ensures a viable and vibrant development of environment across government and industrial laboratories [60]. More discussion is provided in Chaps. 4 and 6.

Fig. 2.13 An illustration of the requirements for description of urban ground-to-water (or water-to-ground) GRFS systems. Reprinted with permission copyright © 2009 Brookner, E., and *IEEE*

Fig. 2.14 An illustration of the requirements for description of urban air-to-water (or water-to-air) GRFS systems. Reprinted with permission copyright © 2009 Brookner, E., and *IEEE*

2.4.8 *Requirements for Description of Urban Air-to-Space (Space-to-Air) GRFS Systems*

Urban air-to-space (space-to-air) GRFS systems illustrate the rendezvous and docking of space shuttles to space stations as illustrated in Fig. 2.15. There are, however, many safety requirements for the astronauts that must be taken into consideration. So, from the safety point of view the requirements for description of air-to-space (space-to-air) GRFS systems are at much higher level of complexity and cost than those of the ground-to-air (air-to-ground) GRFS systems even though both environments are very different from each other due to differences in gravity, speed, aerodynamics, range of operation for humans, level of control and coordination of operations, number of people involved, etc.

After the systems are configured, as shown in Fig. 2.15, for lunar flight, the EDS will fire for the 390-s translunar injection (TLI) burn, which will accelerate the spacecraft stack from 28,000 to 40,200 km/h. The TLI burn will be done in the "eyeballs out" fashion, that is, with the astronauts being "pulled" from their seats. After the TLI burn, the EDS is jettisoned [107]. During the 3-day translunar coast, the four-man crew will monitor the Orion's systems, inspect their Altair spacecraft and its support equipment, and, if necessary, change their trajectory to allow the

Fig. 2.15 An illustration of the requirements for description of urban air-to-space (or space-to-air) GRFS systems. Images courtesy of NASA

Altair to land in a near-polar landing site suitable for a future lunar base [107]. Three days after TLI, the Orion/Altair combination, approaching the lunar far side, will orient the Altair's engines in the proper direction for the lunar orbit insertion (LOI) burn to begin. Once in orbit, the crew will refine the trajectory and configure the Orion CSM for unmanned flight, upon which all of the crew members will transfer to the Altair, and upon receiving clearance from Mission Control, will undock from the Orion [107].

2.5 Requirements for Description for Suburban GRFS Systems

Suburban GRFS systems are defined as systems in which the suburban range of the area of operations is from 10 km up to 100 km in ground, air, space, or water (see Fig. 2.16). It is hoped that the readers in this section will find out an approach to enable inter- and intracommunity communications, *interoperability* between the commercial, public safety, military, space, etc. communities in a way that was never presented before [30]. An example of a suburban GRFS system includes Wireless Metropolitan Area Networks (WMAN) based on IEEE 802.16 WiMAX technology in the 10–66 GHz frequency spectrum that can achieve maximum transmission range of 50 km [28, 41].

Other standards include IEEE 802.22 for wireless regional area networks (WRANs) serving broadband communications for remote communities, effectively achieved through a cognitive radio (CR) idiom [39]. Another example of suburban GRFS system that we are going to discuss extensively in this section is DARPA's Network Centric Radio System (NCRS), first generation mobile ad hoc network (MANET), designed to enable ground and airborne-vehicle-based OTM and OTH network centric connectivity [30].

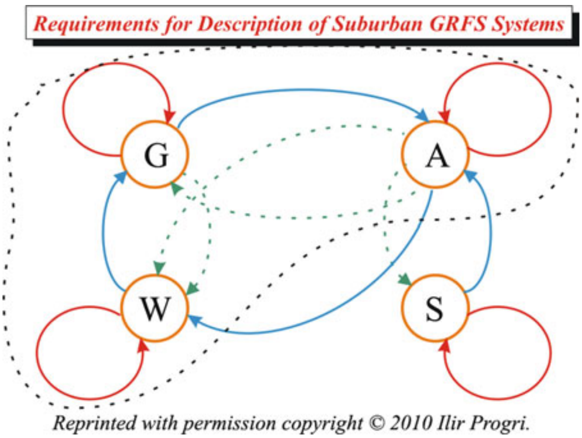

Fig. 2.16 An illustration of the state diagram of requirements for description of suburban GRFS systems. Reprinted with permission copyright © 2010 Ilir Progri

These and many other systems are only subsystems to the Global Information Grid (GIG) communications systems which is the network fabric with which to build a "system-of-systems" to fulfill the ultimate goal of network-centric warfare [30]. So, as we move forward to the discussion in this section and in the following sections it should become relevant and understandable to the reader that GRFS systems are in fact subsystems to the GIG communications systems that are designed to exploit the signal design of the interoperability of the Joint Tactical Radio Systems (JTRS) among all other signal designs that are part of the network-centric warfare "system of systems."

Taking into considerations the examples presented, we provide an organization of this section which includes the requirements for description of several suburban GRFS systems as depicted in Fig. 2.16. First, we have the requirements for description of suburban ground GRFS systems discussed in Sect. 2.5.1. Second, we present the requirements for description of suburban air GRFS systems in Sect. 2.5.2. Third, we depict the requirements for description of suburban water GRFS systems in Sect. 2.5.3. Fourth, we analyze the requirements for description of suburban space GRFS systems in Sect. 2.5.4. Fifth, we discuss requirements for description of the suburban ground-to-air (air-to-ground) GRFS systems in Sect. 2.5.5. Sixth, we provide the requirements for description of suburban ground-to-water (water-to-ground) GRFS systems in Sect. 2.5.6. Seventh, we present the requirements for description of suburban air-to-water (water-to-air) GRFS systems in Sect. 2.5.7. Eight, we depict the requirements for description of suburban air-to-space (space-to-air) GRFS systems in Sect. 2.5.8. Ninth and finally, we conclude this section with the requirements for description of suburban ground-to-air-to-water (air-to-water-to-ground or water-to-air-to-ground) GRFS systems in Sect. 2.5.9.

2.5.1 Requirements for Description of Suburban Ground GRFS Systems

An example of suburban ground GRFS systems are WRANs which are aimed at providing alternative broadband wireless internet access in rural areas without creating harmful interference to licensed TV broadcasting [19]. For example, a typical 802.22 WRAN base station with radius of the coverage area of 35 km coexisting with a DTV station with radius of the coverage area of 135 km [19], or an effective range for long-term evolution of mobile broadband of 100 km and beyond [40].

Another example of suburban ground GRFS systems are dynamic spectrum access networks (DSANs), also known as NeXt Generation (xG) networks that enable efficient spectrum usage to network users via dynamic spectrum access techniques and heterogeneous network architectures; DARPA aims to dynamically redistribute allocated spectrum based on cognitive radio technologies (see Fig. 2.17) [20].

Another example of a suburban ground GRFS system is WiMAX that is expected to provide high data rate communications in metropolitan area networks

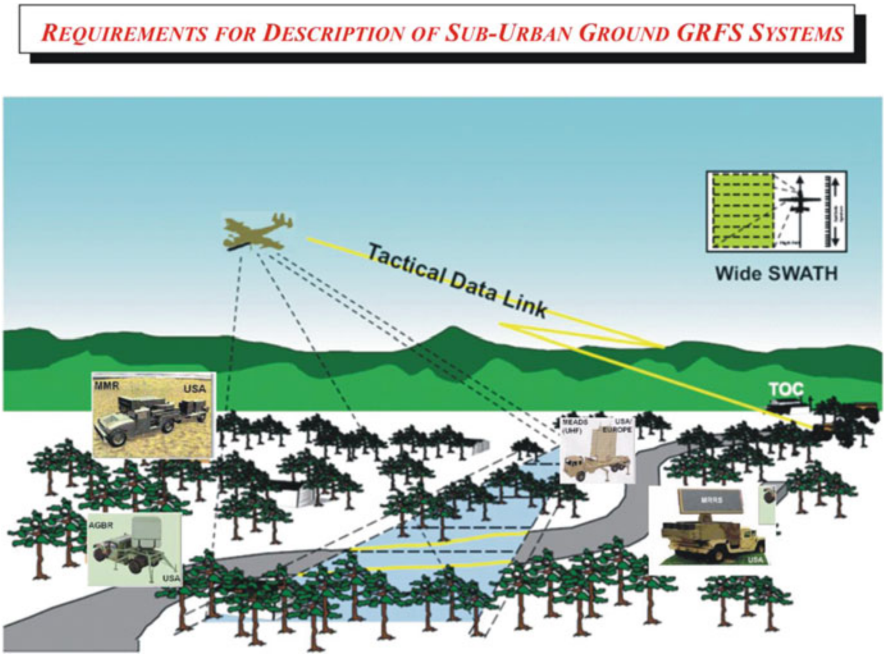

Fig. 2.17 An illustration of the requirements for description of suburban ground GRFS systems. Reprinted with permission copyright © 2009 Davis, M., and *IEEE*

(MANs) based on IEEE 802.16 standard [21, 22]. Details about the signal specifications for WiMAX will be given in Chap. 3.

Other examples include universal mobile telecommunications system (UMTS) multimedia broadcast multicast service (MBMS), digital video broadcasting to handheld (DVB-H), terrestrial digital multimedia broadcasting (T-DMB), MediaFLO, etc. [24]. Suburban ground GRFS systems are perhaps the most crowded systems in terms of technologies such as cognitive radio, dynamic spectrum access, secondary spectrum tracing, and an array of IEEE standards that we have already mentioned. And while we have underlined all the benefits of these technologies, there are also many risks for many stakeholders such as regulators, spectrum right holders, and spectrum operators [25].

2.5.2 Requirements for Description of Suburban Air GRFS Systems

The US Air Force, Navy, and Army (i.e., military) desire, seek, invite proposals, lead programs and projects to design, develop, demonstrate, and commercialize highly interoperable (compatible or noncompatible) radio systems to enable information to be directly exchanged among multiple organizations via NCW [30].

Fig. 2.18 An illustration of the requirements for description of suburban air GRFS systems. Images courtesy of DoD

Figure 2.18 is an example of an airborne network centric suburban air GRFS system. This flight formation will enable the warfighters to take advantage of all the available information within the battlespace in a rapid and flexible manner. An essential capability of the NCRS that was needed since 2003 was *radio interoperability at the tactical level via the network not the radio* [30].

2.5.3 Requirements for Description of Suburban Water GRFS Systems

Requirements for description of suburban water GRFS systems (see Fig. 2.19) is motivated by the recently vested interest in the "Growth of underwater communication technology in the U.S. Navy" [37]. The office of Naval Research has made a significant investment in both theoretical and applied work over the past 20 years and currently funds multiple programs in acoustic communication which includes topics of research increased throughput, better power efficiency, low probability of detection, and compact implementation as depicted in Fig. 2.19.

Figure 2.19 shows an aircraft carrier on the bottom right and Navy aircraft on the top right. Of particular interests for these applications are techniques applied to adaptive arrays space time signal processing [73].

There are multiple existing civil and military systems that provide precision approach and landing for aircraft; a partial list of existing systems includes [81]:

1. Instrument Landing System (ILS) for commercial and limited military
2. Microwave Landing System (MLS) for commercial (Europe) and very limited Military
3. Precision Approach Radar (PAR) for Military
4. Mobile Microwave Landing System (MMLS) for Military
5. Marine Remote Area Approach and Landing System for Military

Fig. 2.19 An illustration of the requirements for description of suburban water GRFS systems. Reprinted with permission copyright © 2009 Brookner, E., and *IEEE*

6. The Instrument Carrier Landing System (SPN-46) for Military
7. Joint Precision Approach and Landing System (JPALS) for Navy's Military envisioned meeting the DoD's need for an allweather, antijam, combat-ready, Category II/III aircraft landing system [80–82]

Navy's JPALS interoperability issues are considered in [82].

2.5.4 Requirements for Description of Suburban Space GRFS Systems

Suburban space GRFS systems may include an array of space vehicle in the spherical environment with effective range from 10 km to 100 km (see Fig. 2.20) [71].

There are four different space vehicles shown in Fig. 2.20: (1) SEASAT built in 1978; (2) SIR-A built in 1981; (3) SIR-B build in 1984; and (4) SIR-C built in 1994. They all operate at the frequency 1 GHz.

SEASAT was the first Earth-orbiting satellite designed for remote sensing of the Earth's oceans and had on board the first spaceborne synthetic aperture radar

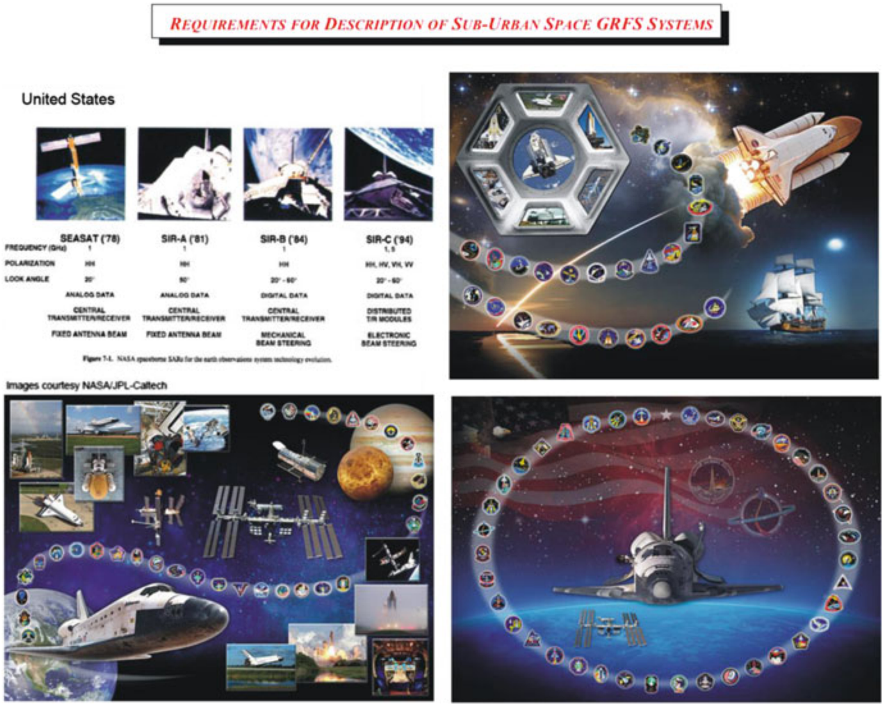

Fig. 2.20 An illustration of the requirements for description of suburban space GRFS systems. Images courtesy of NASA/JPL-Caltech and NASA

(SAR). The mission was designed to demonstrate the feasibility of global satellite monitoring of oceanographic phenomena and to help determine the requirements for an operational ocean remote sensing satellite system. Specific objectives were to collect data on sea-surface winds, sea-surface temperatures, wave heights, internal waves, atmospheric water, sea ice features and ocean topography. SEASAT was managed by NASA's Jet Propulsion Laboratory and was launched on 26 June 1978 into a nearly circular 800 km orbit with an inclination of 108°. SEASAT operated for 105 days until 10 October 1978, when a massive short circuit in the satellite's electrical system ended the mission [74].

SEASAT carried five major instruments designed to return the maximum information from ocean surfaces:

1. Radar altimeter to measure spacecraft height above the ocean surface
2. Microwave scatterometer to measure wind speed and direction
3. Scanning multichannel microwave radiometer to measure sea surface temperature
4. Visible and infrared radiometer to identify cloud, land, and water features
5. SAR L-band, HH polarization, fixed look angle to monitor the global surface wave field and polar sea ice conditions [74].

Many later remote sensing missions owe their legacy to SEASAT. These include imaging radars flown on NASA's Space Shuttle, altimeters on Earth-orbiting satellites such as TOPEX/Poseidon, and scatterometers on NASA Scatterometer (NSCAT), QuikSCAT, and Jason 1. SEASAT was able to detect the wakes of submerged submarines, a discovery not anticipated before launch. The conspiracy theory holds that once this was discovered, the military shut SEASAT down, with a cover story of a power supply short.

Space borne imaging radar missions data (SIR) SIR-A, SIR-B, and SIR-C can be found from [75–77]. SEASAT, SIR-A, and SIR-B SARs operate at 1 GHz as opposed to SIR-C SAR, which operates at 1.5 GHz. SEASAT, SIR-A, and SIR-B SAR signals are only HH polarized as opposed to the SIR-C SAR, which is possibly polarized with all four combinations (HH, HV, VH, and VV). The data in SEASAT and SIR-A is in analog format as opposed to the SIR-B and SIR-C in the digital format. SEASAT, SIR-A, and SIR-B SARs require central transmitter/receiver modules as opposed to the SIR-C SAR which requires distributed T/R modules. Last but not least, SEASAT and SIR-A SARs have fixed antenna beam, SIR-B SAR has mechanical beam steering capability and SIR-C SAR has electronic beam steering [74–77].

With this example we have illustrated what type of satellite radars all future generation of satellites will have.

2.5.5 Requirements for Description of Suburban Ground-to-Air (Air-to-Ground) GRFS Systems

Suburban ground-to-air (air-to-ground) GRFS systems may include many examples of detection, monitoring, tracking and surveillance, etc. as illustrated in Fig. 2.21. Due to the increased range, it might get more difficult to precisely identify, differentiate, and geolocate all the RF emitters in the environment. So, the level of differentiation of a suburban GRFS system is entirely different from the level of differentiation of an urban GRFS system. A suburban ground-to-air GRFS system should be able to locate where the large objects are located as opposed to an urban GRFS system which might be able to even tell how many people are in a certain warfare environment.

There is a wide range of military and civilian applications in which UAVs might be employed successfully such as remote environmental research, pollution assessment and monitoring, fire-fighter management, security, target detection, recognition, and surveillance, etc. [52]. For example in Fig. 2.21, bottom right, a squadron of UAVs can be utilized to monitor QUEEN MARY II Flying Cruise or in Fig. 2.21, top left, UAVs are employed for target detection and recondition in heavy foliage [61].

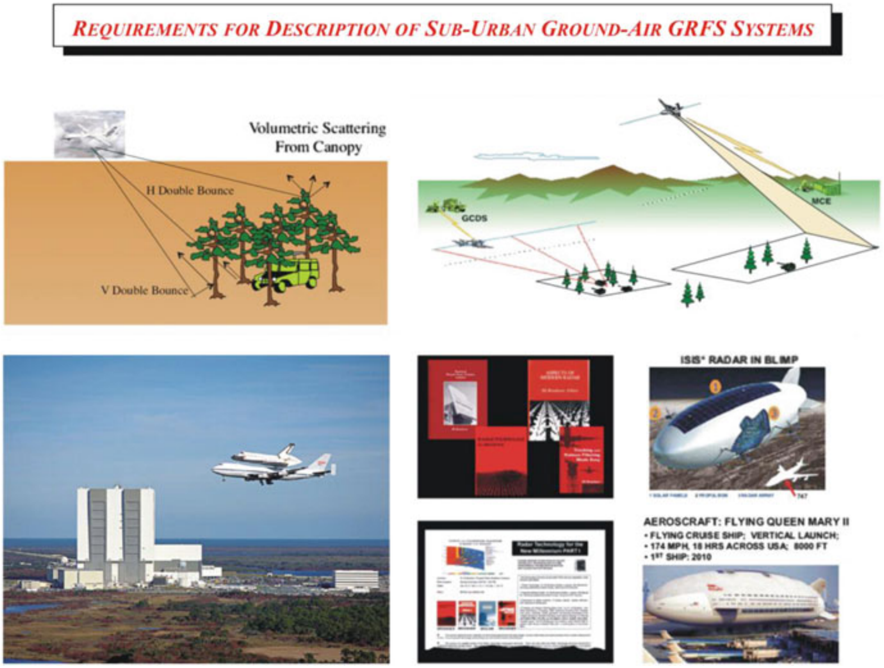

Fig. 2.21 An illustration of the requirements for description of suburban ground-to-air (or air-to-ground) GRFS systems. Reprinted with permission copyright © 2009 Davis, M., Brookner, E., *IEEE*; Image on *bottom left* is courtesy of Wikimedia Foundation, Inc

2.5.6 Requirements for Description of Suburban Ground-to-Water (Water-to-Ground) GRFS Systems

Maritime networks are one of the least studied network configurations and they probably represent the biggest challenge for information and presentation in this chapter [35].

It is hoped that this chapter (and perhaps) this book will expand the readers' perspective on maritime networks and suburban ground-to-water (water-to-ground) GRFS systems (see Fig. 2.22). Maritime networks operate in low-bandwidth environments with varying communications capabilities. Naval at sea (maritime) networks are particularly difficult to manage due to their dynamic, heterogeneous, and low-bandwidth connectivity [35]. Applications in maritime networks must operate differently to take into account mobility (link failures) and scare communications resources (especially bandwidth) [35]. The limited bandwidth connecting each maritime ship is often (node) not sufficient to even support the network traffic generated locally [35]. Maritime networks consist of a network operational center (NOC) (for example one such center is the Naval Base in San Diego (or Perl Harbor on the Pacific) and many other Naval Bases on the Atlantic Ocean) that acts as a land-based relay for all satellite

Fig. 2.22 An illustration of the requirements for description of sub-urban ground-to-water (or water-to-ground) GRFS systems. Top Image reprinted with permission copyright © 2006 Northrop Grumman Shipbuilding[1]. Bottom images courtesy of Wordpress and Wikipedia

communication, a limited number of mobile nodes (ships or maritime land/air units), and the bearers that connect them [35].

2.5.7 *Requirements for Description of Suburban Air-to-Water (Water-to-Air) GRFS Systems*

The Navy is also interested in a link from the acoustical world to the RF line-of-sight or satellite communications which might include gateways of various sorts

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Fig. 2.23 An illustration of the requirements for description of suburban air-to-water (or water-to-air) GRFS systems. Reprinted with permission copyright © 2009 Brookner, E., and *IEEE*

such as small buoys, typically used for coastal applications, and dedicated vehicles, such as solar-powered AUV or gliders used when moorings are not feasible [37]. Several examples of suburban air-to-water (water-to-air) GRFS systems are depicted in Fig. 2.23. These systems should help especially in fighting piracy and ultimately capturing pirate ships [62].

We cannot leave without mentioning: (1) After completing their Lunar Sortie operations, the crew will enter the Altair's ascent stage and lift off from the Moon's surface, powered by a single engine, while using the descent stage as a launchpad (and as a platform for future base construction); (2) upon entering orbit, the Altair docks with the waiting Orion spacecraft, and the crew then transfers themselves and any samples collected on the moon over to the Orion [107].

Other civil applications might include costal boarder monitoring, agriculture and fishery applications, oceanography, communications relays for wide-band applications which can be divided into four large groups: (1) environmental applications; (2) emergency security applications; (3) communications applications; (4) monitoring applications [52].

2.5.8 Requirements for Description of Suburban Air-to-Space (Space-to-Air) GRFS Systems

Suburban air-to-space (space-to-air) GRFS systems are depicted in Fig. 2.24. As the space is getting crowded with more and more satellites, space stations, space vehicles, there are more and more opportunities for these systems to become more popular and so, we might see operations for exchange, deployment, communications, etc. from neighboring satellites, space stations and space vehicles, etc. [64]. For example, in Fig. 2.24 we have the integrated symmetrical concentrator (ISC) solar power satellite (SPS) in geosynchronous orbit produced by NASA's Space Electric Rocket Test (SERT) program in 2001 [64, 78] on the left and Tandem X on the right [79].

The concept of deriving terrestrial energy from space-based solar-electric systems using wireless power transfer has captured the imagination of the US government and private stakeholders for over 40 years [78]. Various studies of this concept were conducted during the 1970s, by NASA and the Department of Energy such as

Fig. 2.24 An illustration of the requirements for description of suburban air-to-space (or space-to-air) GRFS systems. *Left* and *bottom images* courtesy of NASA. *Right image* reprinted with permission copyright © 2009 Balmer, R., and *IEEE*

the 1979 Reference SPS System and the 1979 SPS architecture entailed in deploying a series of as many as 60 SPS into geostationary Earth orbit with each system providing power ranging from 5 to 10 GW of continuous energy [78]. This is perhaps one of the applications that most people on earth are not aware of.

On the other hand, Tandem X Satellites, which are radar Satellites positioned for interferometry in a formation flight at distances of only a few hundred meters, the "twins" record data synchronously in the so-called StripMap Mode (3 m ground resolution) and thus acquire the data basis for a global Digital Elevation Model (DEM) of an unprecedented quality, accuracy, and coverage [79]. While a pair of Tandem X Satellites twins is in fact an urban GRFS system, a few pairs of Tandem X Satellites can form a suburban or a global GRFS system.

2.5.9 Requirements for Description of Suburban Ground-to-Air-to-Water (Air-to-Water-to-Ground or Water-to-Air-to-Ground) GRFS Systems

As depicted in Fig. 2.25, which represents a suburban ground-to-air-to-water (air-to-water-to-ground or water-to-air-to-ground) GRFS system, real world applications require fast convergence, robust STAP, and ultrawideband arrays to differentiation between: (1) sidelobe targets; (2) clutter discretes; (3) multiple mainlobe targets in adjacent range cells; (4) range varying nonhomogenous clutter; (5) and not to forget electromagnetic interference. Military vehicles have to operate under rugged terrain conditions, which lead to motion induced antenna pointing errors, such as when antennas are mounted on fast-moving platforms: aircraft and UAVs (see Fig. 2.25) [27].

How critical are the Operational Requirements Document (ORD) (Chaps. 1–3), an Overarching Concept of Operations (Chaps. 1, 2, 4, and 6) and Technical Requirements Document (TRD) (Chaps. 1–3) to enable the design of GRFS systems [50].

2.6 Requirements for Description of Global GRFS Systems

Global GRFS systems are defined as GRFS systems in which the global range of the area of operations is from 100 km up to 1,000 km in any global environment such as ground, air, space, or water.

Taking into consideration the examples presented, we provide an organization of this section which includes the requirements for description of several global GRFS systems as depicted in Fig. 2.26. First, we have the requirements for description of global ground GRFS systems discussed in Sect. 2.6.1. Second, we present the requirements for description of global air GRFS systems in Sect. 2.6.2. Third, we

Fig. 2.25 An illustration of the requirements for description of suburban ground-to-air-to-water (or air-to-water-to-ground or water-to-air-to-ground) GRFS systems. Reprinted with permission copyright © 2009 Guerci, J.R., and *IEEE*

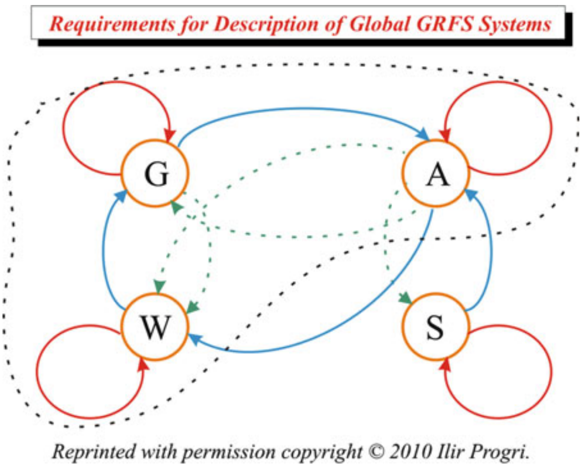

Fig. 2.26 An illustration of the state diagram of requirements for description of global GRFS systems. Reprinted with permission copyright © 2010 Ilir Progri

depict the requirements for description of global water GRFS systems in Sect. 2.6.3. Fourth, we analyze the requirements for description of global space GRFS systems in Sect. 2.6.4. Fifth, we discuss the requirements for description of the global ground-to-air (air-to-ground) GRFS systems in Sect. 2.6.5. Sixth, we provide the requirements for description of global ground-to-water (water-to-ground) GRFS systems in Sect. 2.6.6. Seventh, we present the requirements for description of global air-to-water (water-to-air) GRFS systems in Sect. 2.6.7. Eight, we depict the requirements for description of global air-to-space (space-to-air) GRFS systems in Sect. 2.6.8. Ninth and finally, we conclude this section with the requirements for description of global ground-to-air-to-water (air-to-water-to-ground or water-to-air-to-ground) GRFS systems in Sect. 2.6.9.

As we are going to see in Chap. 3 for the signal design point of view, these systems are made possible only as the result of the existence of the satellite GRFS systems.

2.6.1 Requirements for Description of Global Ground GRFS Systems

An example of a global ground GRFS systems are web services to realize service oriented architecture (SOA) in military communications networks such as shared situation awareness among military units is essential for network-enabled capabilities (NES) operations [26]. In order to enhance interaction within the allied forces there is a focus in NATO on the establishment of a SOA that will focus on rapid reaction, demand more adaptive and efficient solutions for information exchange, and quickly create and dynamically update a relevant picture, which will make military resources available as services [26].

The primary focus of the NATO NEC feasibility study (NNEC-FS) was to develop a NATO concept to adapt, extend, and expand national concepts such as the U.K. NEC and U.S. network-centric warfare (see Fig. 2.27) to the NATO context that will support all communications requirements of the member nations' forces such as communications among people, shared situation awareness, and end-to-end quality of service [26].

2.6.2 Requirements for Description of Global Air GRFS Systems

Global air GRFS systems include global airspace as illustrated in Fig. 2.28. Global air GRFS systems should be able to detect, differentiate, and accurately geolocate each military aircraft or civilian airplane in any kind of situation. A global coverage with acceptable communications [geolocation] performance is still missing today, especially for remote and oceanic areas [51].

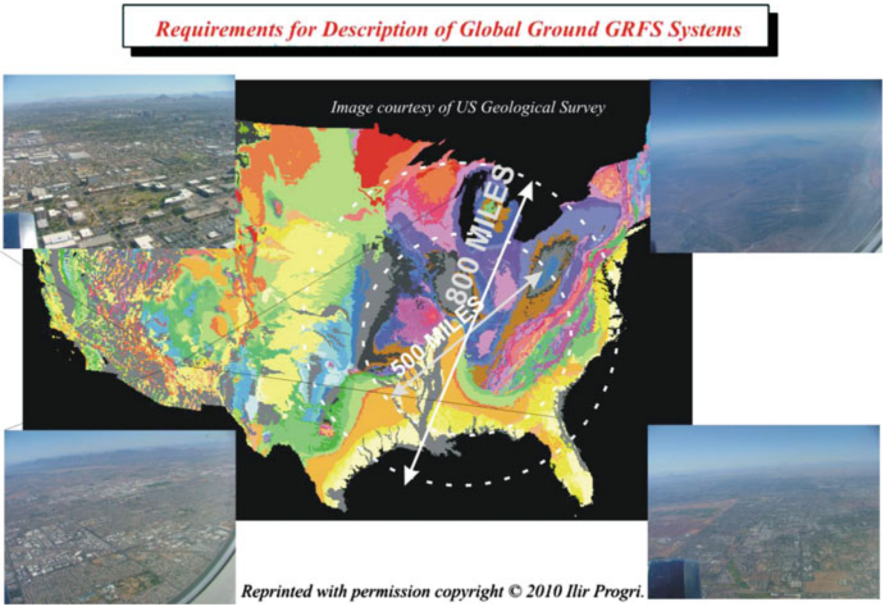

Fig. 2.27 An illustration of the requirements for description of global ground GRFS systems. US map image courtesy of US geological survey. Other four images are copyright © 2010 Ilir Progri

The FAA and Eurocontrol have already identified the upcoming bottlenecks in ATC/ATM communications and have started to develop the "Future Communications Infrastructure" (FCI) under the framework of the International Civil Aviation Organization (ICAO) [51]. Besides the development of new concepts and paradigms, one important part of the FCI is the development of the new aeronautical communications system able to cope with the demands and requirements of future ATC/ATM concepts [51].

2.6.3 Requirements for Description of Global Water GRFS Systems

Global water GRFS systems include global water as illustrated in Fig. 2.29. Global water GRFS systems should be able to detect, differentiate, and accurately geolocate each naval ship or civilian boat in any kind of situation, either in combat engagement or search and rescue operations.

Figure 2.29 illustrates the seismicity of the North Atlantic Ocean from 1975 to 1995 (left), and a more recent maritime modeling and analysis branch photo of the Atlantic Ocean (*right*) [99] an Earth-observing satellite that has provided early detection of ocean storms, including tropical cyclones, and advanced the scientific exploration of global ocean wind patterns, which has also been recognized for

Fig. 2.28 An illustration of the requirements for description of global air GRFS systems. *Left image* Reprinted with permission copyright © 2007 Phil Makanna. *Right image* courtesy of *Air and Space Magazine Smithsonian* 1999

helping scientists better understand our home planet [103]. NASA and the U.S. Department of the Interior Tuesday presented the William T. Pecora Award to NASA's Quick Scatterometer, or QuikScat, mission team [103].

Greater concerns for these systems are "Piracy at sea: Somalia an area of great concern" from the states which have been marked as "weak" or "lawless" [62]. Although these phenomenon have been observed in the Gulf of Aden, near the Arabian Peninsula closer to the Indian Ocean, no one can guarantee that piracy, or smuggling of arms, drugs, human, or kids trafficking does not exists in the Atlantic Ocean.

2.6.4 Requirements for Description of Global Space GRFS Systems

As we have described in suburban space GRFS systems, global GRFS systems as depicted in Fig. 2.30, are satellite-based GRFS systems with global range 100 km–1,000 km. We have a much richer space environment that includes GPS satellite and other satellites which are discussed more extensively in the Satellite Space GRFS Systems. Global space GRFS systems may include surveillance

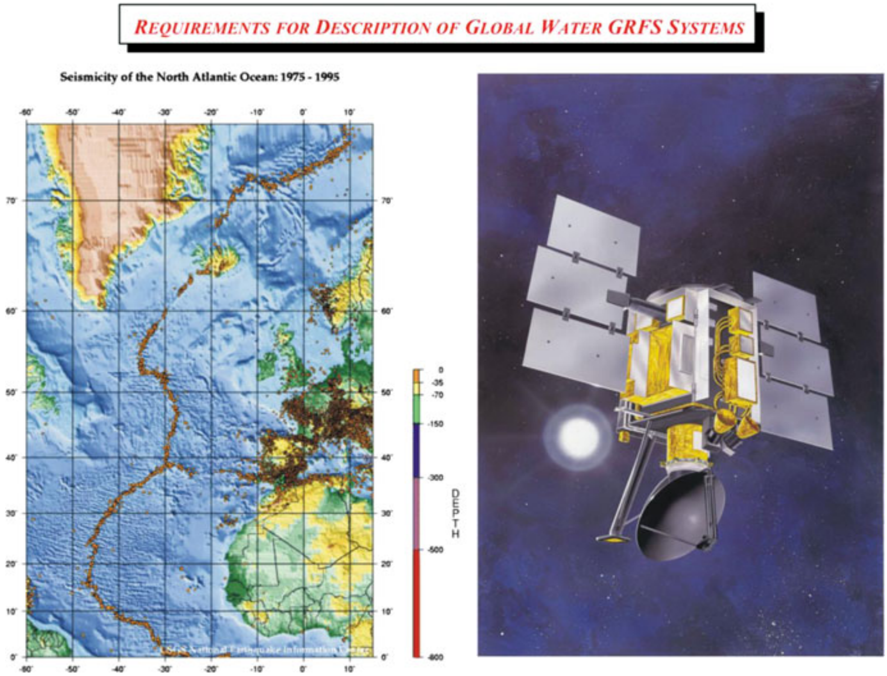

Fig. 2.29 An illustration of the requirements for description of global water GRFS systems. *Left image* U.S. Geological Survey; *Left image* courtesy of NASA

applications as illustrated in Fig. 2.30. In case of GPS, global GRFS systems become a part of the observable satellites from the terrestrial user point of view which could be as much as a third of the total number of satellite in the sky. So if we were to use this observation, then we could also define global space GRFS systems as GRFS systems that include about a third of all space satellites. The reader can also picture that there can only be three mutually exclusive global space GRFS systems.

Huge murals of artwork commemorating three decades of historic explorations and scientific achievements by all five of America's Space Shuttle Orbiters – Columbia, Challenger, Discovery, Atlantis, and Endeavour – now grace the Shuttle Firing Room inside the Launch Control Center (LCC) at NASA's Kennedy Space Center in Florida [116].

2.6.5 Requirements for Description of Global Ground-to-Air (Air-to-Ground) GRFS Systems

An example of a global ground-to-air (air-to-ground) GRFS systems may include a military communications network that consists of a large number of ground-based

Fig. 2.30 An illustration of the requirements for description of global space GRFS systems (Tandam-L). Images courtesy of NASA

high-mobility vehicles, fast-moving aircrafts, UAVs deployed in intelligence, surveillance and reconnaissance (ISR) (see Fig. 2.31), and several naval vessels [27].

Satellite Communications Systems (SCS) are advantageous when connecting such terminals scattered over large distances; and SCS form by itself a satellite space GRFS system that are discussed more extensively in the following section. The United States Army is currently developing a satellite-based network-centric waveform capable of supporting military applications in highly mobile environments (see Fig. 2.31) [27].

Research to date on tactical wireless communications has focused on increasing bandwidth, improving reliability, and enabling adaptations for focusing on areas such as network coding, dynamic spectrum exploitation, robust routing, protocols, and cross-layer design which should lead to better bandwidth utilization and higher throughput [44]. Some of the most severe issues that these systems face are coming from additional range, interference, mobility, and security which cause severe bandwidth reduction and throughput reduction [44].

The purpose of the ground–air GRFS systems is, perhaps by integration with Blue Force Tracking (BFT) [44] or as part of BFT, to provide warfighters with location information about friendly military forces and also with location of RF interference enemy sources. Illustration details on how this is accomplished in more

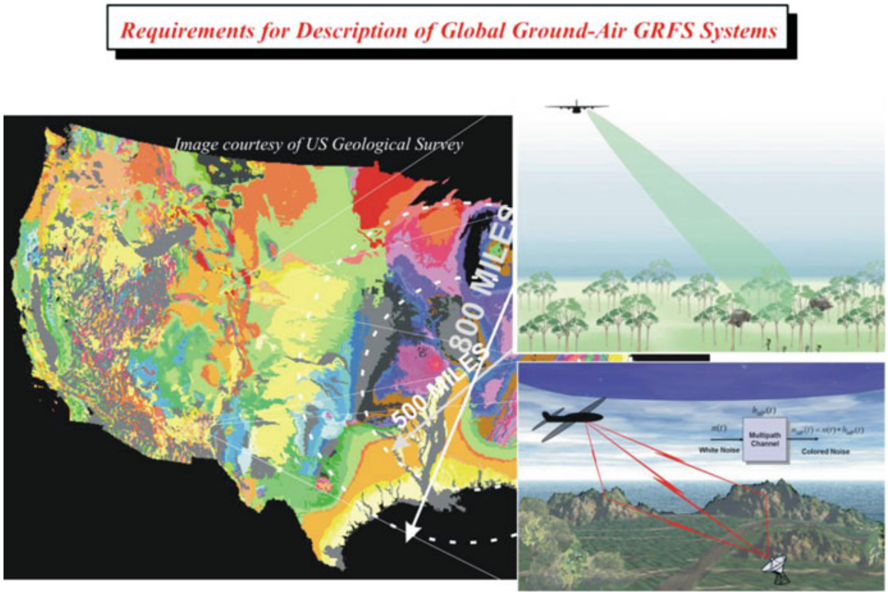

Fig. 2.31 An illustration of the requirements for description of global ground-to-air (air-to-ground) GRFS systems. *Left image* courtesy of US Geological Survey. *Right images* copyright © 2009 Davis, M., Guerci, J.R., and *IEEE*

practical principle simulation examples the reader may obtain further details in Chaps. 4 and 6.

2.6.6 Requirements for Description of Global Ground-to-Water (Water-to-Ground) GRFS Systems

Following the discussion on global ground GRFS systems, ground-to-water will exhibit similar application as global water GRFS systems. Of particular interests are water board patrolling, search and rescue operation by the US Coast Guard, loading and unloading of ships in and around huge ports, monitoring of huge cargo ships, international water patrolling, etc. as shown in Fig. 2.32.

2.6.7 Requirements for Description of Global Air-to-Water (Water-to-Air) GRFS Systems

US Navy has expressed concerns that current passive, phased array antennas are heavy, bulky, and often exhibit poor *aperture efficiency and response linearity* when attempting to design them to cover large RF bandwidths.

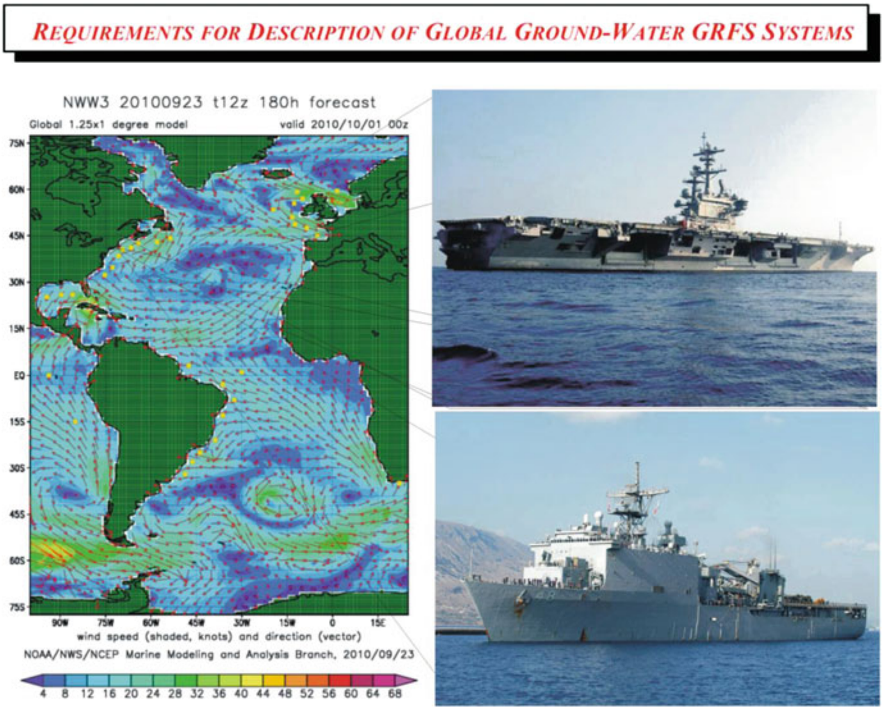

Fig. 2.32 An illustration of the requirements for description of global ground-to-water (water-to-ground) GRFS systems. *Left image* courtesy of US NOAA/NWS. *Right images* courtesy of Wordpress and Wikipedia

This book addresses US Navy's needs for innovative, passive phased array antennas for *drastic improved physical profiles, performance characteristics* to support multiple developmental programs across multiple missions.

Figure 2.33 provides an outstanding illustration of global air-to-water (water-to-air) GRFS systems. As illustrated in Fig. 2.33, a global air-to-water (water-to-air) GRFS system can perform one of the following: (1) horizon search track-white-scan; (2) limited volume search; (3) uplink/downlink; (4) cued acquisition; (5) electronic protection from electronic attach platform; (6) environmental mapping; (7) counter fire; (8) sector search; (9) periscope detection; (10) surface search navigation; (11) target illumination; (12) horizon search track white scan [66].

2.6.8 Requirements for Description of Global Air-to-Space (Space-to-Air) GRFS Systems

Global air-to-space (space-to-air) GRFS systems may include numerous applications such as weather satellites, ozone layer monitoring, ionosphere electronic

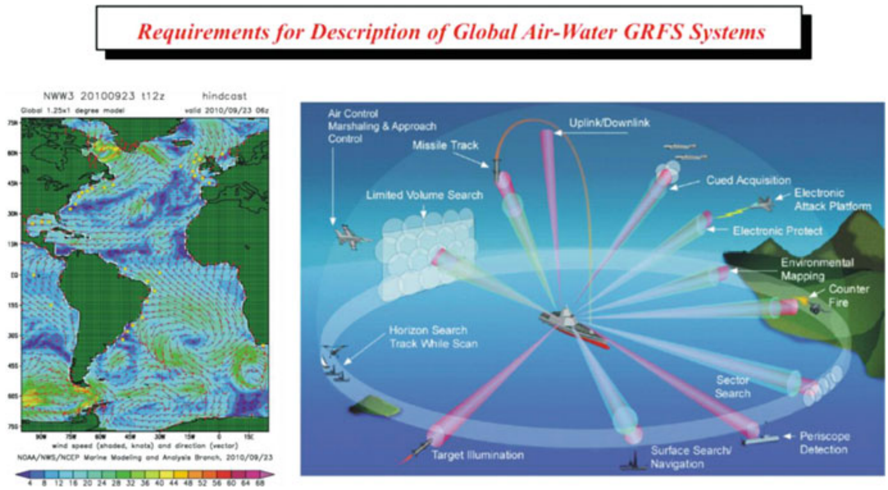

Fig. 2.33 An illustration of the requirements for description of global air-to-water (water-to-air) GRFS systems. *Left image* courtesy of US NOAA/NWS. *Right image* reprinted with permission copyright © 2009 Jeffrey, T., and *IEEE*

content monitoring, etc. Earth observation' satellites are mainly located in low earth orbit (LEO), usually less than 1,000 km from the Earth's surface, and are characterized by the need for downloading huge amounts of data, which are generated by their instruments and are stored onboard during the day [53]. Other applications might include monitoring of health and conditions of other satellites, space stations, space shuttle, etc. as illustrated in Fig. 2.34. It is well accepted that satellites play an established and well-organized role in some "nice" markets such as navigation and localization services, broadcast services, specific observations of Earth observation, and remote sensing [11]. One such system is high-altitude platforms (HAPs) also known as aerial unmanned platforms carrying communications relay payloads and operating in quasistationary positions at altitudes between 15 and 30 km from the surface of the earth [11, 53]. Such systems can be used from telephony and broadband services, navigation systems for providing fleet management and traffic-control services [11, 53]. Other applications might include data-relay satellite systems such as NASA's Tracking and Data Relay Satellite. Other roles of HAPs are support of services such as required navigation performance (RNP) or position navigation, and timing (PNT), to Global Navigation Satellite Systems (GNSSs) [119–138] such as GPS and Galileo, Local Area Augmentation Systems (LAAS), Wide Area Augmentation Systems (WAAS), terrestrial stratospheric Ranging, Integrity, and Monitoring Station (RIMS) network, Local-area Differential GPS (LADGPS), etc., which will be discussed briefly in the *Indoor Geolocation Systems: Theory and Applications* book.

For example, Challenger (Fig. 2.34, top right): This Tribute Display features Challenger, which blazed a trail for other vehicles with the first night landing (STS-8) and also the first landing at Kennedy Space Center (STS-41B).

Fig. 2.34 An illustration of the requirements for description of global air-to-space (space-to-air) GRFS systems. Images courtesy of NASA

The spacewalker represents Challenger's role in the first spacewalk during space shuttle mission (STS-6) and the first untethered spacewalk (STS-41B). Crew-designed patches for each of Challenger's missions lead from earth toward our remembrance of the STS-51L crew. Other significant accomplishments include the first night launch with STS-8; the first in-flight capture, repair, and redeployment of an orbiting satellite during STS-41C; the first American woman in space (Sally Ride on STS-7); the first African-American in space (Guion Bluford on STS-8); and the first American woman to walk in space (Kathryn Sullivan during STS-41G). Credit: NASA [116].

2.6.9 Requirements for Description of Global Ground-to-Air-to-Water (Air-to-Water-to-Ground or Water-to-Ground-to-Air) GRFS Systems

A satellite GRFS system can be very handy for detecting insurgents and intruders hiding other foliage [61]. Moreover, if there is a need for rescue operation in heavy rain and high wind, the detection, discrimination, and differentiation range may be affected [61]. A US Navy surveillance aircraft may experience great difficulty detecting humans and vehicles on the ground or even small ships in a harbor if antennas are not above the masking (or hiding) environments which may consists of trees, foliage, larger ships, or heavy wind induced clutter [61].

Giftet Inc proposed that a satellite ground-to-air-to-space-to-water GRFS system will serve the unique purposes of the US Navy for detecting and characterizing manmade objects of any kind as long as these objects have a transmitter which transmits at any of the frequency ranges in 100 MHz to 66 GHz much better than passive sonar systems under any environment, geometry, clutter, signal intensity, density, etc. [48].

As depicted in Fig. 2.35, which represents a satellite ground-to-air-to-space-to-water (all other combinations of four) GRFS system, real world applications require differentiation among many tasks.

Some of the most important tasks include: (1) main lobe targets; (2) side lobe indoor or undertunnel geolocation targets; (3) sidelobe targets hiding in under power or telephone lines; (4) civilian moving targets; (5) multiple side lobe targets hiding in under foliage and clutter; (6) and not to forget electromagnetic interference.

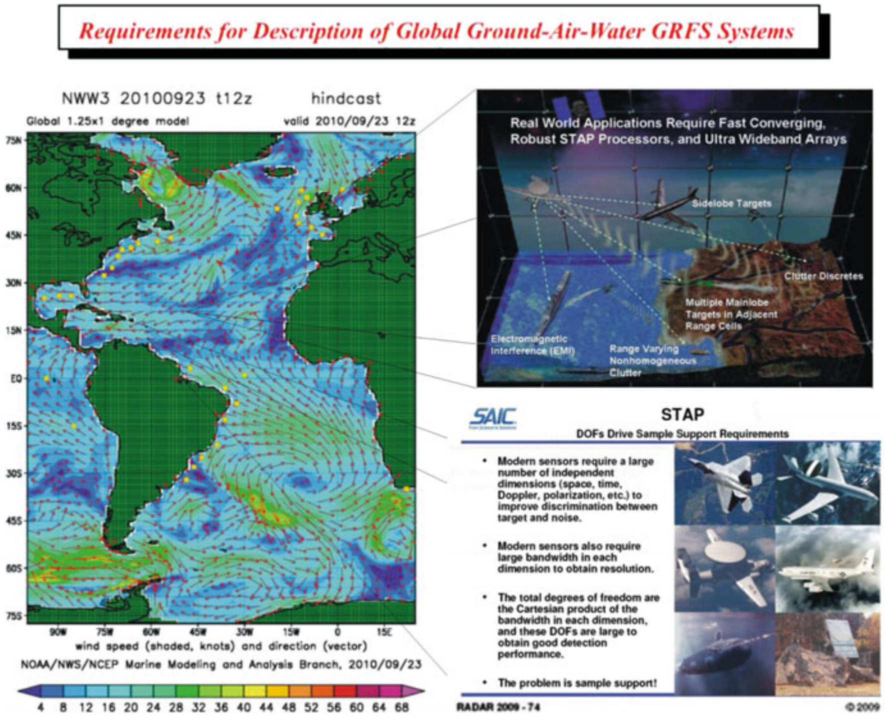

Fig. 2.35 An illustration of the requirements for description of global ground-to-air-to-water (air-to-water-to-ground or water-to-ground-to-air) GRFS systems. *Left image* courtesy of NOAA/NWS. *Right image Top* copyright © 2009 Goldstein, M., Picciolo, M., Griesbach, J., and *IEEE*. *Right image Bottom* copyright © 2009 SAIC

Network-centric operations also referred to as network-enabled capability and network defense, is the cornerstone of modern warfighting, which rely on robust network communications to support timely exchange of information between geographically dispersed entities [44]. Tactical networks which are the basis of the network centric warfighting operations also provide one of the most challenging environments for communications, which included inherently that mobile nodes must communicate by using wireless ad hoc links in hostile radio frequency (RF) environments, creating unreliable networks that have limited bandwidth and variable latency (see Fig. 2.35) [44].

Applications in tactical networks have different, sometimes peculiar requirements; therefore, a one-size-fits-all approach to transport protocol leads to inefficiencies [44] which is the reason why we have the last section of this chapter dedicated to requirements for description of satellite GRFS systems.

2.7 Requirements for Description for Satellite GRFS Systems

Satellite GRFS systems are defined as GRFS systems in which the satellite range of the area of operations is from 1,000 km up to 100,000 km in any global environment such as ground, air, space, or water.

Satellite GRFS systems play an important role for: (1) both military and civilian applications; (2) both for research, development, and commercial needs; (3) both for cutting edge technologies as well as mature and well-established technologies. After the World War II, satellite technologies started to dominate and lead the research and development in aerospace, astronomy, space navigation, radio-cosmology, interplanetary rocket science, radars, celestial navigation, etc. initially by the United States and the former Soviet Union and later by the European Union, Japan, and Australia, and more recently by China and India, and other nations.

There are many advantages of the satellite systems in terms of global coverage, global availability of signals, global means to achieve communications, global time transfer, global location to all the users on the ground, air, water, etc. Moreover, satellite systems give us the much needed information from the universe which is distorted to get from the observatories on earth. Since satellite systems cover almost the entire usable spectrum of frequencies, we are going to restrict our discussions to the desired frequency spectrum of 100 MHz to 66 GHz. Chapter 3 discusses in great detail the signal structure or design or RF signals used in Satellite GRFS Systems. It is without any doubt that one can write an entire book only on Satellite GRFS Systems.

As we have also mentioned previously, it is hoped that this preliminary classification is only going to provide a firsthand overview of the description of the satellite GRFS systems and also an outline for future direction of the research. It is hoped that future editions of this book are going to expand the discussion provided here and include information that will be suggested from reviewers and readers. This is usually the information that is generally not accessible to the author at first hand which is the reason why writing a book for the first time is so important. Without further due let us begin the discussion on the description of requirements of satellite GRFS systems.

At this stage, the reader should be familiar that a GRFS system can be conceptually thought either as a single system in order to address the requirements of a single case study or as a complex system of systems that will be a collection of individual, possible heterogeneous, but functional GRFS systems integrated together to enhance the overall robustness, increase reliability and performance of the overall complex (SoS) system [54]. Although this is a viable option, for the most part we are going to be treating all our case studies as individual and independent GRFS systems and as we gather information for all case studies, we could propose future design that might include concepts of the System of system design and integration in the future editions of the book [54].

Taking into considerations the examples presented, we provide an organization of this section which includes the requirements for description of several satellite GRFS systems as depicted in Fig. 2.36. First, we have the requirements for description of satellite space GRFS systems discussed in Sect. 2.7.1. Second, we present the requirements for description of satellite ground-to-air (air-to-ground) GRFS systems in Sect. 2.7.2. Third, we depict the requirements for description of satellite ground-to-space (space-to-ground) GRFS systems in Sect. 2.7.3. Fourth, we analyze the requirements for description of satellite air-to-water (water-to-air) GRFS systems in Sect. 2.7.4. Fifth, we discuss the requirements for description of satellite air-to-space (space-to-air) GRFS systems in Sect. 2.7.5. Sixth, we provide the requirements for description of satellite ground-to-air-to-water (air-to-ground-to-water or water-to-air-to-ground) GRFS systems in Sect. 2.7.6. Seventh, we present the requirements for description of satellite ground-to-space-to-water (space-to-ground-to-water or water-to-space-to-ground) GRFS systems in Sect. 2.7.7. Eight, we depict the requirements for

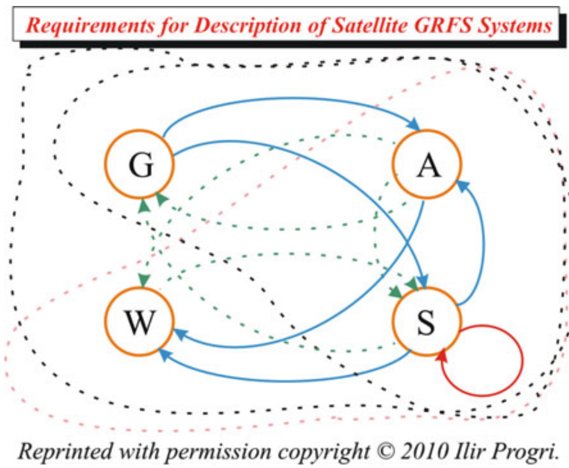

Fig. 2.36 An illustration of the state diagram of requirements for description of suburban GRFS systems. Reprinted with permission copyright © 2010 Ilir Progri

description of satellite air-to-space-to-water (space-to-air-to-water or water-to-space-to-air) GRFS Systems in Sect. 2.7.8. Ninth and finally, we conclude this section with the requirements for description of satellite ground-to-air-to-space-to-water (all other combinations of four) GRFS systems in Sect. 2.7.9.

2.7.1 Requirements for Description of Satellite Space GRFS Systems

Figure 2.37 represents satellite space GRFS systems which are secondary systems to the primary Radar systems shown in the figure because GRFS systems are passive array systems.

There has been a monumental advancement in space exploration from the NASA as depicted in Fig. 2.37 with Jason-1, QuikSCAT, ERBS, ACRIMSAT, Landsat 7,

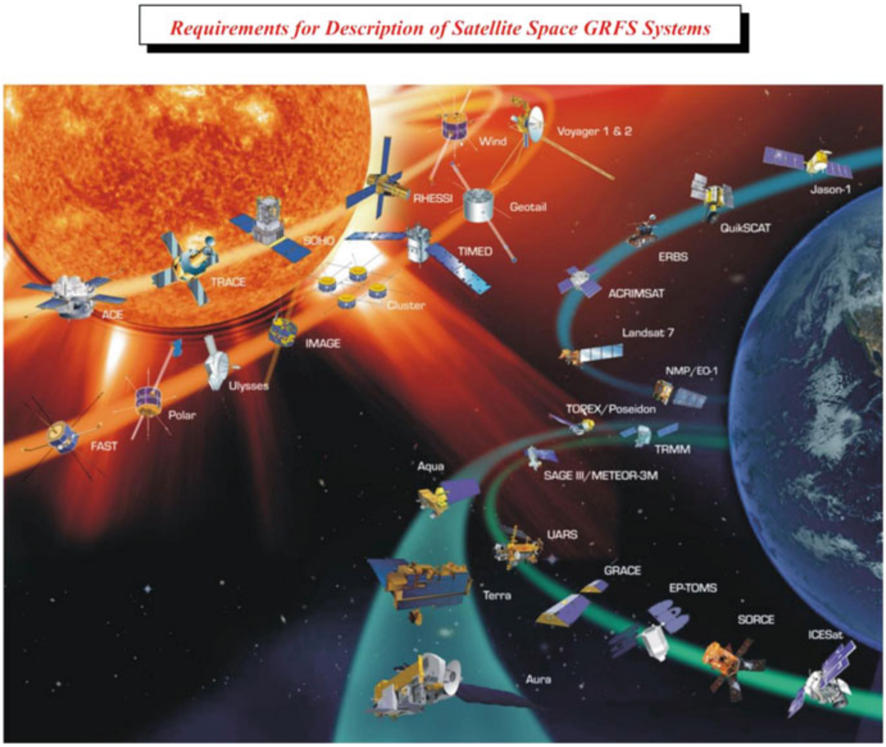

Fig. 2.37 An illustration of the requirements for description of satellite space GRFS systems. Image courtesy of NASA

Table 2.1 Classifications of satellites

Class	Cost	Mass (kg)
Large satellite	$ >100 M	>1,000
Small satellite	$50–100 M	500–1,000
Minisatellite	$5–20 M	100–500
Microsatellite	$2–3 M	10–100
Nanosatellite	$ < M	<10

NMP/EO-1, TRMM, TOREX/Poseidon, Saga III/METEOR 3M, GRACE, EP-TOMS, SORCE, Aura, and Terra [104].

Other space GRFS systems which go beyond the scope of this chapter are voyager 1 and 2, Wind, Geotail, RHSSI, TIMEO, SOHO, Cluster, Image, Trace, Ulysses, Ace, Polar, and Fast. Based on class, cost, and mass satellites can be classified as shown in Table 2.1 [53]:

Recent advances of microelectronics has generated a new species of modern, highly sophisticated, computationally powerful, rapid-response microsatellite (and minisatellites) that have reduced the cost of a single satellite by more than one order of magnitude (see Table 2.1; [53]). These "faster, cheaper, and better" microsatellites now make the implementation of such a disaster network both practicable and affordable as well as offering possibilities for improved weather predictions, real-time monitoring of a stricken area, and nearly immediate restoration of communications services needed for relief efforts [53].

2.7.2 Requirements for Description of Satellite Ground-to-Air (Air-to-Ground) GRFS Systems

An example of a satellite ground-to-air (air-to-ground) GRFS system is shown in Fig. 2.38 which illustrates a space shuttle rocket launch, space shuttle rocket passing through the atmosphere, a space vehicle positioning in orbit, and the return and landing of a space shuttle from its missions [105–108].

These systems are characterized by very high accelerations (or g-s); therefore, during these missions the astronauts' crew is set to be static with respect to the space shuttle rocket during takeoff or landing as shown in Fig. 2.38.

2.7.3 Requirements for Description of Satellite Ground-to-Space (Space-to-Ground) GRFS Systems

An example of requirements for description of satellite ground-to-space (space-to-ground) GRFS system is shown in Fig. 2.39 which depicts most radio telescopes

Fig. 2.38 An illustration of the requirements for description of satellite ground-to-air (air-to-ground) GRFS systems. Image on the *left* is courtesy of NASA

as reflectors, such as: (1) Arecibo is 305 m diameter (73,000 m^2) spherical dish (fixed position); (2) Lovell Telescope is the third largest steerable radio telescope in the world; (3) Haystack is 37 m diameter (1,075 m^2) (re-positionable) © MIT; and (4) Proposed Square Kilometer Array (SKA) will be some form of ESA [71].

Another example of a ground-to-space GRFS system includes a description of S-WiMAX: adaptation of IEEE 802.16e for mobile satellite services [42]. It is desirable that Satellite adaptation of WiMAX have baseband affinity with the WiMAX physical (PHY) and medium access control (MAC) layers primarily a power and size efficient dual-mode satellite/terrestrial application-specific integrated circuit (ASIC) and drives a contemporary handheld mobile device [42].

Another example is the digital video broadcast-return channel satellite (DVB-RCS) which includes aeronautical, maritime, and land [59]. This case study will be discussed further in Chaps. 3 and 4.

Fig. 2.39 An illustration of the requirements for description of satellite ground-to-air (air-to-ground) GRFS systems. Reprinted with permission copyright © 2009 Williams, J., and *IEEE*

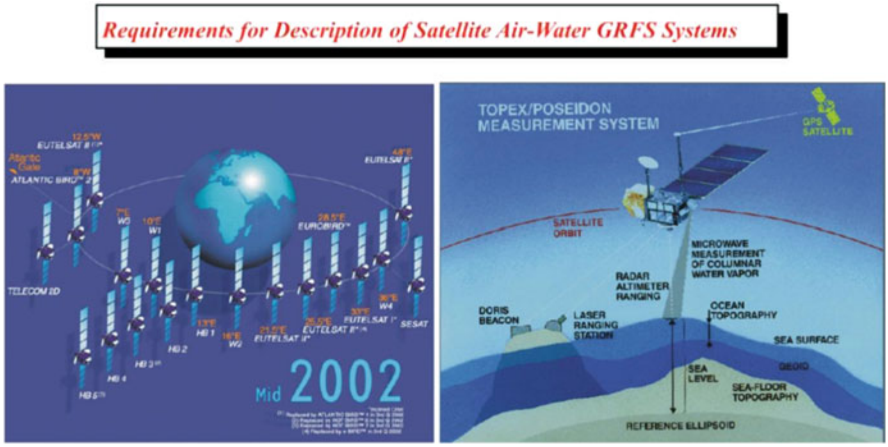

Fig. 2.40 An illustration of the requirements for description of satellite air-to-water (water-to-air) GRFS systems. Reprinted with permission copyright © 2009 Griffiths, H., Willis, N. and *IEEE*; copyright © 2009 Zyl, J.V., and *IEEE*

2.7.4 Requirements for Description of Satellite Air-to-Water (Water-to-Air) GRFS Systems

Satellite Air-to-Water (Water-to-Air) GRFS systems are used for a number of remote sensing oceanographic studies as depicted in Fig. 2.40 (*right*).

The oceanographic satellite is equipped with laser altimeter ranging instrument, microwave measurement of columnar water vapor instrument; and is also able to detect a number of laser ranging stations [67, 68].

The TOPEX/POSEIDON Project was a joint US and French mission to develop and operate an Earth-orbiting satellite with sensors capable of making accurate measurements of sea level by means of the NASA radar altimeter (NRA), a fifth-generation US altimeter that provides the primary measurement for the TOPEX/POSEIDON Project altimetric mission [67].

Contrast this with the left of Fig. 2.40 where we have a number of geostationary European satellites that allow for long integration time that are used for satellite DBS-TV monitoring from 2002 until the present days with beams shaped to provide coverage over land [70].

2.7.5 *Requirements for Description of Satellite Air-to-Space (Space-to-Air) GRFS Systems*

Satellite air-to-space (space-to-air) GRFS systems may include the space shuttle rocket ascension and dissension as illustrated in Fig. 2.41. After jettisoning the Altair to allow it to crash into the lunar far side, the crew, using the onboard engine performs the Trans Earth Injection (TEI) burn for the return trip to Earth. After a

Fig. 2.41 An illustration of the requirements for description of satellite air-to-space (space-to-air) GRFS systems. Images courtesy of NASA

2½ day coast, the crew jettisons the service module (allowing it to burn up in the atmosphere) and then reenters the Earth's atmosphere using a reentry trajectory designed to both slow the vehicle from its speed of 40,200–480 km/h and allow for a West Coast landing [107].

The Orion spacecraft is able to dock with the International Space Station. The six-man crew, the largest number that can fly on an Orion spacecraft, then enters the station and performs its activities for the duration of their flight, usually lasting 6 months, but can be shortened to 4 or lengthened to 8. Once completed, the crew reenters the Orion, which has been kept attached to the station as an emergency "lifeboat," seal off the hatches between it and the ISS, and then undock from the station [107].

2.7.6 Requirements for Description of Satellite Ground-to-Air-to-Water (Air-to-Ground-to-Water or Water-to-Air-to-Ground) GRFS Systems

Satellite ground-to-air-to-water (air-to-ground-to-water or water-to-air-to-ground) GRFS systems may include space shuttle rocket launch during takeoff, space shuttle rocket ascension into space, and oceanographic water monitoring as illustrated in Fig. 2.42.

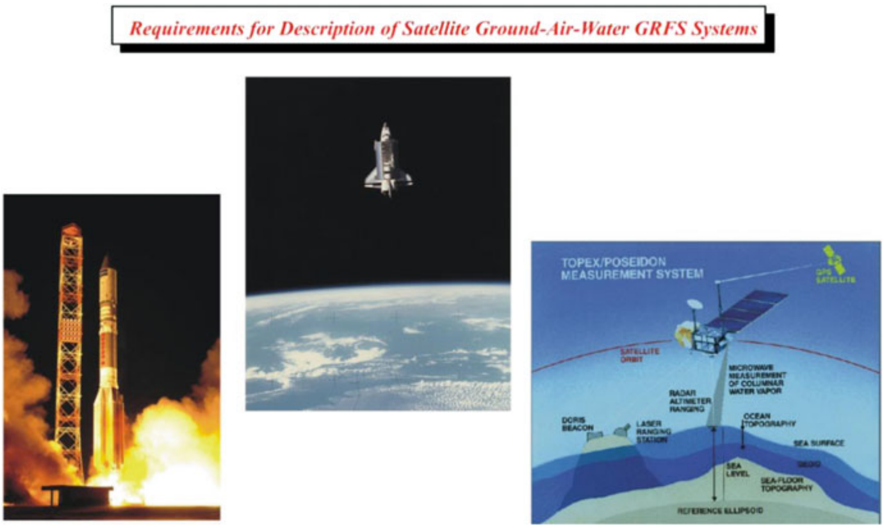

Fig. 2.42 An illustration of the requirements for description of satellite ground-to-air-to-water (air-to-ground-to-water or water-to-air-to-ground) GRFS systems. Image on the *left* is courtesy of 2004–2009 Orbitcast Media LLC. Image in the *center* is copyright © 2009 OrbitalHub. Image on the *right* is copyright © 2009 Zyl, J.V., and *IEEE*

2.7.7 Requirements for Description of Satellite Ground-to-Space-to-Water (Space-to-Ground-to-Water or Water-to-Space-to-Ground) GRFS Systems

Satellite ground-to-space-to-water (space-to-ground-to-water or water-to-space-to-ground) GRFS systems may include space shuttle rocket launch during takeoff, satellite orbiting into space, and oceanographic water monitoring as illustrated in Fig. 2.43.

Another example of a ground-to-space-to-water GRFS system may include a microwave ranging radiometer and aperture synthesis (MIRAS) that was developed by EDAS CASA Espacio with major subcomponents built by companies in Spain and 17 European countries overall [63].

The MIRAS instrument employs 69 individual antenna elements and receivers and two-dimensional aperture synthesis in order to achieve the needed horizontal spatial resolution of the 1.4 GHz brightness temperature measurements [63].

2.7.8 Requirements for Description of Satellite Air-to-Space-to-Water (Space-to-Air-to-Water or Water-to-Space-to-Air) GRFS Systems

The Soil Moisture and Ocean Salinity (SMOS) mission, also known as ESA's Water Mission, is the second one of the European Space Agency's Earth Explorer series launched on 2 November 2009 into a LEO at ~760 km altitude [63].

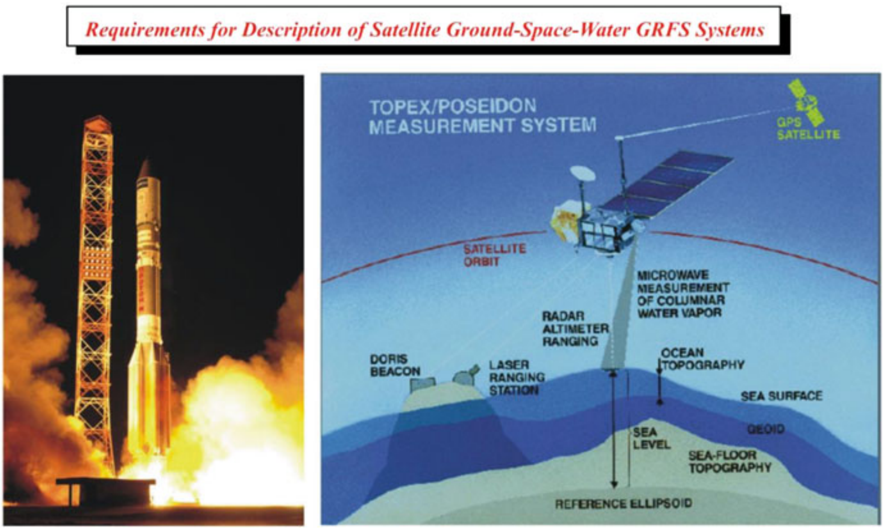

Fig. 2.43 An illustration of the requirements for description of satellite ground-to-space-to-water (space-to-ground-to-water or water-to-space-to-ground) GRFS systems. Image on the *left* is courtesy of 2004–2009 Orbitcast Media LLC. Image on the *right* is copyright © 2009 Zyl, J.V., and *IEEE*

The L-band measurements provide sensitivity to changes in soil moisture and sea surface salinity, but are relatively insensitive to variations in atmospheric effects in water vapor and vegetation cover. These measurements were initially important because they measured and tracked water for agriculture and monitoring desertification which is recently strengthened due to applications for improving weather forecasting and climatology studies [63] or the Katrina Hurricane, or the HUGE BP Oil Spill. The International Space Station or the Hubble Telescope may also be used to gather useful oceanographic information as depicted in Fig. 2.44.

2.7.9 Requirements for Description of Satellite Ground-to-Air-to-Space-to-Water (All Other Combinations of Four) GRFS Systems

Satellite systems are the most effective ways to provide mobile MBMS; its association with hybrid satellite-terrestrial networks (HSTN) enables the formation of cooperative systems by seamlessly combining the most powerful aspects of each network [31]. Satellite system can provide the best and most effective coverage for low-density populations in global and satellite environments, while the terrestrial

Fig. 2.44 An illustration of the requirements for description of satellite air-to-space-to-water (space-to-air-to-water or water-to-space-to-air) GRFS systems. Images courtesy of NASA

Fig. 2.45 An illustration of the requirements for description of satellite ground-to-air-to-space-to-water (all other combinations of four) GRFS systems. Images courtesy of NASA

network can provide the highest bandwidth and lowest cost coverage for high-density populations in indoors, urban, and suburban environments [31].

In the end, satellite ground-to-air-to-space-to-water (all other combinations of four) GRFS systems have the largest coverage possible for all geospatial, geointelligence, georeference, etc., applications (see in Fig. 2.45, NASA's exploration roadmap [118]).

2.8 Conclusions

We now conclude this chapter. This is probably the most exciting chapter and the bedrock of the entire book and there are numerous reasons why this is such an exciting chapter.

This chapter has a brand new and original organization which illustrates very vividly the local reference environments (indoor, urban, suburban, global, and satellite) and global reference environment (ground, air, space, and water), a wealth of technical requirements on description and discussions on each GRFS system motivated by extensive world-class literature publications from the *IEEE Communications Magazine*, *IEEE Systems Magazine*, etc.

From this point onward, this chapter will help tremendously the reader to understand the scope, the issues, the interests on each subsystem from the government, commercial, application, usability, etc. point of view, areas that have mature technologies, areas that are lacking in new and innovative research, and system development and deployment.

The most exciting news is not only for the benefits of this book or the research on GRFS Systems per se but also on the need to research and develop many sensors and sensory systems in the context of "systems of systems" that will serve to support many primary systems that are already deployed and will illustrate the need for more sophisticated system integration concept networks and systems in order to meet the requirements of the GRFS systems as proposed in Chap. 1.

The other good news in the context of this chapter is that we have already prepared the ground work for a detailed discussion on RF signals in Chap. 3. This chapter has already provided the template on how Chap. 3 organization should look like and we have already had a great discussion on how the environment looks like and also what the IEEE standards are involved.

In Chaps. 4 and 6 we are going to refer back to this chapter: (1) when discussing case studies; (2) when analyzing principle simulation examples; (3) when assessing deployment scenarios; (4) when presenting new ideas and innovative technologies; (5) when building databases for geospatial solutions and maps; (6) when setting parameterization values for selecting values of different system parameters, etc.

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