Chapter

Emergency Communications Network for Disaster Management

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Abstract

In recent years, from the majority of field experiences, it has been learned that communications networks are one of the major pillars for disaster management. In this regard, the exploitation of different space technology applications to support the communications services in disasters plays an important role, in the prevention and mitigation of the natural disasters effects on terrestrial communications infrastructures. However, this chapter presents the design and implementation of an emergency communications network for disaster management, based on a topology that integrates communications satellites with remote sensing satellites into an emergency communications network to be activated in disaster events, which affect public or private terrestrial communications infrastructures. Likewise, to design the network, different technical and operational specifications are considered; among which are: the emergency operational strategies implementation to maneuver remote sensing satellites on orbit for optimal images capture and processing, as well as the payload and radio frequencies characterization in communications satellites to implement communications technology tools useful for disaster management. Therefore, this emergency communications network allows putting in operation diverse communications infrastructures for data and images exchange, making available the essential information to accomplish a fast response in disasters or to facilitate the communications infrastructures recuperation in emergencies situations.

Keywords: disaster management, space technology applications, emergency communications network, communications satellites, remote sensing satellites, communications technology tools, images and data exchange

1. Introduction

At the present time around the world, the use and integration of different space technology applications that contribute to planning and designing alternative communications networks for the relief of the disaster's impact, on the terrestrial communications infrastructures, have gained great importance in the disaster management scenario. In each one of the disaster stages, the information flow between the disaster management organizations, the population, and other actors, in general, is a critical and fundamental factor to provide a quick and opportune response to all aspects linked to a disaster event. Frequently in diverse disasters situations, the terrestrial communications infrastructures are affected by the disaster impacts, phenomena that cause the communications services unavailable to support in the disaster management. In most cases, the disasters impact mainly communications services, such as the mobile phone networks, fiber optic systems, terrestrial microwave systems, fixed telephone services, private and public TV networks, commercial radio networks, and also the Internet services infrastructures. Scenarios that have a considerable impact in all processes are related to the preparedness, response, and recovery in disaster conditions, since the communications services have an important function in the disaster management tasks.

Regarding current space technologies applications, a remote sensing satellite is a space technology whose operations make possible the analysis and understanding of the damages caused by nature's disaster. It is also a technology that has the ability to provide valuable information to assist in all the disaster management phases. From this perspective, the integration of the remote sensing satellites and communications satellites in a novel and practical topology with the purpose of implementing an emergency communications network to manage disaster events represents an important and necessary resource to enhance the abilities to monitor, manage, and control the critical data flow associated with the occurrence of one or more disasters in a specific region. In the same way, this operational integration offers a suitable and versatile resource to improve the emergency response time, and it is helpful to formulate the different indispensable measures to reduce the consequences and impacts of the disaster on the terrestrial communications infrastructures as well as on other public and private properties.

As a result, extensive works have been done over the last few years, proposing the integration of the space technology applications for disaster management, for example, studies about the role of the mobile satellite services and the remote sensing satellites in disaster management, with the aim to decrease the human casualties in natural events through the utilization of both technologies [1]. Similarly, various space technology applications and their utility to prevent the causes or mitigate the disaster's consequences have been investigated and analyzed. Concluding through this analysis, space technologies, such as active and passive remote sensing satellites, communications satellites systems, global navigation satellite systems, and weather satellites platforms, among others space technology applications, have a significant usage and importance in the processes or activities of risks reduction and disaster management, due to the flexibility in their operation characteristics [2]. In the same way, diverse organizations linked to the space sector around the world have focused their studies on the use and applications of space technology in the different stages involved in the disaster management. For instance, in pre-disaster planning, during disaster, and also in post-disaster phase, an integrated approach of using remote sensing and communications systems, disaster warning radar systems, the portable communications systems, and many others combined with satellite links to carry out the disaster management tasks is considered [3].

Nevertheless, the work presented in this chapter addresses the design and implementation of an emergency communications network for disaster management. A network designed is based on a topology developed through the analysis and formulation of operational and technical strategies that allow combine the capacities and resources available in the communications satellites and remote sensing satellites inside a topology which facilitates the implementation of diverse communications technology solutions and different schemes or medias for images exchange between the entities or organizations involved in the disasters management tasks, during each stage that comprise the disaster management in case of disaster events that affect the public and private communications infrastructures.

Equally, the emergency communications network, designed and developed methodically through this chapter, is an operational scheme useful and reliable to carry out the disaster management in different scenarios of hazard, considering the operational resources available through the integration of the communications satellites and remote sensing satellites on orbit and also their infrastructures at ground segment level. Operational schemes that provide the capabilities to put into operation services or technology solutions are as follows: Communications architectures for disaster warning/management, radio and TV broadcasting services by satellite, cellular phone services over satellite, video conference services, very small aperture terminal (VSAT) networks, broadband satellite Internet services, and distinct architectures to images exchange, among other technology resources useful in the disaster management field.

2. Emergency communications networks role in disaster management

Most organizations recognized globally with the active participation in the communications technology area and their applications, including the International Telecommunication Union (ITU), propose that "when a disaster strikes, telecommunications save lives." Therefore, the Information and Communication Technology (ICT) has been recognized as a powerful instrument for the national economic, social, and cultural development, since they have the objective to increase the countries production levels and enhance the quality of life of people in the world [4]. In this regard, numerous studies and field systematic experiences have shown the great importance of preserving the communications services operation and also ensuring, at all times, the operability of their associated infrastructures; as the main challenge is presented throughout the disaster events or in hazard scenarios that must be faced by the entities and the personnel responsible for disaster management, since the communications services are a key resource and indispensable to carry out the disaster management tasks in numerous risk situations.

It is important to highlight the high demand that exists during the disaster events for several types of communications services available, and also for keeping fast access and effective update of the information. In the same way, standardized communications and information processes have increased the reliability of communications traffic, besides easy access to the communications services through a fast and reliable system integration and interoperability, to keep the communications flow in operation in all disaster events stages. These are the primary functions and requirements to be guaranteed by the communications networks with the aim to support continuously the communications services operation during a disaster. In **Figure 1**, some disaster events that can affect the communications services operation are pointed out; the

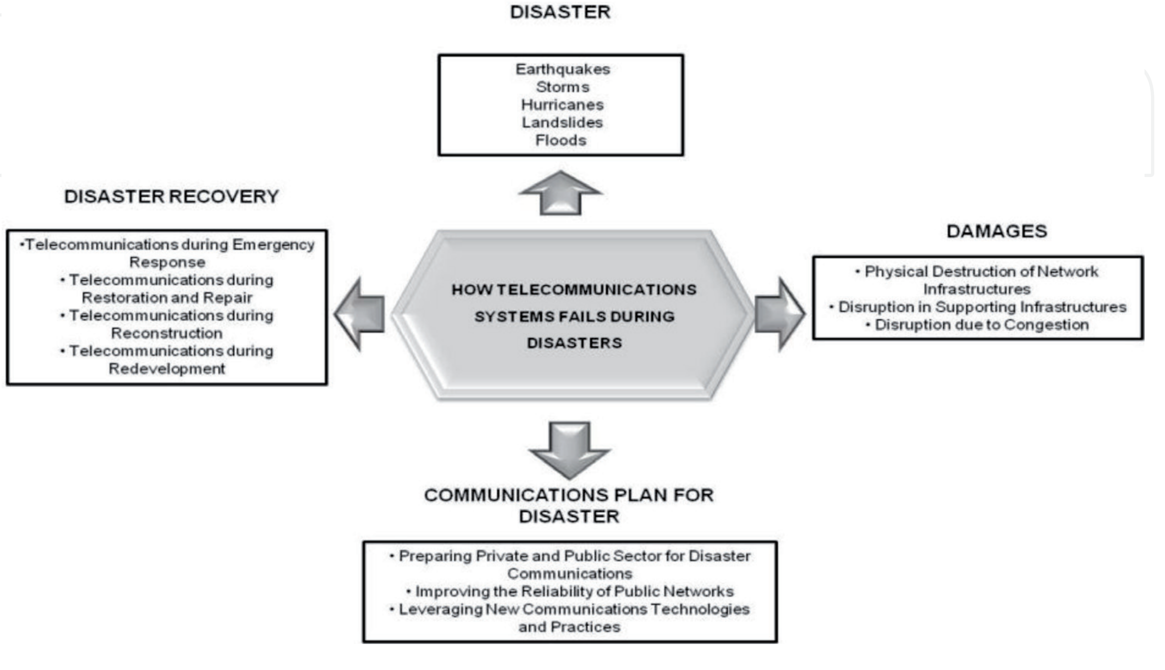

Figure 1.
Communications systems damages and recovery in disasters.

figure details the likely damages on the communications networks infrastructures caused by disasters, the potential communications planning required to guarantee the communications services operation, and the actions that must be taken to recover the communications services in the event of a disaster.

Since the communications terrestrial infrastructures may be damaged partially or totally in disaster events, the communications satellite systems' exploitation in disasters has been increased in the last years, because this technology is fast and reliable to restore the terrestrial communication infrastructures affected by disasters. This is especially due to the flexibility that offers the communications satellite systems hardware to be installed easily in disaster zones, facilitating the fast communications services recovery.

In fact, the importance of the emergency communications networks in disaster events has been proved in many countries; for instance, the Dominican Republic, Central America, is ranked as one of the 10 countries most affected by climate risks worldwide, because it is exposed to diverse recurrent natural phenomena such as hurricanes, tropical storms, floods, earthquakes, landslides and forest fires according to the Global Climate Risk Index of the last years. Large recurrence of disaster events have originated in the Dominican Republic, and the creation of a national plan for emergency communications in disasters is not only based on the use and management of the communications infrastructure existing in the country but also in the implementation of alternative communications infrastructures and technologies to mitigate the impact of the disaster in this region. Emergency communications network combines the use of the communications satellites with the exploitation of different data set coming from the remote sensing satellites, meteorological satellites, telemetry systems, and specialized equipment with the objective to manage the real-time information exchange in disaster as well as provides a technological platform useful for early warning, mitigation, and forecasting disasters events. Therefore, this emergency communications network in the practice has contributed to the coordination of relief operations carried out by national entities and the international community in the Dominican Republic, becoming an effective resource in the management of the disasters occurred in this country.

Identically, another practical experience shows the significance of the emergency communications networks in disasters management; it was noticed in the Sichuan Earthquake occurred in the People Republic of China on May 12, 2008, at 14:28 Hrs, with 8.0 magnitude on the Richter scale, causing the death of numerous people and damages in many critical infrastructures of this province. In particular, due to this earthquake, the telecommunications systems were seriously affected, losing half of the wireless communications in Sichuan province and telecommunications services in Wenchuan and in four nearby counties. Nonetheless, to evaluate the infrastructure and system damages caused by this earthquake, the Chinese government used the remote sensing data (multisensor data) captured from 13 remote sensing satellites through the activation of the International Charter for "Space and Major Disasters"; equally utilized remote sensing data from Chinese institutions were linked to this field and images were downloaded from the Chinese remote sensing satellites.

In the same way, to mitigate the damages caused by the earthquake on the telecommunications infrastructures and services, the International Telecommunication Union (ITU) deployed 100 satellite terminals to help restore vital communications links in the regions affected by the earthquake. Additionally, the Chinese government activated the use of the national communications satellites network to recover the communications services in all affected areas, through the satellite communications services implementation to recover the terrestrial communications services affected in the earthquake. In this sense, not counting China for the earthquake date with an emergency communications network structured formally, both technologies, remote sensing satellites and communications satellites, were used simultaneously to manage the Sichuan earthquake consequences or impacts.

General speaking, in the Sichuan earthquake, the remote sensing satellites helped to analyze diverse damages, including the damages to communications systems. Moreover, they facilitated the formulation of measures to mitigate potential hazard situations, and provided the images with diverse resolutions required. In this same context, the communications satellites were employed to recover the communications services and also to support the alternatives technologies solutions implementation for different data types exchange between the entities in charges to management of the Sichuan earthquake. All the applications and tasks described above, covered by the remote sensing satellites and communications satellites combination in the Sichuan earthquake, are the most practical and compelling evidence to establish the design and operation philosophy of the emergency communications network developed in this chapter; and also they make clear the communications networks importance in disaster management.

3. Emergency communications network design strategy

The design and implementation of the emergency communications network for disaster management integrated by communications satellites and remote sensing satellites and also their ground stations can be divided systematically into six (06) main tasks: In first place, an operational procedure is formulated to maneuver the remote sensing satellites in orbit for optimal images capture in disaster events, considering the spatial and spectral resolution; then a model to images management and processing at ground segment level in emergency is designed, following which the technical characterization of the communications satellites transponders and radio frequency spectrum is carried out, with the aim to design the communications services necessaries for disasters management labors; subsequently, diverse communications applications and technology solutions are formulated, essentials for images and data exchange in disaster events, and the communications satellites transponders technical specifications to carry out the planning and design of the communications links budgets for priority services in emergency are analyzed afterward; lastly, the design of the topology and infrastructure required to integrate the communications satellites and remote sensing satellites to operate in an emergency communications network for disaster management, functional to be activated in events that affect the communications services facilities, is developed.

Nevertheless, to exemplify the emergency communications network design and describe the strategies proposed to maneuver the remote sensing satellites and communications satellites in emergency scenarios, two remote sensing satellites (Remote Sensing Satellite-1 and Remote Sensing Satellite-2) and one communications satellite (Satnet-3) were selected to integrate the network. More satellite platforms could also be integrated into the network, according to the availability thereof in disaster events. **Figure 2** describes the six tasks defined to design the emergency communications network for disaster management proposed in this chapter.

3.1 Operational procedure to maneuver the remote sensing satellites spatial resolution in disaster events

The remote sensing satellites spatial resolution refers in specific to the capacity that has the sensor installed on the satellite platform to distinguish or characterize the resolving power captured, with the aim to identify and also categorize the characteristics of two or more objects observed on the area scanned. This resolving capacity is related to the instantaneous field of view (IFOV) size of the sensor and intrinsically associated with the sensor geometrical characteristics, the sensor capacity to

Figure 2.
Emergency communications network design strategy.

discriminate the targets tracked, the sensor capacity to calculate the periodicity of distinct targets tracked, and also to the sensor ability to determine the small targets spectral properties to obtain their spectral signatures. It is important to point out that the remote sensing spatial resolution has significant use in disaster events; its adequate application allows the sensor capturing images with details or specific characteristics required of the area tracked, affected by one or more disasters.

Especially, different spatial resolutions are necessaries that depend on the disaster occurred to ensure the images acquisition accuracy of diverse objects or of the earth surface characteristics through the sensor. In disaster management or emergency response, the spatial resolution is used principally to distinguish the diverse damages on the infrastructures affected by disasters, to establish the adequate measures for fast recovery of damages, to determine the respective scale for images analysis, and to characterize or define the location and areal precision on a surface given. In this way, to scan small areas and capture the more precise features thereof, it is necessary to use high resolution, but for wide areas, the smallest resolutions are frequently enough to recognize the features desired. On the other hand, the remote sensing satellite has a spatial coverage, an operational characteristic that defines the remote sensing satellite's geographical coverage in an interval of time; aspect that must be analyzed altogether with the sensors spatial resolution, since the different satellite land coverage variations, produced by the sensor scanning angles changes, will influence the sensor spatial resolution performance.

Figure 3 illustrates the remote sensing satellite terrain coverage and its field of view (FOV) angle. In this respect, at the first place, the sensor field of view (FOV) angle is represented on the figure; this angle corresponds to the whole area viewed by the sensor at a specific period of time and in particular is referred to the sensor radiometric resolution ability to capture the energy from the surface scanned. Equally, the same figure shows the sensor instantaneous field of view (IFOV), which represents the smallest solid angle subtended by the sensor opening from a specific height in orbit at one interval of time during a scanning period. However, the sensor observing area size can be obtained from IFOV angle multiplied by the distance, that is, from ground to the sensor in orbit, and the result represents the ground resolution cell viewed by the sensor, specifying the maximum sensor spatial resolution on the surface scanned. Finally, the figure describes the satellite trace direction and the sensor scan trajectory on the terrain. Both the sensor spatial resolution and the pixels size have a relation between them since the pixels size are modified by the sensor sweep on the earth surface due to the curvature thereof, which is more prominent at the border of the earth's surface scanned.

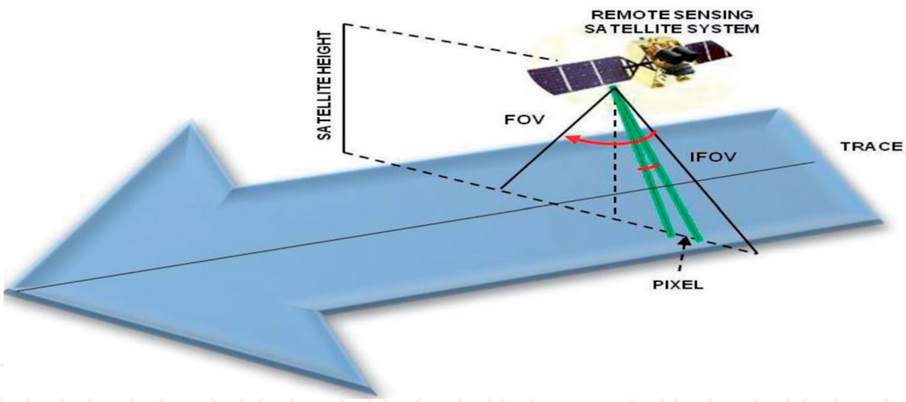

Figure 3.
Remote sensing satellite terrain coverage and field of view (FOV).

Satellite	Camera	Resolution	FOV (nadir)
Remote Sensing Satellite-1	PMC	PAN: ≤2.5 m MS: ≤10 m	5.15°
Remote Sensing Satellite-1	WMC	≤16 m	16.44°
Remote Sensing Satellite-2	HRC	Pam ≤1 m MS ≤ 4 m	2.93°
Remote Sensing Satellite-2	IRC	30 m (SWIR) 60 m (LWIR)	2.8°

Table 1.
Remote Sensing Satellite-1 and Remote Sensing Satellite-2 cameras resolution and field of view (FOV) angles.

Regarding the previous considerations, about the remote sensing satellites spatial resolution and its application in disaster management, the remote sensing satellites sensors have operational technical specifications that influence the images capturing performance. These specifications are considered during the emergency communications network design and proposed to be managed with the objective to optimize the sensors spatial resolution performance in disasters events. Such technical specifications are specified following: remote sensing sensor terrain swath coverage estimation, potential remote sensing sensor terrain swath coverage in nadir and at off-nadir angle, remote sensing sensor pixels size estimation at nadir and off-nadir angle, and remote sensing sensor dwelling time for an along track scan; strategies are useful to achieve the best remote sensing satellite platforms performance inside the emergency communications network during the disaster management.

In **Table 1**, as examples are shown, the cameras resolutions and their fields of view (FOV), for the two (02) remote sensing satellites, are proposed to be part of the emergency communications network in disasters. In this regard, the Remote Sensing Satellite-1 has PAN and multispectral cameras (PMC) and also wide swath multispectral cameras (WMC) and the Remote Sensing Satellite-2 has high-resolution cameras (HRC) and infrared cameras (IRC).

3.1.1 Remote sensing sensors terrain swath coverage estimation in disaster events (RSTSC$_e$)

The remote sensing satellites on orbit operation have the capacity to change the view pointing angle of their sensors through the roll maneuvers; operational strategy implemented with the aim to allow the sensors to observe in different positions in direction to the vertical trajectory view angle on the terrain; from the nadir angle, until some degrees above this angle. In consequence, by mean of this operational characteristic, the remote sensing satellites have the ability to change their coverage on the terrain, which allows the sensors to cover a greater terrain extension in each satellite pass, through the different pointing angles. Principally, the pointing angles variation of the remote sensors view on orbit from nadir, achieved through the roll maneuver, is useful in disasters management to scan from two different view angles identical areas involved in disaster events, with the aim to obtain images in different perspectives of the areas affected by disasters. Also it is useful to images analysis in a three dimensional model for the best understanding of damages in disasters; in the same way, the sensors pointing angle change is effective to accomplish the mapping and interpretation of the zones affected by disasters with the purpose to create simulations model for damages to facilitate the emergency response task and recovery.

For this reason, a proposal based on a methodology following a reliable operational procedure to manage the remote sensing sensors terrain swath coverage estimation ($RSTSC_e$) in emergency or hazard events is formulated. Accordingly, first, a procedure to determine the remote sensing sensors terrain swath coverage estimation ($RSTSC_e$), minimum in nadir pointing angle and maximum off-nadir pointing angle is established, considering the remote sensing sensors field of view (FOV) specifications for this estimation as a reference. Subsequently, the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle ($\mathrm{RSTSC_p}$) using the spherical trigonometry mathematical method considering the law of sines for this aim is determined. In this sense, Eq. (1) specified below is proposed to calculate the remote sensing sensors terrain swath coverage estimated ($\mathrm{LSC_s}$) minimum in nadir pointing angle and maximum off-nadir pointing angle in emergency response.

$$RSTSC_e = 2 \cdot S_r \cdot (tan\ FOV_s) \quad (1)$$

where $RSTSC_e$ is the remote sensing sensors terrain swath coverage estimation; S_r is the satellite ranging or altitude; tan tangent; and FOV_s is the sensor field of view angle.

For instance, to demonstrate the application of Eq. (1), the computation to estimate the terrain swath coverage ($RSTSC_e$) minimum in nadir pointing angle, and the terrain swath coverage ($RSTSC_e$) at maximum off-nadir pointing angle for the PAN and multispectral camera (PMC) of the Remote Sensing Satellite-1, as well as to the high-resolution camera (HRC) of the Remote Sensing Satellite-2, is executed; in this case, for both remote sensing satellites, an average ranging or altitude on-orbit operation around 640 km is considered. In **Table 2**, the results obtained once the corresponding calculations have been done are specified.

It is notable, through the results obtained and specified in **Table 2** using Eq. (1), that the Remote Sensing Satellite-1 and Remote Sensing Satellite-2, using their

Satellite platform	Satellite camera	Camera FOV in nadir angle	Camera FOV max-off nadir angle	RSTSCe in nadir angle	RSTSCe max-off nadir angle
Remote Sensing Satellite-1	PMC	5.15°	31°	115.328 km	768 km
Remote Sensing Satellite-2	HRC	2.93°	29°	65.51 km	709 km

Table 2.
Remote Sensing Satellite-1 and Remote Sensing Satellite-2 cameras terrain swath coverage estimation.

operational abilities to re-pointing the cameras in direction to the vertical trajectory of the view angle on the terrain from the nadir, can reach a wide swath coverage on the terrain. Operational capacity is useful to plan and develop diverse remote sensing satellite missions in disasters, with the aim to cover one or more specific terrain extensions affected during disasters in less time through different cameras view angles' characteristic that allows providing quick response in disasters events.

3.1.2 Remote sensing sensors potential terrain swath coverage in disaster events ($RSTSC_p$)

In emergency scenarios, the remote sensing sensors potential terrain swath coverage estimation, in nadir angle and off-nadir angle ($RSTSC_p$), as an operational procedure implemented on the satellite platform through the roll maneuvers, is an effective and reliable operational strategy to forecast in diverse disaster events, the expected terrain swath width to be scanned with the remote sensing sensors in the future satellite passes, using different view angles of the sensors over the terrain or areas that will be covered in a planned mission. In consequence, it is an important strategy in the disaster management, because it makes possible the prediction and planning in advance the terrain extensions affected by the occurrence of disasters that possibly will be explored by the satellite sensors. Fundamentally, three mathematical approaches can be used to calculate the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle ($RSTSC_p$). These mathematical formulations or methods are the next: oblique spherical triangle method, the spherical method using intersecting lines, and the planar surface projection method [5]. In specific, the oblique spherical triangle method based on the earth model illustrated in **Figure 4** is the method selected to predict the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle ($RSTSC_p$), because it is the most reliable and accurate method to perform the aforementioned operational calculation.

The oblique spherical triangle method previously mentioned and selected to predict the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle ($RSTSC_p$) is taken into account; It is specified that this methodology is based on a mathematical approach or solution by which is projected a straight line from the remote sensing satellite on-orbit operation until a perpendicular plane

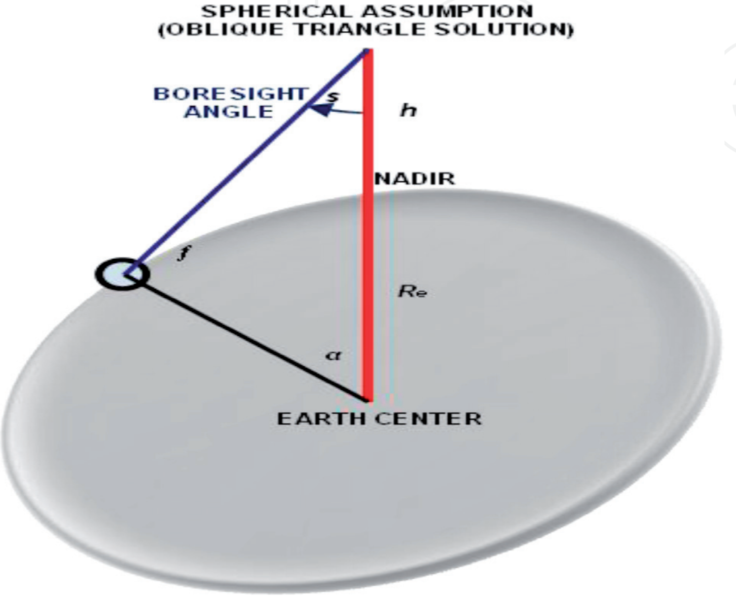

Figure 4.
Oblique spherical triangle method to predict the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle ($RSTSC_p$).

with reference to the earth's surface, creating in this intersection point between the projected line and the earth surface an angle denominated non-included angle, designated with the letter (f), as it is shown in **Figure 4**; this angle corresponds to the remote sensing sensors' instantaneous field of view (IFOV) and represents the smallest solid angle subtended by the sensor opening from a specific height in orbit at one interval of time given on the earth surface. Generally speaking, the instantaneous field of view (IFOV) is the area on the ground viewed by the sensor at a given instant of time, an area that specifies the dimension on the ground of each pixel over the surface scanned. Additionally, in reference to an oblique triangle, three more angles characterized like included angles, described also in **Figure 4**, are created by imaginary lines represented for the remote sensing satellite ranging or height (h) in orbit, the earth radius (r_e), and the boresight angle or sensor FOV (s), forming altogether all these angles a triangle [6]. As result, considering the oblique spherical triangle method and the law of sines implementation to solve the triangle formed in **Figure 4**, it is feasible to calculate the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle (RSTSC_p). Therefore, the mathematical formulation using the law of sines to estimate the $RSTSC_p$ is next discussed.

Since the three angles (α, ø, s) described in **Figure 4** must sum 180°, so$f$ = 180 – α –s, solving (α) through the law of the sines, we have Eq. (2):

$$\alpha = sin^{-1} \cdot \left(\frac{\sin{(s)} \cdot (r_e + h)}{r_e} \right) - s \tag{2}$$

where α is the non-included angle (IFOV); s is the boresight angle (FOV); r_e is the radius of the earth; and h is the satellite height.

However, to compute the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle (RSTSC_p) Eq. (3) is used.

$$RSTSC_p = \left(\frac{\alpha}{2\pi} \right) \cdot r_e \tag{3}$$

where $RSTSC_p$ is the remote sensing sensor potential terrain swath coverage; α is the non-include angle (IFOV); and r_e is the radius of the earth.

For instance, with the purpose of demonstrating the previous mathematical formulation for the high-resolution camera (HRC), of the Remote Sensing Satellite-2, a field of view angle after roll maneuver on orbit operation is considered: FOV (s) = 17° (12 degrees under the maximum FOV reached by this camera through the roll maneuver strategy). In the same way, to this satellite, an average ranging or height on orbit = 645 km and for the earth's radius, a value = 6378.137 km, is précised. Nevertheless, taking as a reference the triangle illustrated in **Figure 4**, which geometrically describes the oblique spherical triangle method to predict the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle (RSTSC_p), from Eq. (2), α is solved and obtained for the High-Resolution Camera of the Remote Sensing Satellite-2, an IFOV = 1.78°, and then with Eq. (3), it is computed for this High-Resolution Camera, a potential terrain swath coverage off-nadir angle (RSTSC_p) = 1807.81 km. Through this result, it is noticed that the high-resolution camera (HRC) of the Remote Sensing Satellite-2 in successive passes in different adjacent orbits due to the roll maneuver strategy implementation has the capacity to cover an extension equal to 1807.81 km of land over a defined territory.

Therefore, given that the maximum swath coverage of the high-resolution camera (HRC) off-nadir to 29° of inclination (maximum off-nadir angle) is = 709 km (information specified in **Table 2**) and the potential terrain swath coverage off-nadir angle (RSTSC_p) = 1807.81 km calculated from Eq. (3), it is estimated a period of time: 1,807,810/709,000 = 2.5 days, through successive passes of the Remote Sensing

Figure 5.
Remote Sensing Satellite-2 high-resolution camera (HRC) potential view capacity with field of view at +29°.

Satellite-2 in different adjacent orbits with the high resolution camera (HRC) using a FOV (s) angle of: 17°, to cover the terrain extension obtained from the calculation of the potential terrain swath coverage off-nadir angle ($RSTSC_p$). In **Figure 5**, the Remote Sensing Satellite-2 high-resolution camera (HRC), potential view capacity with a field of view maximum at +29° achieved through the roll maneuver to cover a territory of 916,445 km^2 in consecutive passes is shown.

In resume, the prediction of the remote sensing sensor potential terrain swath coverage in nadir angle and off-nadir angle ($RSTSC_p$) is a strategy or operational procedure useful for planning the images collection opportunities on the diverse areas that are required to be scanned immediately after disaster events or on those zones that are involved in imminent hazard situations. It is possible to obtain results that are more accurate about the potential sensor terrain swath coverage in nadir angle and off-nadir angle ($RSTSC_p$) in real operation by the use of the satellite ranging data, measured and obtained periodically from its ephemerides predictions. Information provided through the operational software packages is installed in the remote sensing satellites ground control stations, since the satellite fly height on orbit influences the sensors' field of view (FOV) performance, which also affects the sensor swath coverage on the surface explored and the images resolution captured by the sensor. At the same time, besides to the strategies or operational procedures implemented for management the remote sensing satellites roll maneuvers on orbit, with the aim to change the cameras field of view (FOV) angles to enhance the cameras' coverage and also their revisit capability on the distinct areas affected by disaster events, there also exist other important technical aspects mentioned before in this chapter related to the cameras spatial resolution, and that must be considered to improve the remote sensing satellites operational performance inside the emergency communications network. Technical cameras or sensors parameters such as remote sensing sensor pixels size at nadir and off-nadir angle and the remote sensing sensor dwelling time for an along track scan are considered; and operational parameters taken into account are to be estimated as part of the strategies proposed to accomplish a better coverage and images capturing on the areas required in the course of emergency response in disasters.

3.1.3 Remote sensing sensors pixels size estimation at nadir and off-nadir angles to disaster management

The images captured for the remote sensing sensor have a particular structure based on a format integrated by a matrix of organized rows and columns or cells (pixels), denominated altogether, all these rows and columns, as raster imagery. In this sense, one pixel constitutes the smallest physical point sampled of a raster image, and the pixels size in the raster image represents the smallest point size on the surface captured by the remote sensing sensor in function to the sensor instantaneous field of view (IFOV). Especially, the sensor pixel resolution is affected by the change in sensor scan angles due to the roll maneuver strategy between others operational aspects, which originates variations in the pixels dimensions, becoming increasingly distorted away from the nadir as view zenith angles increase. For this reason, the remote sensing sensor resolution looks distorted along the track and also across track direction at the extreme edges on the surface scanned [7].

However, the images pixels size captured by the remote sensing sensor is an important sensor performance characteristic necessary to be estimated, when the sensor scan angle is changed through the satellite roll maneuvers, with the objective to increase their potential swath coverage off-nadir angle to cover a specific extension of terrain in a region previously planned; since the pixel size estimation at nadir and off-nadir angles in disaster events is a useful method to define how much the sensor resolution can vary through the pixels spatial size variation along track scan and across track scan. It will also help to define the relation between the sensor resolution variation with reference to the different scan angles or FOV, as well as the influence of different FOV angle on the resolution of the images captured over the terrain in the diverse remote sensing satellites roll maneuvers required on orbit in case of emergency. The remote sensing pixels size geometrical characterization in nadir and off-nadir angles is described in **Figure 6**, where it is explained through a graphical representation the sensor FOV angles changes and their influence on the pixels size variation on the ground resolution cells.

In particular, the Remote Sensing Satellite-1 and Remote Sensing Satellite-2, satellites platforms considered to integrate the emergency communications network proposed in this chapter, are designed with cameras whose resolution is adequate to observe the geometry of diverse objectives and the characteristics related to the phenomena associated with the disasters events. In this respect, the sensors resolution belonging to these satellites platforms is represented by the ground sampling distance (GSD) and for each pixel with a defined spatial size in function to the sensor pointing angle or field of view (FOV) in nadir or off-nadir angle; next, for the aforementioned satellites platforms, their camera resolution characteristics are specified with the respective spatial pixels size to each one: the Remote Sensing Satellite-1 payload is integrated for two (02) PAN and multispectral cameras (PMC) designed with PAN and MS detectors to operate using both functions at the same time in the images capturing process; the panchromatic (PAN) sensor has a ground

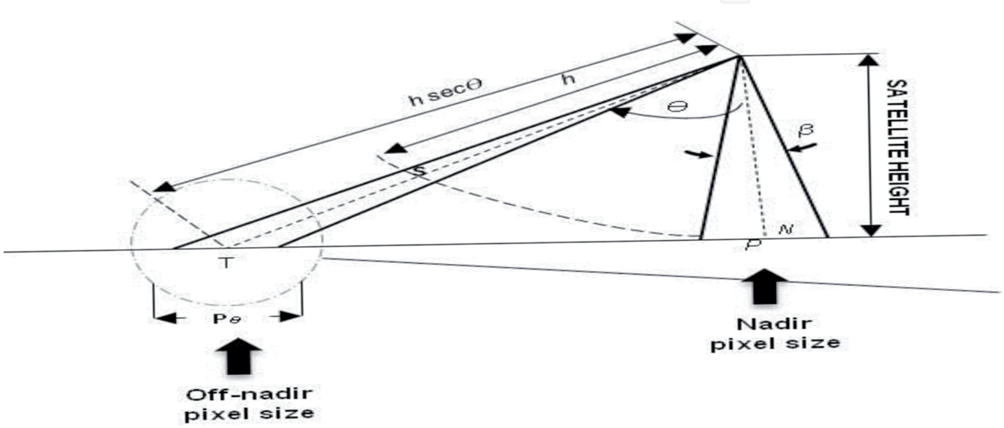

Figure 6.
Pixels size geometrical characterization in nadir and off-nadir angles.

sampling distance (GSD) in nadir ≤ 2.5 m and a pixel spatial size ≤ 6.25 m^2; in multispectral (MS) function, the sensor has a ground sampling distance (GSD) in nadir ≤10 m with a pixel spatial size ≤ 100 m^2; also, this satellite platform is designed with two (02) wide swath multispectral cameras (WMC) which operate in four (04) spectral bands with a ground sampling distance (GSD) in nadir ≤ 16 m and pixel spatial size ≤256m^2.

On the other hand, the Remote Sensing Satellite-2 has one (01) high-resolution camera (HRC) with optical sensors to produce panchromatic (PAN) and multispectral (MS) data simultaneously. In panchromatic (PAN) operation, this sensor has a ground sampling distance (GSD) in nadir ≤ 1 m with pixel spatial size ≤1m^2, and in multispectral (MS) operation, the sensor has a ground sampling distance (GSD) in nadir ≤ 4 m with a pixel spatial size ≤16 m^2. Likewise, in this satellite platform, the shortwave infrared (SWIR) sensor in nadir has a ground sampling distance (GSD) ≤ 30 m and pixel spatial size ≤900 m^2 and the long wave infra-red (LWIR) sensor has a ground sampling distance (GSD) ≤ 60 m in nadir with a pixel spatial size ≤3600 m^2. Overall, the camera's resolution performance characteristic of the satellites platforms that integrate the emergency communications network is a critical aspect that must be managed in an accurate way, with the aim to optimize the resolution of the images captured depending on the type of disaster events. Each step of the mathematical formulation to estimate the pixels size in nadir and off-nadir angle is introduced which is as follows:

Step 1: first, Eq. (4) is specified and next, the sensor field of view (FOV) swath width is estimated.

$$\boldsymbol{SFOV_{sw}} = 2 \cdot \boldsymbol{h} \cdot \mathbf{tan}\left(\frac{\beta}{2}\right) \tag{4}$$

where $SFOV_{sw}$ = sensor field of view (FOV) swath width; h = satellite height; tan = tangent; and β = sensor field of view (FOV).

Step 2: Using Eq. (5), the sensor effective resolution is computed.

$$\boldsymbol{SE_r} = \frac{\boldsymbol{SFOV_{sw}}}{\boldsymbol{SP_n}} \tag{5}$$

where SE_r = sensor effective resolution; $SFOV_{sw}$ = sensor field of view (FOV) swath width; and SP_n = sensor pixels number.

Step 3: Finally, solving Eq. (6), the pixel size captured by the sensor is estimated.

$$\boldsymbol{SP_{se}} = (\boldsymbol{SE_r})^2 \tag{6}$$

where SP_{se} = sensor pixels size estimation; and SE_r = sensor effective resolution.

To explain the application of the previously mathematical approach formulated to estimate the pixels size in nadir and off-nadir angle in the remote sensing sensors, as an example, wide swath multispectral camera (WMC) as a remote sensor is taken which is installed in the payload of the Remote Sensing Satellite-1. This WMC is a medium-resolution push broom sensor with time delay integration (TDI) and capability to observe, in the visible range, a field of view (FOV) = 16.44° in nadir and maximum field of view (FOV) = 31° off-nadir achieved through the roll maneuver in orbit operation. Also, as additional information to develop this example is regarded for the Remote Sensing Satellite-1 on-orbit operation an average altitude or height = 650 km. Therefore, in first place, from Eq. (4), the computation of the WMC field of view (FOV) swath width in nadir is carried out, whose value is ≤187.796 km; afterward using Eq. (5) and given that this sensor has 12,000 pixels with 6.5 μm of size, the sensor effective resolution, (SE_r) =

≤187,796/12,000 = ≤15.64 m in nadir, and with Eq. (6), the pixels size in nadir to this sensor, (SP_{se}) = ≤245 m^2, are estimated. In the same way, by Eq. (4), at the WMC maximum off-nadir pointing angle (31°), a field of view (FOV) swath width ≤ 360.521 km is also calculated. As already known, this sensor has 12,000 pixels with 6.5 μm of size, and considering these specifications with Eq. (5), the sensor effective resolution, CE_r = 354,975/12,000 = 29.58m SE_r = ≤360,521/12,000 = ≤30 m with an off-nadir pointing angle in 31° of FOV is calculated; finally, through Eq. (6), a pixels size at the same pointing angle off-nadir for this sensor is computed, (SP_{se}) = ≤902 m^2. In summary, through the analysis of the above results, it is easy to deduct that the ground area represented by each pixel in nadir pointing angle has a better resolution than the pixels at off-nadir pointing angles. Such a phenomenon is due to the spatial resolution, which varies from the image center to the swath edge, and hence, also the pixels spatial size. Technical aspects are considered in those maneuver situations in which the changes of pointing angles of the sensors are necessaries to management of diverse disaster events in a shortest possible time.

3.1.4 Remote sensing sensors dwell time estimation in disaster events

At the present time, there are principally two (02) types of passive sensor technologies for optical cameras used frequently in the remote sensing satellites applications to images scanning and collection over the earth surface; such technologies are the whisk broom scanning sensors and the push broom scanning sensors. In this regard, the whisk broom scanning sensors, also known as spotlight in the across-track scanners, is a technology that uses a mirror to scan across the satellite's path over the ground track, reflecting the light captured into a single detector which collects the pixels of the images one at a time through the movement of the mirror back and forth [8]. In this type of sensor, the mechanism used to move the mirror makes this technology vulnerable to rapid degradation in function of the working hours to which the mechanism is subjected. It is also an expensive technology since it demands a special design of the movement mechanism parts. **Figure 7** describes the whisk broom sensors scanning working principle, where the remote sensing satellite camera sweeps in a direction perpendicular to the satellite flight path.

Likewise, the whisk broom sensors have the following operation characteristics: each line over the earth surface is scanned from one side of the sensor to the other through a rotating mirror, while the satellite platform moves forward over the earth's surface. Different successive scans of the mirror build up a two-dimensional image of the earth's surface, and by means of a bank of internal detectors in the

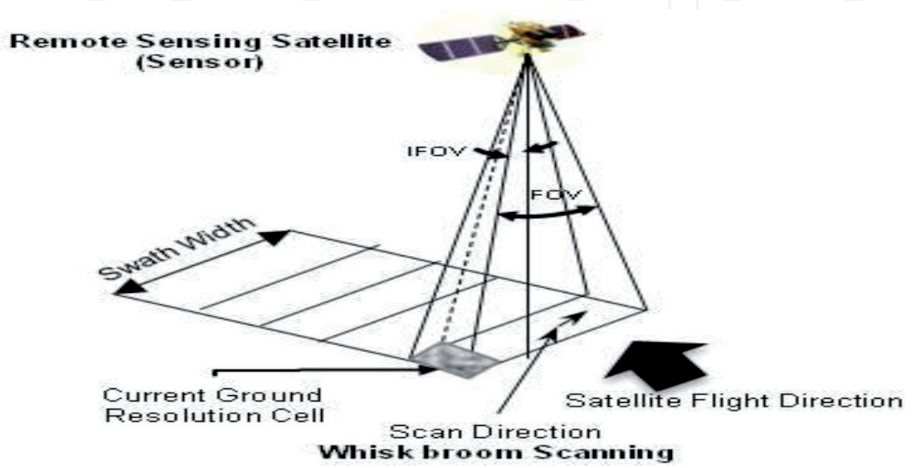

Figure 7.
Whisk broom sensors technology scanning principle.

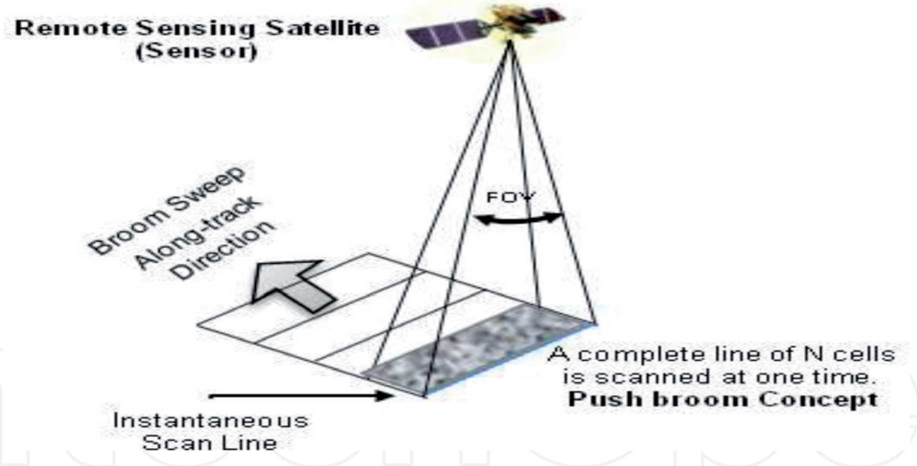

Figure 8.
Push broom sensors technology scanning principle.

cameras, each one sensitive to a specific range of wavelengths is detected and the energy for each spectral band is measured; after the energy is captured by each detector like an electrical signal, it is transformed into a digital data and stored on the remote sensing satellite. In the whisk broom scanning, the IFOV and the satellite height in orbit define the sensor spatial resolution, whereas the images swaths are in function to the mirror sweep that is represented by the sensor angular field of view; angle measured in degrees and used to record the pixels of the scan lines of the images. All the whisk broom sensor data are collected on the land surface within an arc below the satellite system usually of around 90–120°.

On the other hand, the push broom scanning is also referred to as along-track scanning; the sensors used here is a linear array of detectors, arranged perpendicular to the flight direction of the satellite to cover all the pixels in the along-track dimension at the same time. In consequence, as the spacecraft flies forward, the image is collected one line at a time, with all pixels in a line being measured simultaneously [9, 10]. It is important to highlight that the push broom sensors have a drawback in its sensitivity which is very varying; if they are not perfectly calibrated, this can cause stripes in the data acquired. **Figure 8** shows the push broom sensors scanning working principle.

The push broom sensors have the next working principle: these optical sensors are designed with a linear matrix of detectors situated at the focal plane of the image. In specific, this matrix is formed by a lens system, which is pushed along track in direction to the satellite flight track projection over the scanning surface; the detectors matrix movement is similar to the displacement of the sows of a broom being pushed along a floor; during this displacement, each detector captures or measures the energy of every land resolution cells on an individual basis; after the energy has been detected, it is sampled electronically and digitally stored on the satellite platform. The push broom sensor's spatial resolution is determined by the size of its instantaneous field of view (IFOV) angle. Also, the push broom sensors are integrated by an independent linear matrix in charge to measure each spectral band or channel. In this sense, the linear matrixes normally consist of numerous charge-coupled devices (CCDs) positioned end to end.

A push broom sensor receives a stronger signal than a whisk broom scanner since it looks at each pixel area for longer; this provides a much longer detector dwell time than the across-track scanner on each surface pixel, thus allowing much higher sensitivity and a narrower bandwidth of observation, operation characteristic that improves the radiometric resolution. General speaking, the sensor dwell time is the amount of time the scanner has to collect photons from a ground resolution cell. However, the dwell time depends on some factors, such as satellite speed, the width of the scan line, time per scan line, and time per pixel. Therefore, it is a sensor performance parameter that requires to be estimated, when the remote sensing satellite sensors view angle is changed through the satellite roll maneuvers, to scan areas affected by disasters from different scan angles, due to its impact on the sensors radiometric resolution.

Since the remote sensing satellites with push broom sensors are the proposed platforms to integrate the emergency communications network planned, the mathematical approach applicable to calculate the dwell time, considering the push broom sensors through its along-track scanning, is specified in Eq. (7):

$$\boldsymbol{DT_{ats}} = \left(\boldsymbol{GR_{ce}} | \boldsymbol{Sat_v}\right) \tag{7}$$

where DT_{ats} = dwell time for along-track scan; GR_{ce} = ground resolution cell; and Sat_v = satellite orbital velocity.

From the above mathematical approach, considering the Remote Sensing Satellite-2 High-Resolution Camera (HRC) specifications in Multispectral (MS) band, with a ground resolution cell of: ≤4 m •≤4 m, information specified in section 3.1.3, a Remote Sensing Satellite-2 mean orbit velocity of 7.8 km/s; using Eq. (7), the dwell time computation for Satellite-2 High Resolution Camera (HRC) along-track scanning is carried out, $DT_{ats} = \left(\le 4\text{m} \cdot cell \mid 7.8\frac{\text{km}}{\text{s}}\right) = \le 0.51\text{ms} \cdot \text{cell}$; average time projected to be used by this High Resolution Camera (HRC), to collect photons from a ground resolution cell over the earth surface; technical specification must be taken into consideration to maneuver the remote sensing satellite in orbit with the aim to change the cameras scanning angles, in order to know the cameras photons acquisition time on each ground resolution cell for each satellite pass over an specific area affected by disasters using different cameras scanning angles; sensor operating characteristic that influences its radiometric resolution. To optimize the cameras dwell time calculation for the along-track scanning, it is recommended to use the satellite ephemerides data to obtain its speed projection on orbit, since the satellite speed is not constant and varies according to the satellite position on the orbit, phenomena that impact the cameras dwell time estimation.

3.2 Operational procedure to manage the remote sensing sensors spectral resolution in disaster events

The electromagnetic spectrum is integrated for a range of different wavelengths or spectral energy divided into regions defined as bands, and each object or target on the ground responds to a spectral reflectance inside this spectrum or has a spectral signature. In this context, the remote sensing sensors' spectral resolution describes the ability presented for these sensors to discriminate or capture wavelengths' intervals of the electromagnetic spectrum. While finer is the spectral resolution, narrower will be the wavelength range for a particular channel or band resolved by the sensor.

For instance, there are panchromatic sensors designed particularly, the with a single channel detector and capacity to capturing or resolving spectral data in a broad wavelength range of the visible electromagnetic spectrum. Therefore, the black and white bands of the spectral data are only solved by these sensors and the physical properties are measured in the apparent brightness of the targets. In specific, the spectral information related to the colors of the objectives is not captured in the panchromatic band. Furthermore, there are multispectral sensors designed with multichannel detectors to capture spectral data in different narrow wavelength bands inside a spectral band defined, resolving multilayer images that contain both the brightness and spectral colors information of the targets captured. On the other hand, the hyperspectral sensors can collect 50 or more narrow bands. Particularly, the multispectral bandwidths are quite large, generally from 50 to 400 μm, frequently covering an entire color; for example, a whole red portion, while the hyperspectral sensors measure the radiance or reflectance of an object in many narrow bands, often from 5 to 10 μm.

From this point of view, there are remote sensing sensors with different spectral resolutions; for instance, panchromatic band for medium spectral resolution with a center wavelength located at 0.675 μm; panchromatic band for high spectral resolution with a center wavelength situated at 0.65 μm; multispectral band with center wavelengths in: B1/blue at 0.485 μm, B2/green at 0.555 μm, B3/red at 0.66 μm, and in B4/NIR at 0.83 μm; and also infrared spectral resolution with wavelengths in short-wave infrared (SWIR), covering the next spectrum: 0.9 ± 0.05 μm ~ 1.1 ± 0.05 μm, 1.18 ± 0.05 μm ~ 1.3 ± 0.05 μm, 1.55 ± 0.05 μm ~ 1.7 ± 0.05 μm, and in long wave infrared (LWIR), with wavelengths in the following range: 10.3 ± 0.1 μm ~ 11.3 ± 0.1 μm and 11.5 ± 0.1 μm ~ 12.5 ± 0.1 μm [11, 12].

Regularly, the remote sensing sensors are designed with a specific purpose focused on the applications of their spectral bands, whose objective is to collect different types of images, taking advantage of the microwave spectrum and its incidence angle on the earth's surface; operation characteristics allow establishing the appropriated exploitation or application for each sensor, since it was before mentioned that each target and ground characteristic presents a particular spectral signature or spectral response to the different wavelengths of the electromagnetic spectrum. Reflectance behavior provides the sensors the adequate spectral information to discriminate the different details of the targets measured. In this regard, due to the importance of the spectral resolution application in disaster events considering the diverse phenomena with specific features that may occur, a methodology inside the emergency communications network to management of the remote sensing sensors spectral resolution capabilities is proposed, in order to optimize and achieve a proper performance for each spectral resolution band of the remote sensing sensors in disaster events.

Methodology based on the operational technical strategies implementation, such as: databases design and management to store the images pixels considering their spectral derivation with the aim to create the spectral signatures thereof (tagging) inside the sensors field of view, technical criterion formulation to management of the wavelengths specifications handled for each sensor in reference to the targets spectral features to be captured and the technical procedure implementation to accomplish the real-time spectral data analysis with the objective to discriminate and evaluate the diverse scenes colors that potentially can be presented in diverse images

Spectral band	Remote sensing sensors potential spectral applications in disaster management
Multispectral (MS)	For monitoring and assessment: deforestation scenarios, water mass courses, fuels leak or oil spill limits, ice block coverage, terrain geological patterns, wildfire threats and spread, droughts, vegetation classes, coastal characteristics evolution, bathymetric trends, sediment-laden waters behavior, landslide, floods, urban damages differentiation and recreation, epidemic diseases behavior, emissions of diverse gases in particular and aerosols components, between others polluting elements.
Infrared (IR)	For monitoring and assessment: volcanoes eruptions and their associated events, moisture content of soil and vegetation, earthquake damages magnitude, surfaces thermal trends, hotspots, lava lakes formation, gas emission and propagation, land desertification and deforestation evolution, coastal erosion development, wildfires progress, damages in fires scenarios by the observation through the smoke, climate behavior and floods scenarios behavior.

Table 3.
Remote sensing sensors potential spectral applications in disaster management.

based on the design of a library with the known spectral signatures of the targets previously studied or analyzed. In **Table 3**, an overview of the applications of remote sensing sensors' potential spectral resolutions in the multispectral (MS) band and infrared (IR) band is provided, taking into consideration diverse disaster scenarios.

3.3 Operational procedure to manage the remote sensing sensors images in disasters events

In each disaster event or hazard situations, the demand levels and uses of the remote sensing sensors images increase exponentially, since a large number of institutions, public or private, are responsible to coordinate all the activities' necessaries for management of different disaster events, requiring a wide variety of images with features and specifications necessaries for assessing in a reliable and expeditious way the damages caused by one or more disaster events, with the aim to identify and categorize the potentials vulnerabilities or hazards that may be present in the disaster relief phase or in other disaster management stages. It is well known that each disaster event has its own characteristics; for such reason during the disaster management, different types of images with details or features in specific of the zones affected by disasters are required in order to evaluate and have a well understanding of the phenomenon produced, and so, this way formulates the more suitable strategies to carry out the disaster management tasks according to the scenarios presented. In essence, the accessibility to different images levels or products from the remote sensing sensors is a significant resource in the various stages of disaster management. Currently, the remote sensing satellites and their ground segments have the capability to provide a variety of images levels or products fundamental to manage disasters events in the phases of preparedness, assessment, and mitigation. However, in **Table 4** regarding the Remote Sensing Satellite-1 and the Remote Sensing Satellite-2 selected to be integrated into the emergency communications network developed in this chapter, the products and the general characteristics of the images captured and processed in the ground segments of these satellites platforms are specified. Essential images products need to be managed by taking into consideration the specifics of operational requirements involved in each disaster events.

Also in all the activities executed along the disaster management, the response time to the different hazard scenarios is the paramount element to optimize the actions that will be adopted during the disaster events management. In this sense, the remote sensing sensors' images products provide the necessary information to give a quick response to an extensive variety of disaster events, and even to their consequences by

Products levels	Images products specifications
Level 0: Data set in series or rows	Synchronized data frame, compatible with computerized data protocols and software packet
Level 1: Products with radiometric correction	Matrix of data radiometrically corrected, without geometric correction
Level 2: Products with systematized geometric correction	Data with radiometric and geometric correction using systematic models, without the use of terrestrial control points (GCP)
Level 3: Products with precise geometric correction	Radiometric and geometric correction using terrestrial control points (GCP)
Level 4: Products corrected through digital elevation terrestrial models	Data with radiometric and geometric correction using terrestrial control points and digital elevation terrestrial models in order to remove the terrain displacement effects, produced by the relief deformations

Table 4.
Remote Sensing Satellite-1 and Remote Sensing Satellite-2 images products specifications.

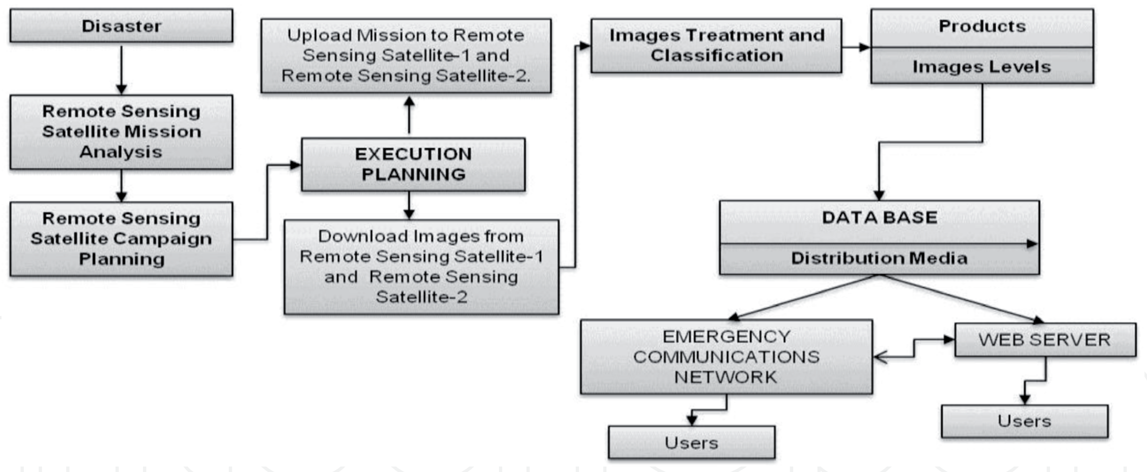

Figure 9.
Remote sensing sensors model to images management and processing at ground segment level in emergency scenarios.

means of the analysis and assessment of the factors tied to the phenomena occurred and recreated in the images captured through the remote sensing sensors using different spatial and spectral resolutions; taking into consideration, every sort of disaster has its own physical characteristics or particularities that require be evaluated through the analysis of images whose properties describe the details related to a particular disaster event or natural phenomena under study. As described in **Table 4**, the Remote Sensing Satellite-1 and Remote Sensing Satellite-2 typical raw data are treatment and processing using the software applications and methods available in the ground station of both platforms to obtain images products by levels. A process is carried out with the aim to reduce the radiometric and geometric errors in the images obtained and also to create images with the necessaries information to evaluate and understand the different disaster events based on their characteristics.

In specific, the radiometric correction in the remote sensing satellite images processing consists in removing from the images captured by the sensors all the errors effects created by the sun incidence angles and then added to the images from different atmospheric factors during their capturing; whereas the images geometric correction is a process that has the objective to remove from the images the geometric distortion errors, through the relation established between the images coordinate system and the geographic coordinate system used as reference. This correction is achieved using the sensor calibration data, the position and attitude measured data of the satellite in orbit, the terrain control points and the information about the atmospheric conditions that may affect the images captured. In consequence, due to the notable value of the remote sensing sensors images products in the disaster management, images with particular characteristics and suitable to analyze diverse type of disasters and even to support in the decision-making during the disasters management, there is the necessity to implement fast and accurate systematic processes for management of the sensor's images products at the ground segment in disaster scenarios. Hence, a systematic model is proposed in **Figure 9** for managing and processing the remote sensing satellites images at the ground segment in emergency response; considering the Remote Sensing Satellite-1 and Remote Sensing Satellite-2 ground segment infrastructures.

3.4 Communications satellites transponders and radio frequencies characterization for emergency services in disaster events

Due to the dizzying evolution of space technology, nowadays there are communications satellites with different payload characteristics and communication capacities and also ground stations, teleports, and hardware for communications with a large variety of operation characteristics; whereby in disaster management, the analysis and characterization of the communications satellites payload and their capacities are crucial at the time to plan the communications services required in each disaster phase, and even it is an operational procedure necessary to recover the terrestrial communication services when their infrastructures are affected by the disaster events. In the same way, the communications satellites payload analysis provides the essential information to implement services and design communications links reliable and adjusted to the scenarios demanded in all the disaster management cycle. In the satellite communications field, there are a number of radio frequencies ranges used for communications links, such as C-band, X-band, Ku-band, Ka-band, and Q/V-band, each of them having their own propagation characteristics in the space, which makes one frequency more or less vulnerable with respect to other one when they propagate through the free space and are affected by diverse phenomena that take place at the earth atmosphere.

Generally, the most used frequencies bands in commercial communication satellites are the C-band, Ku-band, and Ka-band. Equally, many are the services and applications that can be implemented using the aforementioned frequencies bands. From this point of view, in this chapter, the transponders and radio frequencies characterization for emergency services in disasters is focused directly in the C-band, Ku-band, and Ka-band communications payload, with the objective to define the adequate use of these frequencies bands, at the time to implement technologies solutions in disasters scenarios.

However, with the purpose to describe in practical way the transponders and radio frequencies characterization methodology to implement useful and reliable emergency communications services in disasters, the communications payload of the satellite platform Satnet-3 is selected; communications satellite proposed to operate in the emergency communications network, designed with ben-pipe transponders technology type, is also known as transparent payload, and mainly integrated for the next devices: sixteen (16) transponders in C-band with 36 MHz of bandwidth and uplink frequency range from 6050 to 6350 MHz and downlink frequency range from 3825 to 4125 MHz. Fourteen (14) Ku-band transponders with 54 MHz of bandwidth and an uplink frequency range from 14,080 to 14,500 MHz and downlink frequency range from 11,280 to 11700 MHz. Three (03) Ka-band transponders with 120 MHz of bandwidth and frequency range for the uplink from 28,800 to 29,100 MHz and frequency range for the downlink from 19,000 to 19,300 MHz, one (01) antenna in C-band, one (01) antenna in Ku-band for the north beam and one (01) antenna in Ku-band for the south beam, likewise one (01) antenna in Ka-band [13].

Fundamentally, the Satnet-3 payload operates in three (03) frequencies ranges or bands, such as C-band, Ku-band, and Ka-band. Each of these bands is located inside the microwave spectrum frequencies range; electromagnetic waves sensitive to multiple attenuations factors when they propagate through free space are affected by the moisture of the atmosphere and others atmospheric conditions. For instance, for frequencies above 10 GHz, phenomena as rain, clouds, fogs, and diverse particles in the space have an important impact on their propagation and attenuation. In this regard, considering the communications satellite Satnet-3, as well as its payload operation frequency bands, and the phenomena or atmospheric factors that can affect the propagation of these frequency bands in the free space due to the attenuation caused by the phenomena that take place in troposphere, the characterization of the Satnet-3 frequencies spectrum is carried out, and illustrated in **Table 5**, their potential applications in order to implement communications links and emergency services reliable in diverse disasters scenarios or hazard existing.

Frequency band	Potential uses in disaster events	Frequency vulnerability
C-band	Earthquakes, Landslide, Volcanic eruptions, Subsidence of earth, Storms, Tornado, Hurricane, Wildfires, Typhoons, Tsunami, Floods, Coastal Erosion, Desertification, and Deforestation	This rage of frequency works properly without significant perturbation in adverse atmospheric conditions
Ku-band	Earthquake, Landslide, Volcanic eruptions, Subsidence of earth and Wildfires	Frequency range that cannot be used in adverse atmospheric conditions
Ka-band	Earthquake, Landslide, Volcanic eruptions, Subsidence of earth and Wildfires	Frequency range that cannot be used in adverse atmospheric conditions

Table 5.
Satnet-3 frequencies bands characterization for emergency services implementation in disasters.

Characterization takes into account the following technical aspects: for C-band frequencies spectrum used for Sanet-3 from 6050 to 6350 MHz (uplink frequencies) and from 3825 to 4125 MHz (downlink frequencies), in heavy rain around 16 mm/h, the signal attenuation is 0.03 dB/km, in moderate rain close to 4 mm/h, the C-band signals attenuation is nearly to zero, and the attenuation due to clouds and fog is very low. In the same way, for Ku-band Sanet-3 frequencies from 14,080 to 14,500 MHz (uplink frequencies) and from 11,280 to 11,700 MHz (downlink frequencies), in heavy rainfall around 150 mm/h, the signal attenuation is approximately 5 dB/km and in moderate rainfall, it is close to 0.5 dB/km. Equally for Ka-band from 28,800 to 29,100 MHz (uplink frequencies) and from 19,000 to 19,300 MHz (downlink frequencies), in heavy rainfall around 150 mm/h, the signal attenuation is just about 14.5 dB/km and in moderate rain, the signal attenuation is near to 0.9 dB/km; for both Ku and Ka-band, the signals attenuation per clouds and fog must not be neglected [14].

As result, in **Table 5**, it is noticed that the Satnet-3 C-band payload and radio frequencies offer more reliability, taking into account their less vulnerability against adverse atmospheric conditions in case of disasters, while the Ku and Ka frequencies bands are more vulnerable to the unfavorable atmospheric conditions, limiting the use of them only to specific disaster situations.

3.5 Technology solutions formulation for disasters management

The space information products and services are essential to build strong and effective response mechanisms that enhance the media and tools required for emergency response in disasters. Moreover, information technology and different communications services are the backbone in all the phases of the disaster management, due to the wide variety of data from diverse sources that must be gathered, organized, and displayed logically for decision-making in events of disasters. From this perspective, the space technology and in specific the communications satellites inside the emergency communication network play an important role, because they have the function of handling all the communications traffic and also provide the technology solutions in reference to the communications services required in the areas affected by one or more events of disaster.

In the same way, the communications satellites in combination with the remote sensing satellites in the emergency network have the ability to transmit and receive different types of images in function to the technologies solutions implemented. For such aim, the communications satellites teleport and also their associated infrastructures must meet different technical specifications to cover the communications services requirements and the technology solutions operation specifications required for emergency response. It becomes important to point out that the technology solutions implementation process in disasters is based on the analysis of diverse aspects; some of them are mentioned as follow: disaster scenario determination, disaster classification and magnitude determination, space technology resources availability identification, communications satellites and remote sensing satellites operation technical specifications analysis, analysis of the demand for information and communication services, data flow analysis, terrestrial communications networks assessment and critical emergency communications network planning, among others, related with the characteristics of each disaster type.

However, the satellite link budget software Satmaster is the tool used in the emergency communications network to design the communications links and implement the services required in disaster. This software is widely used for satellite service providers to carry out the satellites links budget calculation since it is supported for specific communications standards and atmospheric models used to calculate the communications links budget, considering the services requirements and hardware specifications that had been defined to implement different technology solutions of services.

On the other hand, to exemplify the technology solutions implementation methodology in the emergency communications network, the communications satellite Satnet-3 and its teleport is regarded and selected to be integrated in the emergency communications network, both with the ability to support the implementation of different technology solutions to satisfy the diverse communications services required in the areas affected by disasters. The Satnet-3 teleport counts with satellite HUBs to provide a large variety of services, also with various communications infrastructure resources and connection to the national communication terrestrial network, among other capacities for communications services.

In consequence, as example, various communications services solutions that can be implemented through the Satnet-3 platform and its teleport infrastructure, integrated to the emergency communications network for disaster management, are described as follows: broadband satellite internet services, remote access for video conference services, radio and TV broadcasting services by satellite, dynamic databases to manage and store human or material losses due to disasters, remote access for video camera connections, cellular phone services over satellite, facilities with the technology required at the disaster site to manage hazard events or download and processing images, infrastructures for cloud computers and physical networks, unmanned aerial vehicle (UAV) networks, command and control center for land surveillance or assessment, technology platforms for exchange and images processing

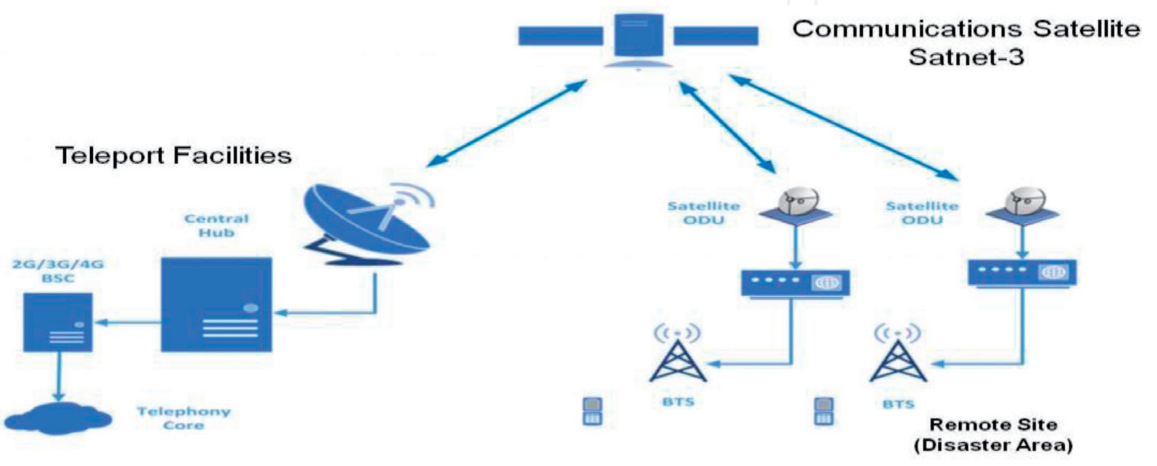

Figure 10.
Technology solutions for disasters management cellular backhaul-SCPC over satellite.

Cellular backhaul-SCPC teleport site to radio base station in remote site (outbound link)	
Uplink and downlink operation parameters	
Transponder (TP): Ku-1A	Teleport EIRP: 68.41 dBW
Carrier type: digital modulation	Teleport SFD: −95.55 dBW/m^2
Teleport antenna TX gain: 63.90 dBi	Carrier Modulation: QPSK
Teleport antenna RX gain: 62.18 dBi	Carrier Bandwidth: 1.9575 MHz
Uplink frequency: 14167.60 MHz	TP Carrier Occupied BW: 1.9800 MHz
Downlink frequency: 11367.60 MHz	TP Carrier Downlink EIRP: 22.58 dBW
Carrier polarization: horizontal/vertical	Carrier to Noise: 17.52 dB
Teleport HPA power required: 4.51 dBW	E_b/N_0: 5.4 dB

Table 6.
Cellular backhaul-SCPC outbound link budget.

Cellular backhaul SCPC radio base station in remote site to teleport site (inbound link)	
Uplink and downlink operation parameters	
Transponder (TP): Ku-1A	Remote site EIRP: 51.47 dBW
Carrier type: digital modulation	Remote site SFD: −111.64 dBW/m^2
Remote site antenna TX gain: 47.2 dBi	Carrier modulation: QPSK
Remote site antenna RX gain: 44.5 dBi	Carrier bandwidth: 1.9575 MHz
Uplink frequency: 14166.37 MHz	TP carrier occupied BW: 1.9800 MHz
Downlink frequency: 11366.37 MHz	TP carrier downlink EIRP: 21.56 dBW
Carrier polarization: horizontal/vertical	Carrier to noise: 16.95 dB
Remote site HPA power required: 4.27 dBW	E_b/N_0: 4.9 dB

Table 7.
Cellular backhaul-SCPC inbound link budget.

at different levels, star or mesh topologies for very small aperture terminal (VSAT) networks, among other technology resources, useful in the disaster management field. In this sense, the general architecture of a cellular backhaul single channel per carrier (SCPC) implemented over satellite in case of emergency is shown in **Figure 10**, utilizing the communications satellite Satnet-3 and its teleport.

Likewise, considering **Figure 10**, which describes the architecture of a cellular backhaul by satellite in star topology, using the software Satmaster (tool for communications links design), the link budget calculation for the single channel per carrier (SCPC) service correspondent to the implantation of a cellular backhaul was carried out, using the Satnet-3 Ku band transponders and its teleport, for disaster events that demand this type of services. **Tables 6** and **7** present the results obtained through the Satmaster communications tool for the uplink and downlink of the aforementioned service.

3.6 Emergency communications network topology for disaster events management

After the formulation and analysis of diverse operational strategies with the aim to optimize the processes necessary to integrate the communications satellites platforms and remote sensing satellites platforms and their ground stations inside a network useful to manage different disaster events, in **Figure 11**, the structural topology of the emergency communications network for disaster events management designed in this chapter is presented. Network has a main function to serve as an operational structure to back up the conventional communications networks infrastructures affected by disasters, and in the same way, be an alternative infrastructure that can provide the capacities to implement diverse technology solutions and communications services to support in the tasks inherent to the disasters management in each of their phases.

Nevertheless, the communications satellites platforms in the emergency communication network has the principal function to handle all communications traffic between the areas affected by disasters and the entities in charge to manage the recuperation tasks in disasters, and also provide the necessary channels through their payload to implement the required technology solutions and the communications services demanded in disaster scenarios. Equally, the communications satellites platforms in combination with the remote sensing satellites in the emergency network have the function to transmit and receive different types of images captured for the remote sensing satellites and processed in their ground stations, through the technology solutions implemented for such aim.

In this sense, regarding the communications satellite Satnet-3 and the Remote Sensing Satellite-1 and Remote Sensing Satellite-2, satellites platforms are selected to design and implement the emergency communications network presented in this chapter; Satnet-3 in the emergency network has the main function to handle all the communications traffic and also provide the capacity to implement the communications technology solutions required in the areas affected by the disasters according to its payload capacity and teleport infrastructure. In combination with the Remote

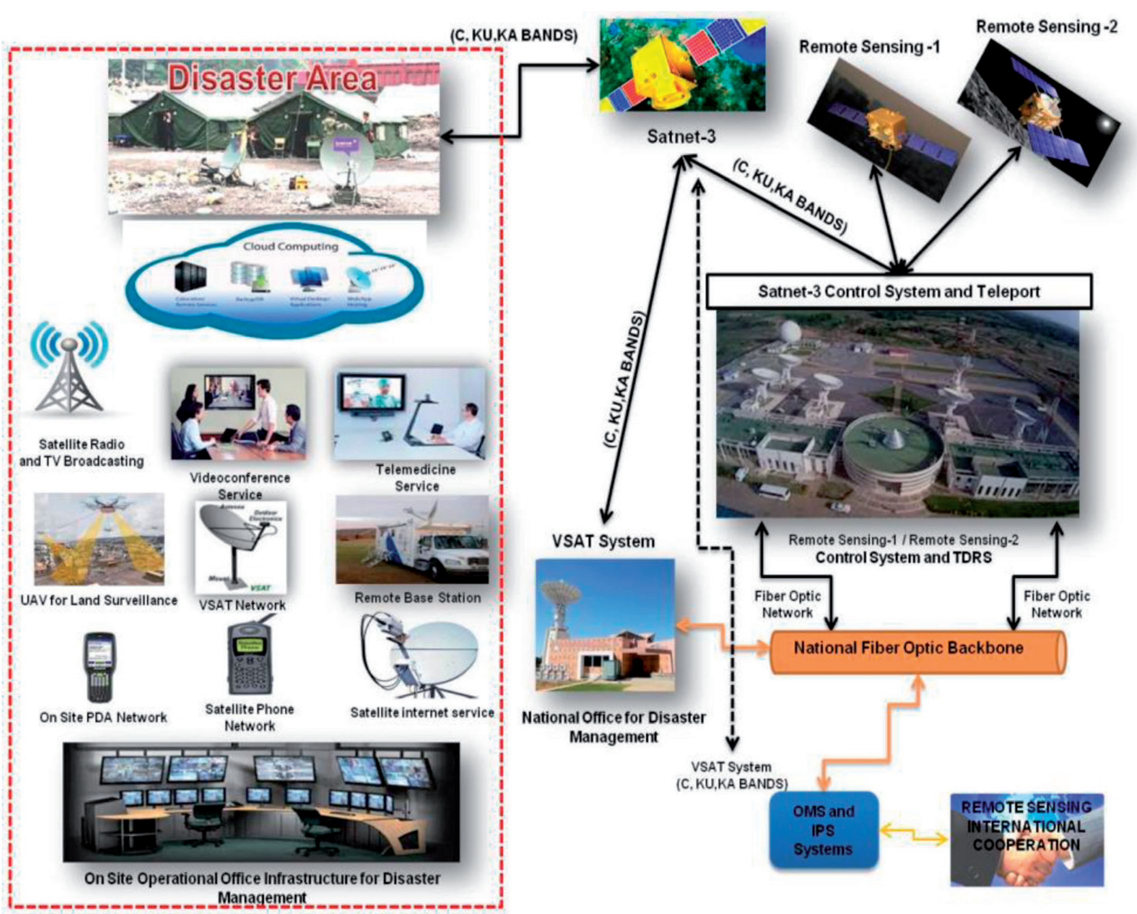

Figure 11.
Emergency communications network topology for disaster events management.

Sensing Satellite-1 and the Remote Sensing Satellite-2, Satnet-3 has the aim to receive images from the ground station of both remote sensing satellites and then transmit thereof through the technologies solutions implemented to the different affected areas in disaster events. The main task of the Remote Sensing Satellite-1 and Remote Sensing Satellite-2 is to capture images over the affected areas according to the different missions loaded from the ground station, following the operational strategies designed to manage both platforms in emergency situations for a quick and reliable response. Additionally, the communications network designed is integrated to a fiber optic backbone which provides to the network the capacity to transmit and receive images and other data types through terrestrial communications infrastructure that are also available in disaster scenarios.

In this way, the emergency communications network for disaster management allows to put in operation the next technology solutions: broadband satellite internet services, remote access for video conference services, radio and TV broadcasting services by satellite, dynamic databases to manage and store human or material losses due to disasters, remote access for video camera connections, cellular phone services over satellite, facilities with the technology required at the disaster site to manage hazard events or download and processing images, infrastructures for cloud computers and physical networks, unmanned aerial vehicle (UAV) networks, command and control center for land surveillance or assessment, technology platforms for exchange and image processing at different levels, star or mesh topologies for very small aperture terminal (VSAT) networks, among other technology solutions or services necessary to manage the disaster events scenarios where the terrestrial communications infrastructures have been damaged or may be at risk of failure due to the disaster's impacts. Likewise, in **Figure 11**, some of these technologies solutions or communications services that can be implemented through the emergency communications network are described as well.

4. Conclusions

Diverse organizations in charge to develop disasters management activities at a worldwide level focus on numerous studies for the improvement and formulation of new technologies to facilitate the execution of the procedures necessaries to carry out the disasters management processes in multiplicity hazard scenarios. Technologies can be novels and reliable to manage and plan the preparedness, mitigation and recuperation tasks in disasters. From this perspective, nowadays, the space technology makes available different satellite platforms on-orbit operation that provides the technology resources necessaries to increase and optimize the response capacities to manage the disaster events in their distinct phases. Therefore, the design of the infrastructure, such as emergency communications networks for disaster management by means of the communications satellites and remote sensing satellites integration, inside an operational topology operates in emergency scenarios; it is a novel communications and remote sensing applications platform useful to manage disaster events in all their phases. This type of emergency communications networks is an essential and adequate communications model to enhance the preparedness, mitigation, and recovery of the communications systems which can be affected by disasters, and besides, it is a reliable infrastructure to images capturing and processing in disaster scenarios.

However, the importance and application of the emergency communications networks in disasters are invaluable as it is noticed in the practical cases described through this chapter. For instance, in the Dominican Republic case, the country has often affected by natural disasters, which has an emergency communications network designed to take advantage of the different data types received from communications satellites, remote sensing satellites, meteorological satellites, telemetry systems, and specialized equipment to manage a technological platform useful for forecast, early warning, and disaster events mitigation that may take place in this country.

Likewise, from the field experiences learned in the Sichuan earthquake, phenomenon occurred in the People Republic of China on May 12, 2008, the use of the remote sensing satellites and communications satellites simultaneously to manage this disaster was a resource useful to carry out diverse tasks of evaluation, mitigation, and recovery of the areas affected by the aforementioned earthquake. In specific, during the Sichuan earthquake, the remote sensing images with different spectral and spatial resolution were helpful to analyze the multiple damages caused by this disaster event, as well as to establish the measures needed to initiate the infrastructures damaged during recovering process. In relation to the communications satellites role in the Sichuan earthquake, these platforms were used to recover the communications services and to support the alternatives technologies solutions implementation for different data types exchanges between the entities in charge to manage the disaster. All the mentioned tasks developed by both satellite technologies in the Sichuan earthquake are the clearest basis of the operational philosophy implemented in the emergency communications networks for disaster management designed through the integration of the communications satellites and remote sensing satellites and, fundamentally, the operational perspective approached in the work presented.

In this sense, the emergency communication network for disaster management designed and described in this chapter is an infrastructure that provides the resources adequate to put in operation different communication technologies solutions and a variety of options or schemes to the images exchange between the actors involved in the disasters management tasks, and so as for the population in general affected by disasters directly. In the same way, the emergency network design is supported by a series of operational strategies formulated to enhance the communications services implementation in disasters through the adequate characterization of the communications satellites payload frequencies bands, as well as by operational procedures to optimize the remote sensing satellites spatial and spectral resolution during their operation inside the emergency communications network with the aim to improve the images capturing and management in events of disasters. In summary, the emergency communications network topology developed provides the capacities or functional resources to make possible the effective response to recover the public and private terrestrial communications infrastructures and services in disasters scenarios. Alternatively, the network may operate at an international scale, since it has the capacity to be managed in order to support other countries affected by disasters with damages on their terrestrial communications infrastructures. Considering only for such aim, the coverage region of the communications satellites that integrates the network, because of their beams coverage change by regions according to the satellite orbit position, unlike to the remote sensing satellites whose coverage is global.

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