SPACE-BASED SENSOR WEB FOR EARTH SCIENCE APPLICATIONS – AN INTEGRATED ARCHITECTURE FOR PROVIDING SOCIETAL BENEFITS

Shahid Habib, Stephen J. Talabac

NASA
Goddard Space Flight Center
Greenbelt, Maryland, USA

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ABSTRACT:

There is a significant interest in the Earth Science research and user remote sensing community to substantially increase the number of useful observations relative to the current frequency of collection. The obvious reason for such a push is to improve the temporal, spectral, and spatial coverage of the area(s) under investigation. However, there is little analysis available in terms of the benefits, costs and the optimal set of sensors needed to make the necessary observations. Classic observing system solutions may no longer be applicable because of their point design philosophy. Instead, a new "intelligent data collection system" paradigm employing both reactive and proactive measurement strategies with adaptability to the dynamics of the phenomena should be developed. This is a complex problem that should be carefully studied and balanced across various boundaries including: science, modeling, applications, and technology. Modeling plays a crucial role in making useful predictions about naturally occurring or human-induced phenomena. In particular, modeling can serve to mitigate the potentially deleterious impacts a phenomenon may have on human life, property, and the economy. This is especially significant when one is interested in learning about the dynamics of, for example, the spread of forest fires, regional to large-scale air quality issues, the spread of the harmful invasive species, or the atmospheric transport of volcanic plumes and ash. This paper identifies and examines these challenging issues and presents architectural alternatives for an integrated sensor web to provide observing scenarios driving the requisite dynamic spatial, spectral, and temporal characteristics to address these key application areas. A special emphasis is placed on the observing systems and its operational aspects in serving the multiple users and stakeholders in providing societal benefits. We also address how such systems will take advantage of technological advancement in small spacecraft and emerging information technologies, and how sensor web options may be realized and made affordable. Specialized detector subsystems and precision flying techniques may still require substantial innovation, development time and cost: we have presented the considerations for these issues. Finally, data and information gathering and compression techniques are also briefly described.

1. INTRODUCTION

Since the inception of the first space-based observing system more than 45 years ago researchers have been investigating science questions/phenomena by deploying and operating single platform missions. Although instrument and platform technologies and on-orbit capabilities have evolved significantly since that time, today's platforms are typically multi-instrument satellites having multiple science objectives. The recent trend is a shift to single instrument platforms. However, there is no conventional way indicating what is the right or best way to do the job. By and large, it is still based on the need and the availability of funds to perform the scientific investigations. Either of the approaches (i.e., multi-instrument and single instrument platforms), have been in use for reasons such as:

- Laws of physics dictating the instrument design
- Technology miniaturization limitations
- Heavy reliance on hardware because of unexplored or lagging development in the software and algorithmic techniques
- Cost and physical limitations inhibiting the accessibility to space
- Limited interest and/or perceived low return on investment by the private sector to conduct science research from space
- Limited international cooperation

Traditionally, the National Aeronautics and Space Administration (NASA), in conjunction with other US Government Agencies such as the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS), have built many large platform missions for Earth science research. For example, Nimbus, Landsat, Polar-Orbiting Operational Environmental Satellite (POES), Upper Atmospheric Research Satellite (UARS), Terra and recently launched Aqua, and Environmental Satellite (Envisat) by European Space Agency (ESA), fall under the large platform classification. These satellites carried many instruments to perform remote sensing in the UV, Visible, IR, microwave, and radio frequency spectral bands. In retrospect if one analyzes an integrated development life cycle for any of these platforms, the duration is approximately 7-10 years and the cost can be nearly half a billion real year dollars. At the same time, let's not forget a large infrastructure cost on the ground in terms of ground communication networks and computational facilities. The idea here is not to play down the important contributions being made by such space assets but to learn critical lessons in order to take advantage of emerging technologies to meet the future scientific measurement needs.

2. WHY SENSOR WEBS?

Since the sensor web concept and the properties that characterize it are still evolving, a high level description of it and the terminology we have used is useful to establish a foundation with which to understand what is meant by these terms. We have defined a sensor web as: *a coherent set of distributed "nodes", interconnected by a communications fabric that collectively behave as a single, dynamically adaptive, observing system.* Through the exchange of sensor measurements and other information, produced and consumed by its nodes, the sensor web dynamically reacts by causing subsequent sensor measurements and node information processing states to be appropriately modified. State modifications are implemented in ways that tend toward optimizing useful science return. The ability to reconfigure itself as a direct reaction to the dynamics of the phenomenon being monitored, uniquely characterizes the adaptive nature of the sensor web. As such, the sensor web must be viewed as a "system-of-systems". It is composed of three types of nodes: sensor nodes, computing nodes, and information storage nodes. The nodes are interconnected by a communications fabric.

In a generic sense, a "sensor" is any sensing device that monitors or physically samples the environment, either remotely or *in situ*, for which it is being deployed. Multiple, potentially heterogeneous sensing nodes, deployed on or below the surface "skin" (e.g., land, water) of the Earth, within the atmosphere, and in space perform the required measurements and provide simultaneous, incremental or real time or near real time information. Measurement data and derived information acquired and possibly locally processed by the sensors, is stored and/or transmitted to other locations for the operators and the physical scientists to analyze and make decisions. Sensor nodes possess the ability to access (near) real-time observations from other sensor nodes, as well as results from numerical model nodes and information storage nodes. They use this information to adjust subsequent measurement techniques and modify their internal information processing state(s) in ways that will tend to maximize the return of only the most useful and significant measurement data to scientists, policy makers, and emergency management decision support systems.

Computing and storage nodes complement the sensor nodes. Computing nodes perform sensor data assimilation to (re)establish initial conditions and they also execute sophisticated predictive environmental models to forecast a future state of the environment (e.g., the atmosphere). Forecast model results may in turn then cause the sensor nodes to reconfigure their measurement technique when making new observations. One key benefit of this model-driven form of Sensor Web is the ability of such systems to reduce the error growth in model ensembles. The third component, information storage nodes, driven by sophisticated data mining techniques, identify potential cause and effect relationships as new measurement data is continually collected and analyzed using sophisticated statistical or other techniques. As new relationships are "discovered", the sensor web may be reorganized to begin making measurements of precursor conditions that will ultimately serve to drive the formation of the phenomenon.

The underlying communications fabric serves as "glue" that facilitates the exchange of sensor measurement data, predictive model results, and event notification messages that the sensor nodes may use to modify their present spatial, temporal, spectral, and perhaps organizational (e.g., form a new sensor cluster) measurement state. Specific characteristics of the communications fabric may vary considerably depending upon the sensor web's unique functional and performance requirements and the properties of the science or applications domain. *However, the communications fabric facilitates the negative feedback loops between sensors, and between sensors and predictive models. These real time closed loop feedback mechanisms are the critical new component of "event-driven" and "model-driven" sensor web systems.* The dynamically reactive and adaptive observing strategies offered by sensor web systems have the potential to yield a substantial improvement in our ability to better understand dynamic interrelationships that drive the formation, behavior, and evolution of a wide variety of complex environmental phenomena.

There is a great deal of variation on what exactly should be the charter of such systems. However, it can be and be narrowed down into the following categories:

- Science Driven: to study, understand and monitor certain phenomena, that can be ozone trends in the troposphere, and/or land cover changes or snow cover variations that contribute to the hydrological cycle
- National Defense Driven: to provide an infrastructure that is useful and reliable in making critical security and defense related decisions such as troop deployment, advance reconnaissance information that may aid in the war/battle machinery in target classification, selection and equipment operation.
- Applications Driven: The area where sensor webs can have major payoffs would be for multiple applications for the society. This can range from monitoring weather or natural disasters to coastal zone erosions, agriculture planning to assess the local air quality issues.

- Distributed Space System (DSS) is a system of more than one satellite distributed in space to acquire science data and transmit to the supporting communication network for further processing. DSS satellites do not need to directly link to other companion satellite(s) and can be free to make independent observations.
- Constellation is a set of satellites that are grouped together to observe a common scientific area of interest. The data acquired from each member of the constellation can be related to the other members analytically.
- Cluster is an element of a constellation and is functionally grouped to make an integrated observation.
- Formation is a grouping of two or more satellites that fly in coordination, maintain cross communication, strictly follow control laws, and observe a common area to make the necessary measurements.
- Virtual platform is a representation of observing systems or satellites, which can be analytically combined to represent a platform at a different location.
- Virtual aperture is an effective aperture that is generated by physically distributed discrete satellites.

The biggest challenge lies in defining, developing, coordinating and operating space based sensor platforms. For example, a simple configuration of two spacecraft offers a significant challenge in maintaining the orbital trajectory and synchronization and is a key prerequisite for the science platforms. On the other hand, this is a lesser challenge for communication type satellites.

3. REMOTE SENSING APPLICATIONS FOR SOCIETY

The remote sensing observations acquired by *in situ*, air borne or space based sensors can be applicable for multiple practical usage that can help in making critical decisions for the societal benefits. In reality, such observations and data can not be directly used for reaching decisions relative to, for example, agriculture fertilization, soil moisture and irrigation planning, red tide infestation in the coastal areas, or any other real life problems. The raw data acquired by the sensors must first be processed using extensive mathematical formulations and image processing techniques before some sensible products can be generated to feed the decision making power. There can be many applications that benefit from the remote sensing data. However, for a comprehensive system to provide timely information, a combination of *in situ* and space based sensors has to deployed and operated. Space based sensors can be very effective, but they can frequently incur a significant data delivery latency, have a poor signal to noise ratio, and possess a coarse resolution. Therefore, a combinatorial approach, one using both *in situ* and remote sensing observations, can offer the best configuration. We have described several applications below.

In a simpler sense, the observations provide data and information; scientific models use these data and produce predictive results that help in reducing potential uncertainties. This may be weather, climate variability, or volcanic eruption. Once this level of information is generated then it can be utilized by civil or governmental entities in making useful decision that may help in improving crop growth or providing an early warning from a disastrous condition.

3.1 Disaster Management

Natural disasters are all too common on our home planet and they can inflict horrible miseries upon human life and property, and have deleterious consequences for local and national economies. Wild fires, tornadoes, earthquakes, floods, cyclones, and volcanic eruptions are just some of these all-too-common events. Scientists have spent enormous efforts to understand these complex natural phenomena and to develop predictive measures that can be used as early warning signs or precursors. Unfortunately, little progress has been made due to the lack of adequate measurements and the depth with which we fully understand the physics of these phenomena. The tropical cyclones, , called hurricanes in Atlantic and Typhoons in the Pacific/Indian oceans, cause significant damage every year. Typhoons not only cause the property damage but also bring large-scale human catastrophe to southeast Asia. The full nature and cause of such cyclones is still not well understood. Property losses of $10-$25 billion or more can likely occur from each individual hurricane. The World Health Organization has estimated that during the last 30 years the tropical cyclones have done almost three times as much damage globally as did earthquakes, while influencing the lives of almost five times as many people. Similarly, there are a number of areas around the world, which are prone to tectonic movements of the earth's plates. These areas, which pose a much higher threat, are located in Turkey, Iran and the Los Angeles basin in the United States. Similarly, floods cause significant damage and uproot lives of thousands of inhabitants of this planet. For example, the recent floods in the Indus Valley led to a major destruction of both human life and agricultural land. Remote sensing multispectral imagery has given us the ability to clearly monitor the evolution and progress of these catastrophic events, such as the swelling and receding of the Indus River, as they happen. Now, one can see and predict what impact similar events may have during the next several years on crop production, disease proliferation and water quality.

3.2 Water Management

Nature constantly demonstrates that Earth's vitality is nurtured by water. Simply put, where water abounds–life in all forms flourishes. Earth is a unique, living planet due to the abundance of water and the vigorous cycling and replenishing of water throughout our global environment. The global water cycle describes the transport and transformation of water within the Earth system, and as such, distributes fresh water over the Earth's surface. Water is, indeed, abundant in our environment, but it is neither evenly distributed over the globe nor always in a form amenable for human use. As populations grow over areas with marginal fresh-water supplies, the risk of catastrophic water shortages will increase. Likewise, increased exposure and density of human settlements in flood plains and coastal regions amplify the potential loss of life, property and commodities that are at risk from intense precipitation events. Given these trends - now more than ever - improved monitoring and prediction of the global water cycle in conjunction with cogent application and operation strategies must be nurtured in order to hold any promise of proactively mitigating future adversities. Overall, key issues of societal concern include: (a) the frequency and intensity of floods, droughts, and extreme precipitation events; (b) the long-term availability of fresh water resources and the competition for water supplies; (c) surface and ground water quantity and quality; (d) ecosystem vulnerability to water stress. Water is a critical resource for the world and resides in reservoirs within the Earth system and also cycles through the system. Only about 3% of the Earth's water resides as freshwater on the land. Two thirds of this fresh water exists in ice caps, glaciers, permafrost, swamps, and deep aquifers, where it is largely inaccessible. It is imperative that these vital resources be preserved and protected for future use.

3.3 Agriculture Efficiency

Food and fiber supplies are fundamental to all human societies. The availability of food is closely related with the availability of water and weather patterns in the changing climatic conditions on this planet. There have been severe cases of famine in Africa, in the arid regions of India, and Pakistan in the recent years. All of this was primarily attributed to the lack of a crucial natural resource i.e., water. There are 170 million children who suffer from malnutrition. High resolution satellite imagery can provide tremendous knowledge assessing the present conditions in the fields and provide necessary initial conditions to generate forecast for the out years. Food production, a vital commodity for sustainable development, impacts societal needs in multiple ways which if not effectively monitored and managed can severely hamper or nearly cripple the life and economic machinery of the affected regions on the planet. Therefore, it behooves the research community of the world to focus their attention in many different areas such as: precision farming, which usually refers to determining optimal fertilizer applications per crop type, soil type, and climate regime; crop yields determinations, estimates, and projections; tree plantations and crop health analysis. Remote sensing offers great promise in obtaining: synoptic, consistent, and repetitive views of farms and regions; including estimates of crop vigor and canopy chemistry. The spectral information that can be related to canopy chemistry and/or temporal changes; and carbon stock monitoring by combining remote sensing and ancillary information through models. This eventually should lead to more comprehensive commodity yields and help us rid famine in the future.

3.4 Public Health

The availability of remotely sensed information and its potential capabilities allow it to be a unique addition to data applied to public health applications. The use of such data for public health has recently opened a new avenue in studying infectious diseases and epidemics. Recent studies have shown that monitoring non-infectious respiratory disease can also benefit from space based observation in predicting near term Asthma illnesses in certain geographic areas. These findings have ushered in a new era of satellite remote sensing with greatly increased accuracy and new observational capabilities. These data, when combined with data collected by other satellite platforms, provide improved temporal and spatial resolution adequate for local level investigations critical for public health. Remote sensing and *in situ* measurements (satellite and ground based) are critical in determining a number of triggers related to heath such as aerosols, source and spread of pollution, land cover and land use, other environmental data, and spatial data. By combining these satellite and ground based observations with environmental and climate information, a value added product is obtained. This information is further used in predictive models to forecast the outbreak of certain disease patterns. For example one of the most common vector borne diseases, malaria, infects 5 million people per year and 1-3 million die from this controllable human catastrophe in the African continent and in South East Asia. There are other aspects which impact health issues such as air quality due to transport of aerosol and black carbon from across continents and changing the tropospheric chemical conditions. African and Mongolian dust storms, which now can be detected and monitored via the space-based sensors, may be carriers of various diseases. This is a promising area of research that can have a tremendous payback in terms of human safety and medical cost benefits.

4. LEGACY SYSTEMS AND ‘WEBLIKE’ TOPOLOGY

There are many Earth observing satellites that have been placed on-orbit by the US (NASA, NOAA). France (CNES) and JAXA (Japan) are already operating in the helio-synchronous orbit at a nominal altitude of 795 km. They will be joined by other Earth remote sensing spacecraft planned to be launched within the next two years. All of these satellites shown in Figure 1, are either single instrument or multiple instrument satellites specifically designed to study the Earth’s atmospheric chemistry, cloud properties, water cycle, aerosol, and carbon cycle. These satellites are designed as discrete science missions and they will provide data and products to the models which are trying to synthesize these science measurements to improve our understanding of the planet Earth’s behavior as an integrated system. Most of these satellites are capable of making measurements down to the top of the boundary layer: Aura (to be launched in June 2004) and its Troposphere Emission Spectrometer (TES) will penetrate the tropospheric level to measure the ozone and other chemical constituents. Researchers have created a constellation from this configuration, as shown in Fig. [TBD] and provide communication linkage via ground control between satellites. Aura will be inserted into nearly the same orbital plane as Aqua: it will be positioned such that it trails Aqua by approximately 15 minutes. Of significance, TES is a pointable IR-sensitive instrument that will be used to measure Tropospheric ozone. As such, it is desirable that TES make its measurements in cloud-free regions. This form of formation flying provides an opportunity to maximize useful TES science data return. For example, data collected by the Moderate Resolution Infrared Spectrometer (MODIS) on the Aqua satellite can be used to produce, in real time, a cloud mask from which cloud free regions can be identified to point Aura’s TES instrument. This method of course can be used by other instruments on the other satellites operating in the same trajectory. These satellites were not originally designed with space-based crosslinks. Yet one can still take advantage of these assets and operate them as a small-scale event-driven sensor web constellation via a bent-pipe ground processing and communications approach. Similar arrangements can be made for the various land imaging satellites currently operating in the same orbital plane. This includes MODIS, SPOT, LandSat and Earth Orbiter-1(EO-1). However, EO-1 has both multispectral and hyperspectral instruments on board and these instruments have very narrow swath (about 9 km for the hyperspectral and 36 km for the multispectral). But, the idea is to detect some event such as fire, flood or dust storms via the conventional system and pass it on to the hyperspectral imager for a detailed look and examination. To date this has been demonstrated via ground operations.

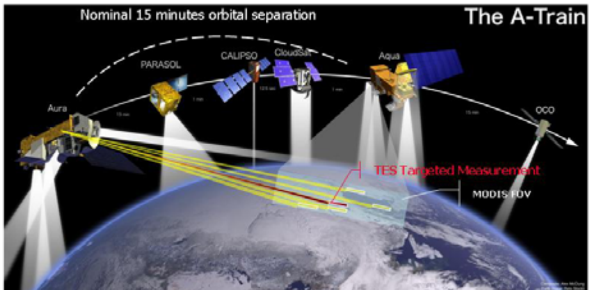

Figure 1. International constellation of atmospheric satellites.

5. MULTIPLE VANTAGE POINTS

One of the most complex and difficult areas to reach via remote sensing techniques from space is the troposphere. However, this region has a much to offer in terms of understanding its photochemistry, anthropogenic impacts, carbon budget, air-sea exchange, other polluting factors, the tropopause and the stratosphere transition layer. Therefore, it is imperative to study these processes in detail and make useful predictions regarding the health of the planet system. Ultra long duration balloons (ULDB) that can be deployed in troposphere at a high altitude (> 40,000 meters) offer a great promise for extended periods of time (~ 6 months). Although keeping balloons stationary at one observation point (i.e., station keeping) will be an intricate problem, the advancements in GN&C technology may be able to address this problem.

The basic concept in this configuration as shown in Figure 7 is to deploy a series of ULDBs with atmospheric sensing payloads around the globe. For example, these ULDBs can be distributed:

- In polar regions to constantly monitor the ice caps
- In mid latitudes for chemical species and transport phenomena
- To study invasive species in the tropical regions
- For coastal zone management
- To monitor vegetation and crop growth patterns
- To monitor Earth faults and surface deformation
- To monitor volcanoes

Balloons can provide constant surveillance with high resolution in the troposphere and communicate the relevant data to processing sites either in space or on the ground. The LEO platforms can gather upper atmospheric data and similarly send it to the processing sites. Geosynchronous satellites can provide the communication pathway and balloon constellation management and control. All of this can be integrated in high-resolution temporal models for analytical and predictive studies.

The ultimate goal is to have an integrated web, as depicted in Figure 2, of sensors sweeping the globe with active and passive sensors in a variety of spectral bands. This requires constellations to be intra-connected and interconnected with extensive communication networks. These sensors can be in various orbits to provide a global coverage with high temporal and hyperspectral resolution for both ground and atmospheric observations. Additionally, suborbital sensors can be mounted on ULDBs and aircrafts for discrete process studies and observations. The major task will be to coordinate all of these sensors and maintain a close measurement synergy. This is not only a challenge to come up with the operational scenarios, but is even a greater challenge for the users to coordinate and decipher the multitude of measurements from a mix of sensors.

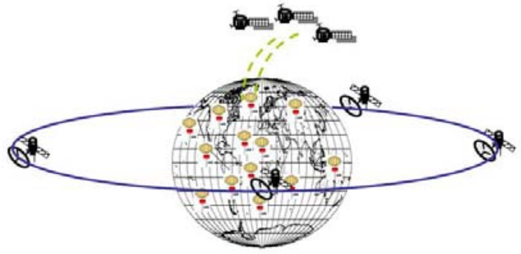

Figure 2. Sensor web concept in LEO, GEO and suborbital plains.

6. GENERIC TOPOLOGIES

There are many potential defining concepts for designing the sensor web configurations. However, one of the most difficult challenges is to develop the efficient protocols and communication methodologies for making effective observations. Sensors can come from many classes of technologies. Sensor can be an electrical detector, an optical detector, a magnetic detector, a radiation sensor, a biological or a chemical sensor; or a combination of any one of these devices connected or deployed in the environment under study. However, there should be some attributes of any of such sensing devices and these should be:

- Detector system and a signal conversion mechanism
- Communication system and processing
- Intelligent sensing for decision making
- Event driven observations
- Self organizing and adaptable to new configurations
- Easily deployable schemes
- Cost effective
- Minimize communication overhead
- Reliable for remote or space based applications
- Capable to operate both in autonomous and/or supervised modes
- Standardized interfaces
- Maintainable with modular replacement units
- Programmable spectral bands
- Easily mountable on their respective platforms
- Self organizing
- Self configuring

Majority of the above criteria can be easily met for in situ type sensors and their mounting platforms. However, this problem is much more complex and complicated to deal with for space-based systems. This is because of multiple constraints such as: severe thermal and radiative environment, poor signal to noise ratio, power limitations, platform stability, space debris impact, and maintenance inaccessibility. The following paragraphs present basic building blocks of any possible observing architecture.

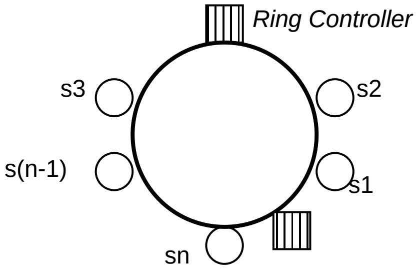

Figure 3. Sensors connectivity via a communication Ring.

Ring Topology: This configuration in Figure 3, has all the observers linked in a Ring. The Ring provides basic means for communication, control and data flow. However, in case of smart sensors, the activities on the Ring can be kept to a minimum level because of the autonomy of decision making, presumably it can be delegated to each independent sensor. This is relatively easier for the in situ or ground based sensors. However, the problem becomes rather acute when majority of the sensors are space based. This is due to the fact that the data products are based on the global observations. It therefore requires comprehensive schemes for data collection, and archiving so integrated products can be generated. For example, let us consider an example of multiple sensors deployed in a sun synchronous orbit at an altitude of around 800km and 99^{o} inclination. The idea is to increase a spatial, spectral and temporal resolutions so high quality products can be produced showing land cover/use and also report on some disastrous situations such as volcanic eruption or floods. The idea would be to have a much greater field of view so a wide area is observed in real time and critical conditions are reported in a very short time to take corrective actions. This can be accomplished by deploying a large network of sensors which is capable of both providing data for integrated maps and specific signals for emergencies. This further requires a sophisticated coordination scheme among such sensors that would use time, ephemeris, satellites conditions (viewing angle, exact altitude, velocity vector and etc.) for producing the integrated maps. One possible solution can be to have computational nodes inserted in a Ring topology to minimize the data transfer rates and also improve the products availability time. The Ring configuration can have some advantages in data flow rates and overall operating efficiency.

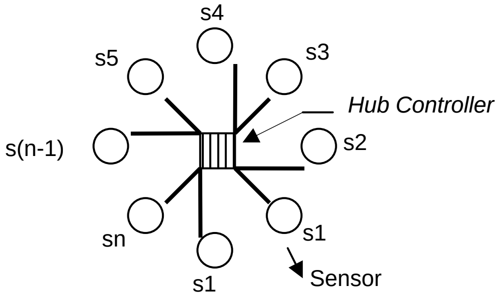

Figure 4. Star concept communicating via single hub.

Star Topology: In this configuration shown in Figure 4, all nodes are directly linked to a central node. The central node serves as a hub controller to provide bi-directional communication pathway to all the radial distributed nodes. This configuration offers some disadvantage i.e., it limits the number of nodes due to its push through capacity since each respective node has to connect via this hub. On the contrary it puts burden on the hub handler in terms of its overall push through capacity and efficiency. This type of architecture is beneficial when shorter turn around times are required and observing environment is somewhat confined in terms of its geographic boundaries. One can deploy multiple Star links over a larger area and then connect them via a super hub handlers which is very similar to the computer clusters for large distributed networks. A good example depicting the use of this configuration can be a Star configuration in an inclinde LEO (Low Earth Orbit) collecting precipitation data or continuously looking for other disasterous events such as wild fires or volcanoe eruptions. The sensors can be spread out over a large distance to provide a wider spatial coverage. The central hub can be located in a geostationary orbit or on the ground. This configuration can be further augmented with ground based network of sensors as well. The ground sensors can be provided in fixed locations to closely monitor the localized area and the space based sensors can provide a broader perspective. In case of a suspect situation, either sensor i.e., ground based or space based may trigger an event signal for a more focused view or an analytical feedback to the decision makers.

Chain Topology: This configuration allows sensors to link linearly in an open path. This is rather a simple if individual sensors are linked with each other. However, it can be very complex arrangements if multiple Star or Ring topologies are linked with each other. This scheme is useful when large areas need to be covered in shorter time and it should be applicable to both space and ground deployments. In fact, it can be an interesting concept to install such arrangements along the earthquake fault lines around the globe and link them all further with a space based observer to continuously monitor the tectonic movements and deformation. It is conceivable that this may not give as comprehensive Earth's surface deformation maps as synthetic aperture radar (SAR), but can be a less expensive alternate to a constellation of SARs.

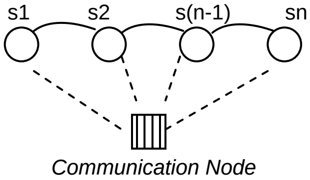

Figure 5. Sensors in linear connectivity.

Hybrid Topologies: It is possible to mix network structures combining any of the above configurations. In fact, this probably would be a common practice and practical approach in the future. However, this can be a communications nightmare if all the collected information ends up going through some main communication nodes. In fact, an integrated web composed of many architectures can be more efficient if it has intelligent processing and its own communications paths for extensive data flow and frequent controls. The main communication nodes should only be used for the integration of the critical information and dissemination.

7. SUMMARY

As described above, the sensor web observing architecture can employ large number of agile sensors operating from multiple vantage points to simultaneously collect suites of observations from multiple regions. This further can improve temporal, spatiale and spectral resolutions. However, it is still crucial to have a strong tie to the applications and societal benefits as one of the most critical justification for such endeavors. No doubt, there is lot to gain in the science arena and answer many unknown phenomena as they command our planet, but such knowledge gain must be applied to more accurately predict hurricanes, air quality, water resources and others. There is also a great potential in understanding and predicting earthquakes and volcanic eruptions. This naturally requires many more observations to feed into the analytical engines and sensors webs may be the way to proceed.

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