The Distributed Surveillance Concept
A Backbone for Network Centric Warfare

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1.0 – Introduction

1.1 – History of the Distributed Surveillance Concept.
In the mid to late 1980's a group of distinguished scientists that included Dr. Edward Teller (of nuclear fame), Dr. George A. Keyworth II (Science Advisor to President Reagan), and Dr. Gregory Canavan (a distinguished scientist at Los Alamos National Laboratories) conceived the idea of merging computers and communications into high speed digital networks to enable a new concept of remote sensing. For the military these merged technologies introduced the opportunity to improve markedly the flow of real-time information directly to commanders at all echelons to provide an improved means of assessing rapidly changing situations and making informed, shared decisions. The heart of this concept was the use of real-time imagery integrated into distributed networks. It was, in fact, a vision of Network Centric Warfare by another name.

1.2 – Perspective and Overview
Throughout history, warfare capabilities have been forged by technology. Technology creates "dimensions" and "discontinuities." The exploitation of a new dimension has always had a profound effect on warfare. Introduction of the submarine and carrier aircraft are two examples. The submarine added the undersea dimension, and the aircraft carrier opened the skies and expanded the horizons of naval power projection. Less obvious, but equally or even more significant are other dimensions such as the "electromagnetic spectrum" and "space." Electronic warfare has become pervasive and impacts all other warfare areas. The impact of space, on the other hand, is sometimes complicated by perceptions of war-in-space that can occlude the more immediate use of space for tactical purposes. Yet space has, and will have even more far reaching effects on every mission and enterprise.

Space is particularly important because of what may be called the "cross dimension phenomena." Simply stated, it allows projection of capability into other dimensions. A submarine launching a cruise missile at a surface or land target is an illustrative example. Cross dimension attacks often are characterized by tactical surprise and powerful psychological impact (consider the unexpected torpedoing of a ship, for example). The exploitation of space systems has the potential to cross each of the other dimensions. Obvious examples include wide area surveillance to track ships and airplanes, precise triangulation of terrestrial emitters for target localization or search and rescue operations, or imagery to support military planning. Further along the continuum of the imagination, however, one can conceive of a space-based targeting capability that would enable real-time control of long range weapons from launch to target impact. Other examples might include simultaneous tracking of all moving vehicles in a particular area.

The Iraq war was considered by some to be the first "Space War." During that war, the United States and her coalition allies utilized a full menu of space systems from commercial to military to national. It demonstrated how very dependent our armed forces are upon space, while at the same time, it highlighted numerous deficiencies and vulnerabilities in our exploitation of space. Former Defense Secretary Dick Cheney stated: "Field commanders wanted more tactical reconnaissance and imagery. We had difficulty with battle damage assessment and with communications interoperability.[1]

Generally, while civilian imaging satellites such as LANDSAT and the French SPOT have provided imagery to supplement military reconnaissance resources in the past and continue to be used today, they could never be used as the primary source of such imagery. Commercial imagery often would not be timely enough for fast-moving military situations and there is concern about the lack of protection on civil systems that makes them more susceptible to jamming or other attacks.[2]

Therefore, the US Military must plan to deploy its own robust, hardened system of surveillance satellites.

2.0 – Distributed Surveillance: System Description

Distributed Surveillance is an approach to space-based sensing that proposes using a network of small satellites to provide high resolution imagery (less than 1 meter) directly to users. Primarily an optical imagery system, it would also have integrated multi-spectral and radar sensors to achieve all-weather performance.

This type of networked system represents a significantly new approach to space-based sensing. It is conceived as a network of platforms, with the network embedded in space-based and terrestrial command, control, communications, and intelligence systems. It is a system that would have broad applicability and flexibility. The same configuration could provide sensing of narrow or broad areas, serve both strategic and tactical needs, directly address growing emphasis on better real-time products for military users, and provide the long-awaited means of matching the *guidance precision* that can already be built into long-range weapons with the *targeting precision* that is still lacking in many cases.

Distributed Surveillance is also a new approach to exploiting space for intelligence, reconnaissance, and targeting. The concept draws upon enormous advances in digital technology (by this we refer generally to two things—memory and mips [million instructions per second]—both of which are commercial products of the personal computer [PC] driven field of distributed processing). Present surveillance and intelligence systems are the equivalent of space-based main mainframe computers. And just as the PC caused a discontinuous change from the

[1] "Conduct of the Persian Gulf Conflict," An Interim Report to Congress, Pursuant to Title V Persian Gulf Conflict Supplemental Authorization and Personnel Benefits Act of 1991 (Public Law 102-25, July 1991. Introduction.
[2] "The Odd Couple: The Pentagon and Civil Sats," Robert Wall, Aviation Week's Space Business, April 3, 2000, p.S12.

progression to ever larger mainframes (resulting in the end of the traditional approach to computing), Distributed Surveillance would also produce a discontinuity. It would create a different technological mindset, overturning the traditional "systems" approach to space-based sensing.

2.1 – Enhanced Capabilities

Access to high resolution imagery and the ability to stare at a single point on earth are capabilities that would have significant implications in terms of force deployment patterns and force levels.

Consider the kinds of capabilities that such a system could provide, as listed in Table 1.

Table 1

Capabilities provided

- Affordable global coverage
- Synoptic coverage/fused multi-spectral
- Pre-registered imagery (auto-registration)
- All time, all weather
- Direct access and tasking by multiple users in real time
- High performance (especially high resolution)

These capabilities would provide improved means of performing military functions, and in some cases provide new ways of carrying out those functions. A generalized list of how such a system could be used is shown in Table 2.

Table 2

Peacetime uses

- Early warning (weapons testing, arms control, environmental)
- Monitoring force deployments
- Monitoring facilities development, status
- Assessing intentions, changes in readiness
- Ability to “stare” at a single location for an extended period
- Training and wargaming (applications and support)

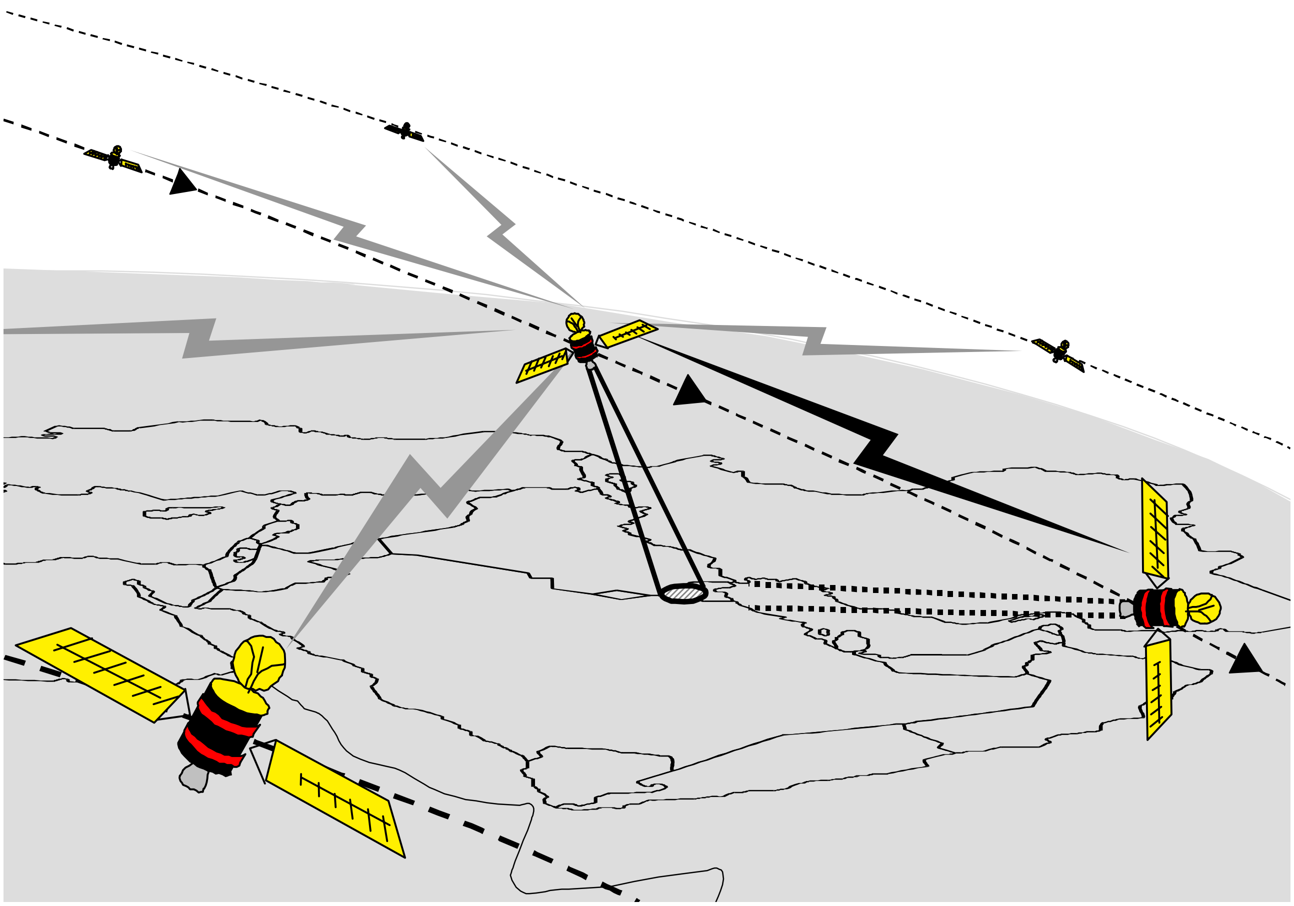
Wartime uses

- Remote real-time targeting
- Monitoring and tracking force movement
- Monitoring facilities and readiness
- Early warning (missile launch)
- Target identification
- Safe, fast-response BDA

2.1 – Staring Capability

The technology exists today to develop and deploy a Distributed Surveillance system utilizing a network of small but highly capable satellites. It could be deployed in phases, with successive phases providing improved coverage (more surface areas with shorter revisit times). This network could provide high resolution (targeting quality) imagery *directly* to tactical commanders and other required users. The platforms would utilize optical, multi-spectral, and radar imaging to achieve day and night, all-weather capability to *stare*, once fully deployed, at any point on Earth. This staring capability would be achieved by the handoff of coverage from satellite to satellite. The number of satellites deployed would be the number required so that there would always be one that could view the target. As one satellite "set" below the horizon, the next would pick up the image (see Figure 1). Because it would be directly accessible by a hierarchy of users, it could provide sensing of narrow or large areas and serve strategic, operational, and tactical needs. Accessibility would be direct, in real time, and users could share the imagery up and down the command chain to greatly enhance shared awareness.

Figure 1



A fully-deployed Distributed Surveillance system that would provide the ability to stare at any place on earth with imagery resolution of 50 centimeters or better would require a network of 500 to 700 satellites. This number reflects an ambitious space network beyond any we have yet deployed, and would be prohibitively expensive if the platforms followed traditional design. Instead, if design of the satellites draws on many recent, demonstrated advances in technology, all 500-700 would likely cost less than a single "mainframe" satellite now in use. Initially, a network of merely 70 satellites could provide ten-minute revisit time to all parts of the globe except the extreme polar regions.

Even this would mean at least a 500% improvement over what high-resolution military imagery satellites can provide today. The two “Keyhole” satellites (popularly referred to as KH-12) that are still the primary providers of optical and infrared imagery have elliptical orbits with perigees and apogees of roughly 300 to 1,000 kilometers. They orbit the earth about 15 times in a 24-hour period. Even assuming that they are moved to staggered orbits that could observe the same terrain, the best consistent revisit time that could be achieved would be roughly fifty minutes between passes. Two “Lacrosse” radar imaging satellites orbit at about 650 kilometers and also make just under 15 revolutions per day. An Enhanced Imaging System (“8X”) satellite (USA 144), providing both optical and radar imagery, was placed in medium earth orbit (2,600-3,100 kilometers) in 1999 in response to the concern of military officers during and after Desert Shield/Desert Storm that satellite imagery capabilities did not permit a wide enough viewing area or a long enough dwell time. Consequently, while the 8X boasts the latest and best optics of any US military satellite in use today, can take high resolution photos of 1,000 square miles at a time (compared to 100 square miles for the Keyhole), and can keep its cameras trained on a location longer than a Keyhole, it makes only 9.7 revolutions per day and suffers a 148-minute revisit time.[3]

What’s more, today’s imagery satellites have only limited ability to provide real-time, or even near-real-time pictures to commanders in theater. For example, until recently, Keyhole images were processed on board the satellite, stored as digital signals, and not transmitted until the satellite passed over a ground station in Greenland or the Pacific. The images were then retransmitted to the National Photographic Intelligence Center in Washington D.C. using commercial communications satellites. From there the signals were passed on to the CIA, the White House, and other intelligence agencies. That meant a typical delay of an hour or more before someone with National Command Authority even decided whether or not to pass the imagery down to the warfighters.

Today, the Keyhole electronic cameras can provide real-time transmission of images to ground stations via Milstar relay satellites, but getting them to commanders in the field can still suffer from technical and administrative delays.

> Despite lessons learned from the 1990-91 Gulf War, NATO forces participating in Yugoslavia as part of Operation 'Allied Force' have not fielded a real-time targeting capability the ability to pass images of enemy installations and troop formations directly from spacecraft…into the cockpit of fighter aircraft or other weapons systems.

[3] Sources included American Federation of Scientists, Jane’s Defense Weekly

> "We learned our lessons in the Gulf War but not well enough," said a US intelligence official. From target identification to weapons delivery, he said, "three to four hours is the best we can do".[4]

2.2 – Flexible, Survivable, and Cost Effective

Because the Distributed Surveillance system would be a network, satellites could be added or replaced as needed. Also, loss of one or more satellites would only degrade, not disable, the network. System capability would be achieved with the first satellite in orbit and grow rapidly as others were added to the network.

Because a DS system would largely exploit commercial digital processing derived off the shelf (COTS), and because it is now possible to build extremely capable satellites at a fraction of previous cost and in much smaller size, a Distributed Surveillance network could be developed and deployed in a very economical and cost effective manner. When one considers the billion-dollar-plus cost of present imaging satellites, and the cost for various weapons systems (over $5 billion for a new nuclear carrier; perhaps $100 million for an F-22 fighter), a Distributed Surveillance system is attractive because it would serve as an across-the-board force multiplier for every Service and their weapons systems.

2.3 – Milestones Along the Way

The Distributed Surveillance concept met with resistance in the early 1990's. This was due to several factors. First, there were many in the scientific and technical community who refused to believe that small imaging satellites were feasible. Their objections centered on the issue of image stabilization. This was a very difficult problem that was originally solved by adding mass to the traditional systems, resulting in very heavy and large satellites. Distributed Surveillance suggested an entirely different approach to the problem. Instead of cameras and massive stabilization devices, Distributed Surveillance proposed using digital focal plane arrays (charge coupled devices) and achieving electronic stabilization by pixel to pixel comparison. Although this process was successfully demonstrated at the Los Alamos National Laboratory, many in the surveillance scientific community refused to accept the concept. Second, many in the Services saw Distributed Surveillance as an ambitious space command and control project that was a direct threat to force structure (i.e., tanks, ships, and airplanes). Finally there was the "Black World" (one couldn't even say NRO – National Reconnaissance Office – in those days) that did not communicate well outside its black boundaries and was apparently loath to open its doors to the commercial world.

The concept was admired, but not pursued. The military liked the potential benefits of a Distributed Surveillance system but wasn't willing to give up an aircraft carrier or a tactical fighter wing for the capability. That short-sighted attitude may be moderating somewhat today as warfighters see the force multiplying advantages of Network Centric Warfare concepts. Thus, it is well to revisit the Distributed Surveillance paradigm. This is particularly relevant in view of the dramatic progress made in space over the past decade.

[4] "Allies Still Lack Real Time Targeting," Jane's Defence Weekly, April 7, 1999

3.0 – The Last Ten Years In Space

It is interesting to look at space-based network initiatives during the 1990s. The capabilities we now have or will soon field exceed the DRS predictions by a wide measure.

3.1 – Small Reconnaissance Satellite Study

In 1996, at the request of U.S. House and Senate Intelligence Committees, John Deutch, then Director of Central Intelligence, formed the Small Satellite Review Panel "to investigate the feasibility of shifting to smaller satellites in our space-borne reconnaissance assets."[5] The panel's report, also known as the "Hermann report" for the panel's chairman, Bob Hermann, included the following statements:

> The most important judgment of the Panel is that now is an appropriate time to make a qualitative change in the systems architecture of the nation's reconnaissance assets.
>
> The technology and industrial capabilities of the country permit the creation of effective space systems that are substantially smaller and less costly than current systems.
>
> The Imint [image intelligence] Directorate…advocates a new generation of imaging satellites. Individual spacecraft would be only half the size and cost of the current and planned versions.[6]

The report cited cost savings, robustness, flexibility, opportunity to continually upgrade by incorporating new technologies and operational techniques, and the positive impact building such a system would have on the industrial base as reasons to move to more smaller satellites.

While the report did not recommend accepting the design of one of "several commercial space imaging companies" because "their performance characteristics were not as great as the NRO proposals and would not satisfy many of our core information requirements," it did note "the role of the emerging commercial sector."

> A substantial segment of the companies which now make up the industrial base upon which the NRO depends are investing with others in commercial satellite ventures. If at least some of them are successful, they will create new industrial capabilities and new systems capable of delivering products of value for our information needs. In addition, the commercial communications sector is investing heavily in systems which involve large numbers of smaller satellites. Taken together, they will create a new base of industrial capabilities, components, systems skills and useful products which should be exploited by the nation for its national security needs.[7]

[5] "Report by the DCI's Small Satellite Review Panel," press release, U.S. House of Representatives Permanent Select Committee on Intelligence, June 28, 1996.
[6] Small Satellite Review Panel Report (declassified version), U.S. House of Representatives Permanent Select Committee on Intelligence, June 27, 1996.
[7] Ibid

3.2 – Commercial Satellite Ventures

The predictions of the 1996 panel were not long in coming to fruition. While the first commercial ventures have not been as successful as their developers hoped, they are developing technologies that could be of great benefit to a DS system.

3.2.1 – Iridium[8]

Sixty-six satellites were launched during 1997 and 1998 to form a network to support Iridium LLC, "the world's first handheld global satellite telephone and paging service." The satellites, which weigh 700 kilograms, are arranged six each in 11 orbital planes. They orbit at 780 kilometers above the earth, which is close enough to receive the signals of currently available handheld communications devices, yet have an expected orbital life of five to eight years. The launch vehicles used to place this system were the Boeing Delta 11 (5 satellites per launch), the Russian Khrunichev Proton (7 satellites per launch), and the China Great Wall Long March 2C (2 satellites per launch).

The concept for the Iridium system was proposed in 1987 by Motorola engineers Ray Leopold, Ken Peterson, and Bary Bertiger. The first complete Iridium satellite was delivered by Motorola in 1996, the same year the first ground station gateway was inaugurated in Japan. Costs originally estimated at $2.6 billion had by 1997 climbed to more than $5 billion. The system entered commercial service in November 1998. Less than a year later, in August 1999, Iridium filed for Chapter 11 bankruptcy protection. The system had proved itself technically, but could not attract enough subscribers to stay in business. In March 2000, Aviation Week & Space Technology reported that Iridium was making plans to destroy their satellites, "deorbiting" them by bringing them down to a lower orbit from which they would make "uncontrolled reentries" during which they would burn up in the atmosphere.[9] Yet, as of May 2000, Iridium was still looking for a buyer for its assets.

3.2.2 – Teledesic[10]

Teledesic is building "a global, broadband Internet-in-the-sky." Founded in 1990 by Craig McCaw, who helped pioneer the cellular-telephone industry in the 1980s, the company completed its initial system design in 1994 and was granted an FCC license in 1997. Motorola joined the effort to build the Teledesic Network in 1998, and Teledesic signed a major launch contract with Lockheed Martin in 1999. Bill Gates is one of Teledesic's primary investors. Service is targeted to begin in 2004. The company estimates total cost of design, production, and deployment at more than $9 billion.

The Teledesic Network plans to use 288 satellites at an altitude "under 1,400 kilometers," divided into 12 planes, each with 24 satellites. In March 2000, McCaw was identified as a potential buyer for Iridium's assets, but as of May, no deal had been struck.

[8] http://www.iridium.com

[9] "Iridium Takes Initial Steps Toward System Shutdown," Aviation Week & Space Technology, March 27, 2000, p. 39.

[10] http://www.teledesic.com

With the ability to "handle multiple channel rates, protocols and service priorities," the Teledesic Network promises to provide "the flexibility to support a wide range of applications including the Internet, corporate intranets, multimedia communication, LAN interconnect, wireless backhaul, etc. In fact, flexibility is a critical network feature, since many of the applications and protocols Teledesic will serve in the future have not yet been conceived."

The Teledesic Network is being designed to support millions of simultaneous users. According to company information, multiple manufacturers will offer a family of user equipment to access the network. Using "standard" user equipment, most users will have two-way connections that provide up to 64 Mbps on the downlink and up to 2 Mbps on the uplink. Higher-speed terminals will offer 64 Mbps or greater of two-way capacity.

3.2.3 – ICO[11]

ICO Global Communications was established in 1995 "to provide satellite-enabled global mobile personal communications services."

ICO planned to use a constellation of satellites operating at an altitude of 10,390 kilometers, divided equally between two orthogonal planes, each inclined at 45 degrees to the equator, to provide "complete, continuous overlapping coverage of the Earth's surface."

The plan called for the satellites to operate in both S-band and C-band, using digital onboard processing and time-division multiple access (TDMA) to handle up to 4,500 simultaneous phone calls per satellite.

Like Iridium, ICO filed for Chapter 11 bankruptcy protection in August 1999. Later that year, Teledesic's McCaw agreed to lead a group of investors in providing up to $1.2 billion to ICO to enable the company to emerge from bankruptcy. ICO now hopes to "begin introducing it satellite services" in 2001.

3.2.4 – Globalstar[12]

This $3.8 billion venture, which also offers worldwide voice services, seems to be succeeding by learning from the mistakes of Iridium and ICO. It uses 48 satellites in 762 nautical mile orbits. But the Globalstar strategy is to leave as much of the communications technology on the ground as possible. Their satellites are little more than relay platforms. Globalstar customer phones work only if they are within 4,000 kilometers of one of the company's ground stations. Thus, the Globalstar system does not provide a good model of what a DS system might be like.

4.0 – DRS System Specifications: Then and Now

In 1991, when Dr. Keyworth, with Bruce Abell and Mario Fiori at the Hudson Institute, published the study, "The Impact of High-Speed Digital Networks on U.S. Defense"[13] they asserted that "sensors, image stabilization, on-board processing, and a high-speed digital

[11] http://www.ico.com
[12] http://www.globalstar.com
[13] "The Impact of High-Speed Digital Networks on U.S. Defense: Distributed Remote Sensing as a New Force Multiplier," Hudson Institute, August 1991 (DARPA Contract DAEA18-90-C-0031)

communication network are all technically feasible elements of a system."[14] They envisioned that "small (on the order of 100-200 kilogram payload) optical imaging satellites can obtain diffraction-limited resolution by taking advantage of clever uses of massive on-board data processing…[and] distinguish ground features substantially less than one meter apart."

What is the reality today? What is the state-of-the-art in space-based imaging and networks capabilities? How does it compare to the predictions made by the proponents of Distributed Remote Sensing (DRS) almost 10 years ago?

Miniaturization has radically enhanced the capabilities of very lightweight satellites.[15] The combination of miniaturization and "high density interconnection programs" have made possible consideration today of micro-satellites weighing less than 30 kilograms that could provide "mid-resolution earth imaging."[16]

Microengineering and microelectromechanical systems (MEMS) are subjects of considerable current interest involving research and development throughout the world. MEMS has significant potential application to satellite subsystems.

Miniaturization can only go so far in reducing the size of reconnaissance satellites, however. Sensor and antenna aperture reduction is limited by the laws of physics. Still there might even be ways around these limitations, such as dispersing the aperture area over several smaller vehicles.[17]

4.1 – Specifications

The 1991 study proposed gradually building up to a system architecture numbering 500 to 700 satellites that would form an orbiting net around the globe at an average altitude of 500 kilometers. This altitude was chosen as the best compromise between the requirements for high-resolution imagery and the requirements for preserving the lifetime of the satellites from atmospheric drag. At 500 kilometers, several techniques could be used to prolong the satellites' lifetime, including eccentric orbits and the use of small thrusters. While each satellite might last only a few years, it was argued that the rate of advancement in sensor and computing technologies made such a "turnover" rate quite appropriate.

> Light, cheap satellites could be operated at low altitudes and allowed to decay from orbit, since their lifetimes would be comparable to the obsolescence times of their sensors and computers.[18]

[14] "The Impact of High-Speed Digital Networks on U.S. Defense: Distributed Remote Sensing as a New Force Multiplier," p.2
[15] See "Miniaturization: Looking Back to Look Ahead" (AIAA 99-4429), paper given by Matt Bille and Martin Oetting of ANSER at the AIAA Space Technology Conference & Exposition, September 28-30, 1999.
[16] "Conceptual Designs for On-Demand Microsatellites and Air-Launched Launch Vehicles" (AIAA 99-4534), paper given by Kevin D. Bell and Ruth L. Moser of The Aerospace Corporation.
[17] "The Inevitability of Small," Alan H. Epstein, Aerospace America, March 2000, p. 35.
[18] "The Impact of High-Speed Digital Networks on U.S. Defense," p. 13.

If anything, the pace of technology advancement has only accelerated. It can reasonably be argued today that the constellation of DS satellites could be put on a schedule for replacement every two to three years.

Three types of imagery were proposed for inclusion in the DRS system: optical, infrared, and radar. The optical element was described as follows:

> The higher-resolution optical system could be built around a monolithic or segmented mirror. Those images would be recorded, not as sweeps, but as whole frames at a time, like a camera. In a process similar to that employed in commercially available electronic cameras, the image would be recorded on charge-coupled devices (CCDs) in an array of perhaps 2000 by 2000. Resolution would be a function of the footprint on the ground for each of those 4 million pixels. The CCDs now available have enough light-gathering sensitivity to capture daylight images in short exposures. Under the best conditions, the system could produce images virtually as fast as it could be aimed and steadied. When less light is available, it may be necessary to take multiple short exposures…of the same scene, then electronically add the images to collect enough light for usable imagery.[19]

Digital imaging technology now available goes well beyond the requirements spelled out in the 1991 study.

The authors of the study observed that if sensor technology could achieve the desired resolution "with the satellites in higher orbits, say 700 kilometers, then only half as many would be required (to ensure whole earth coverage)." Today, digital camera technology has advanced to the point that the optical resolution requirement could easily be met from the higher altitude. Infrared and radar imaging technologies, while much improved from those available 10 years ago, still do not match optical resolutions; but they too would perform more than adequately for their intended purposes from the higher altitude.

Perhaps one question worth asking today that was not addressed in the Hudson Institute study is whether or not a video imaging capability ought to be added to Distributed Surveillance satellites. It is widely believed that the latest "Keyhole" satellites already employ this technology. The questions that needs to be answered for a DS system are 1) whether the resolution of a sufficiently small video camera would warrant its inclusion, 2) whether the value of real-time video streaming from satellites would justify the bandwidth requirement, and 3) whether a rapid sequence of digital optical "snapshots" would provide virually the same movement tracking value at less "cost."

The Hudson Institute study proposed on-board data processing using "parallel processors" and "hybrid computing approaches intended for commercial uses (analog signal processors that are digitally addressable) with promise of providing gigaflops of processing capable of direct analysis of data taken off the imaging pixels. This approach takes advantage of the roughly 100-to-1 improved efficiency of analog chips compared to digital for signal processing, but retains the essential feature of being able to program (and re-program) the processor via software.

[19] "The Impact of High-Speed Digital Networks on U.S. Defense," pp. 14-15.

Affordable, lightweight data processing is not likely to be a stumbling block for these new satellites."[20]

Perhaps none of the points made by the authors of the study was more understated. "Lightweight data processing" continues to revolutionize information technology. Recent developments in electro optics technology to develop low power, lightweight, ultra high speed, compact processors are but one example.[21]

4.2 – Data Processing Tasks

The 1991 study listed five data-processing tasks to be performed on-board each satellite: image stabilization, registration, enhancement, recognition, and hand-off.

Image stabilization was to be achieved through data processing: pixel-to-pixel re-registration of multiple closely-spaced "snapshots." This approach is as appropriate today as it was 10 years ago, with the major difference being that today such "snapshots" could be made in lower light conditions and more closely spaced in time, thanks to advances in cameras and lenses.

In 1991, Dr. Canavan's suggested approach to image stabilization was to use a data processing solution rather than a mechanical device that would add weight to each satellite:

> Taking a series of snapshots, in rapid succession, say one millisecond intervals, and re-registering them using pixel-to-pixel correlation techniques. Thus, for example, a slight rotation or translation between frames that would otherwise result in blurring is effectively removed, and the viewer, who sees only the sum of the now-registered individual images, sees a stable, vibration-free image. That is, the satellite may vibrate, but the imagery will not…Removing the vibration in this manner can yield resolution that is close to the diffraction limit of the optics and, most important, without adding much weight.
>
> The data processing required to accomplish this task, as well as other, more demanding ones, is admittedly massive. Yet it is within today's state-of-the-art in digital electronics. For example Raymond Kurzweil reported, in the workshop held on 1-2 April, on a hybrid analog-digital machine-vision chip capable of processing a 500-by-500-pixel focal plane array at 2.5 billion instructions per second (GIPS), yet costing only a few hundred dollars…16 of them could be combined to process a 4-megapixel square array at a speed of 40 GIPS, and at a cost of about $5,000.[22]

Today's technology would allow far greater performance of such a system at even lower cost. Also, there are other stabilization solutions that have been tested in recent years, such as the spatio-temporal filter-based active vibration suppression technique.[23]

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[20] "The Impact of High-Speed Digital Networks on U.S. Defense," pp. 15-16.

[21] See "Multiprocessors in Memory 5th Generation Computer Simulation System (AIAA 99-4505), and "Multifunctional On-Board Processing for Future Spacecraft" (AIAA 99-4506).

[22] "The Impact of High-Speed Digital Networks on U.S. Defense," p. 9.

[23] See "Robust Line-of-Sight Stability and Jitter Compensation Using Spatio-Temporal-Filtering Based Control Approaches" (AIAA 99-4587).

Another, though lesser, concern was atmospheric image distortion. Dr. Canavan's image-processing stabilization technique was advanced as a possible solution here also, along with the use of segmented or adaptive optics.

Image registration was to be accomplished by using a universal coordinate system made possible by Global Positioning System (GPS) satellites. The value of GPS registration—first validated by the Joint Surveillance/Target Attack Radar System (JSTARS) during the Gulf War—is well-recognized today. GPS-guided bombs achieved very high accuracy against stationary targets during Operation Allied Force, the 1999 Kosovo war. The study also made mention of a Defense Mapping Agency (DMA) project to create "a whole-earth digitized terrain data base" that would be "available in electronic form containing universal registration information." That project was picked up by the National Imagery and Mapping Agency (NIMA), created in 1996 by combining the assets of the DMA and other government mapping entities, which continues to build a digitized terrain data base today.

Image enhancement was to consist of "re-imaging" the same features, using sub-pixel registration; and through the process of "kineopsis," whereby images could be generated from slightly different perspectives, offering "the added benefit of a degree of three-dimensional analysis of the imagery." The solution to the **image recognition** challenge posed by **image hand-off** from one satellite to another was to identify "unique feature information" from the image and use that for common reference. At another level, it was suggested, initial identifications of classes of objects (tanks, planes, ships, etc.) could be made by using data processing to compare objects in images against "an on-board library of those objects viewed from varying angles." The authors also suggested the possibility of using computing—data processing—to "normalize" the images produced by the satellites constantly changing their perspective on a defined area as they passed overhead to a "standard" view. All of these solutions have been validated in the past 10 years.

5.0 – Recent Military Initiatives and Studies

At the AIAA Space Technology Conference in September 1999, Mark E. Davis of the Air Force Research Laboratory, Rome Research Site, presented a paper entitled "Technology Challenges in Affordable Space Based Radar."[24] The Air Force, Davis wrote, came to the conclusion in a 1995 migration to space study that there were "no technical impediments to moving tactical surveillance radar to space." Encouraged by the "cost effective" satellite system put into place by Iridium, the Air Force Research Laboratory commissioned a Space Based Radar Integrated Product Team in 1998. Davis' paper outlined "the methodology and rationale for the critical enabling technologies needed for a Space Based Radar."

The Discoverer II program is a current US Air Force, Defense Advanced Research Projects Agency (DARPA), and National Reconnaissance Office (NRO) joint initiative. The NRO hopes to launch a Discoverer II constellation of 24 small radar imaging satellites orbiting at 700-800 kilometers above the earth in the 2002 timeframe "to achieve broad-area, all-weather, near-continuous radar access that…will allow for direct tasking control to a deployed Joint Task Force tactical commander."[25] This projected program would enable a revisit rate of about 15 minutes to

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[24] "Technology Challenges in Affordable Space Based Radar" (AIAA 99-4474).

[25] Discoverer II (DII) STARLITE, Military Space Programs, Space Policy Project, Federation of American Scientists (http://www.fas.org/spp/military/program/imint/starlight.htm)

most areas of the earth. Still, these satellites would generate only radar imagery and thus would provide neither staring capability nor the full spectrum of imagery.

6.0 – Distributed Surveillance as a backbone for NCW

It is important to note that a Distributed Surveillance network is not intended to be just an ISR system. As envisioned, Distributed Surveillance in its simplest terms would be a visualization-based command and control network providing both targeting quality imagery and an integral command and control. Tied into the planned Global Information Grid, it could provide both a Common Relevant Operational Picture (CROP) and an instantaneous, totally fused, tactical picture. Commanders at different echelons ashore or afloat or in the air would be able to view and communicate about the same tactical/operational/strategic picture in real time. These pictures could be overlaid with tracks from other sensors linked to the Distributed Surveillance network. Target imagery could be sent to aircraft in flight. Missiles could be steered to their targets. BDA would be available as soon as the smoke cleared. Because coverage would be world wide, civilian leaders, commanders, and warfighters would be able to view any place on earth in real time.

> Effective linking achieved among entities in the battlespace…requires the establishment of a robust, high performance information infrastructure, or *infostructure*, that provides all elements of the warfighting enterprise with access to high-quality information services.[26]

6.1 – Importance Of An Infostructure To Realization Of Both DS And NCW Benefits

Developing and deploying such a global infostructure is critical to realizing the benefits of a Distributed Surveillance system, and to the concept of Network Centric Warfare generally.

The authors of the 1991 DRS study predicted that the real challenge would be developing the architecture and command/control network—multi-user high-bandwidth space and terrestrial communications networks—to take advantage of such a system of satellites.

> Even though communications satellites or navigation satellites are increasingly being developed as wide-area space networks, or as elements to be integrated into heterogeneous space C3I systems, most newly proposed *imaging* systems are still envisioned as stand-alone or operating in small clusters.
>
> For that reason, there must be more attention paid to developing a flexible, high-bandwidth communications infrastructure into which new systems can be integrated (i.e., which would permit local use, if not "virtual ownership," of global systems). Just as new satellite technologies are the enablers for high-performance, affordable space capabilities, new networks will be the enablers for integrated, global space systems.[27]

[26] Network Centric Warfare, David S. Alberts, John J. Garstka, and Frederick P. Stein, DoD C4ISR Cooperative Research Program (CCRP), Washington, D.C. 1999, second edition, pp 91-92.
[27] "The Impact of High-Speed Digital Networks on U.S. Defense," pp. 24-25.

This supports the view of the authors of NCW, who caution that in order "to fully leverage Information Superiority and apply the concepts of NCW…a suitable infostructure is required."[28]

> We may be…trapped in a vicious cycle, where a lack of infostructure will hamper the ability of innovators by making it difficult to imagine what is possible and to test out new ideas, and by making the concepts that are developed seem beyond reach.[29]

Both of these perspectives argue strongly for deployment of a Distributed Surveillance system.

A Distributed Surveillance network could flexibly adapt to the entire spectrum of military missions in both peacetime and war. The system could support the continuum of missions from disaster relief, to counter narcotics, to peace keeping, to regional conflict (multiple if needed), to global war. The intelligence and reconnaissance capability of the system would not only yield a quality of information that would allow national leaders to make timely decisions that could preempt potential conflicts through diplomatic or military action, but also serve as a deterrent to those who knew that they could not easily hide from surveillance.

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[28] Network Centric Warfare, p. 9.
[29] Ibid, p. 10.