DEFENSE ADVANCED RESEARCH PROJECTS AGENCY

STRATEGIC PLAN

FEBRUARY 2007

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DARPA's Strategic Plan

1. Purpose

This document describes the Defense Advanced Research Projects Agency's (DARPA) strategy, as required by Section 2352, Title 10 of the United States Code. It provides a top-level view of DARPA's activities for Congress, the research community, and various elements of the Department of Defense (DoD).

This strategic plan describes DARPA's mission, business processes, research thrusts and objectives, and research projects that achieve the objectives.

DARPA's original mission, inspired by the Soviet Union beating the United States into space with Sputnik, was to prevent technological surprise. This mission has evolved over time. Today, DARPA's mission is to prevent technological surprise for us *and* to create technological surprise for our adversaries. Stealth is one example of how DARPA created technological surprise. DARPA's mission is discussed in detail in Section 2.

DARPA's strategy for accomplishing its mission is embodied in strategic thrusts. Over time, as threats and opportunities change, DARPA's strategic thrusts evolve. Today there are nine strategic thrusts, detailed in Section 3, that are key national security research areas building the foundations for innovative joint warfighting capabilities to defeat existing and emerging national security threats.

DARPA's main tactic for executing its strategy is to constantly search worldwide for revolutionary high-payoff ideas and then sponsor projects that bridge the gap between fundamental discoveries and the provision of new military capabilities

2. DARPA

2.1. Mission, Management, and Organization

DARPA's mission implies one imperative for the Agency: radical innovation for national security. DARPA's business processes reflect this in a straightforward way: bring in expert, entrepreneurial program managers; empower them; protect them from red tape; and quickly make decisions about starting, continuing, or stopping research projects.

To maintain an entrepreneurial atmosphere and the flow of new ideas, DARPA hires program managers for only 4 to 6 years because the best way to foster new ideas is to bring in new people with fresh outlooks. New people also ensure that DARPA has very few institutional interests besides innovation, because new program managers are willing to redirect the work of their predecessors – and even undo it, if necessary. Since program managers are not at DARPA for a career, they are willing to pursue high-risk technical ideas even if there is a reasonable chance the idea will fail. Another element of DARPA's strategy is to cultivate entrepreneurial performers in universities and industries by funding ideas that represent revolutionary, vice evolutionary, technical achievements.

Another unique feature of DARPA is that the Agency has very limited overhead and no laboratories or facilities. Again, the idea is to minimize any institutional interests that might distract the Agency from its imperative for innovation.

DARPA's current organizational structure is shown in Figure 1. This chart implies more formal structure than is actually the case at DARPA. In general, the character and mission of DARPA offices must change over time as threats to U.S. national security change and the technological

opportunities change. Offices are fluid, being created and disbanded as appropriate to keep DARPA's organization forward-looking, relevant, and responsive to new opportunities.

DARPA has found that physically co-locating experts with similar or complementary interests leads to the generation of entrepreneurial ideas. The office directors recruit outstanding program managers and develop the office synergy, while keeping the program managers broadly on track with the office theme.

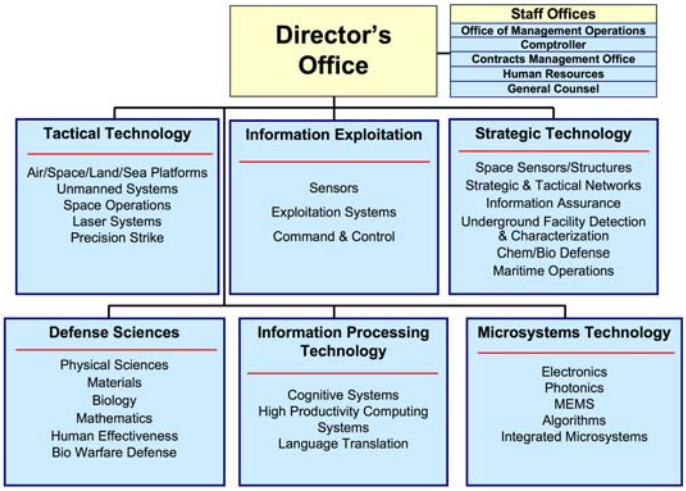

Figure 1: DARPA's organization.

The themes of each office are derived from DARPA's strategy and set by the DARPA Director as a result of assessments of technical advances worldwide and interactions with the Secretary and Under Secretaries of Defense, Chairman of the Joint Chiefs of Staff, Combatant Commanders, Service Secretaries, Service Chiefs, Service units, and the staffs at each DoD level.

There are two basic types of technical offices at DARPA: technology offices and systems offices. The technology offices focus on new capabilities and component technologies that might have significant national security applications. Currently, these offices are the Defense Sciences Office, Microsystems Technology Office, and Information Processing Technology Office. The systems offices focus on solutions to military problems and technology programs leading to products that more closely resemble a specific military end-product; i.e., an item that might eventually be in the military inventory. These offices are the Tactical Technology Office, Strategic Technology Office, and Information Exploitation Office. As a practical matter, a fair amount of overlap exists between the two types of offices; the work in the technology offices often shapes the work of the systems offices, and vice versa.

In addition to the technical offices, DARPA has staff offices that support overall agency operations: Office of Management Operations, which includes facilities, information resources, and security; Comptroller, which oversees financial matters; Contracts Management, which supervises in-house contracting capabilities; Human Resources to recruit and retain staff; and General Counsel, which provides legal advice.

Congress has granted DARPA authorities to assist the Agency in carrying out its unique mission in accordance with its flexible management philosophy. For example, DARPA has an Experimental Personnel Authority that allows it to maintain its entrepreneurial edge by hiring expert program managers from industry at competitive salaries, and do it much faster than under normal Civil Service rules.[1] The DoD, as a whole, now has a similar authority – one actually modeled on DARPA's authority – and DARPA is also making use of it.[2] DARPA also has the use of Other Transactions Authorities, which allow alternative contracting arrangements than the Federal Acquisition Regulations.[3]

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1 5 USC 3104 Note

2 5 USC 9903

3 10 USC 2371 and 10 USC 2371 Note

2.2. DARPA's Role

DARPA is a Defense Agency with a specific role within DoD. DARPA is not tied to a particular operational mission: DARPA supplies technological options for the entire Department, and is designed to be a specialized "technological engine" for transforming DoD.

Near-term needs and requirements generally drive the Army, Navy, Marine Corps, and Air Force to focus on those needs at the expense of longer-term changes. Consequently, a large organization like DoD needs a place like DARPA whose *only* charter is radical innovation.

DARPA looks beyond today's known needs and requirements. As military historians note, "None of the most important weapons transforming warfare in the 20th century – the airplane, tank, radar, jet engine, helicopter, electronic computer, not even the atomic bomb – owed its initial development to a doctrinal requirement or request of the military."[4] *None* of them. Adding to this list, DARPA can include unmanned systems, stealth, the global positioning system (GPS), which was preceded by a DARPA system called Transit, and Internet technologies.

DARPA's approach is to imagine what capabilities a *future* military commander might need and accelerate those capabilities into being through technology demonstrations. These could not only provide options to the commander, but also change minds about what is technologically possible today and how current and future objectives could be met. DARPA often "works the seams" among the military Services to develop new and truly joint capabilities that no military Service could or would support by itself.

Figures 2 and 3 illustrate how DARPA works. These figures show where science and technology (S&T) funding is invested along a notional timeline from "Near" to "Far," which is indicative of the "time to go" for an S&T investment to be incorporated into an acquisition program.

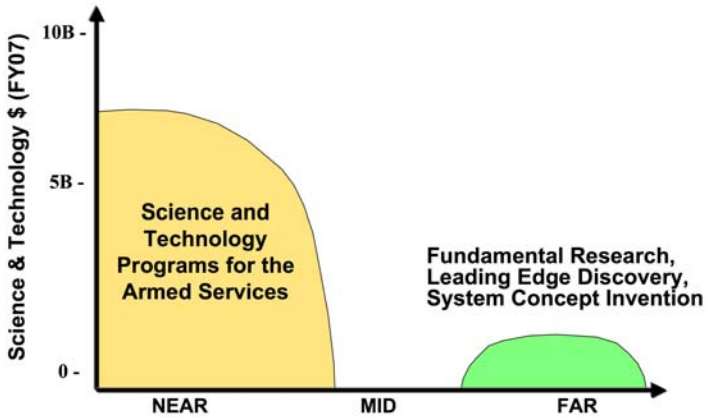

Figure 2: Timelines and investments in science and technology.

The Near bubble in Figure 2 represents most of the work of the Service S&T organizations. Service S&T tends to gravitate toward the Near side because the Services emphasize providing technical capabilities critical to the mission requirements of *today's* warfighter. This is excellent S&T and is crucial because it continuously hones U.S. military capabilities, e.g., improving the efficiency of jet engines. It is typically focused on known systems and known problems.

The Far bubble in Figure 2 represents fundamental discoveries where new science, new ideas and radical new concepts typically first surface. People working on "the Far side" have ideas for entirely new types of devices or new ways to put together capabilities from different Services in a revolutionary manner. But the people on the Far side have a difficult, sometimes impossible

[4] John Chambers, ed., *The Oxford Companion to American Military History* (New York: Oxford University Press, 1999) p. 791.

time obtaining funding from those on the larger Near side because of the Near side's focus on improvements against current, known problems.

Whenever there have been technological surprises, the people typically surprised are on the Near side. There are always people on the Far side who believed that something could be done, but they were not able to obtain the resources to execute their ideas. The Soviets beating the U.S into space with Sputnik in 1957 is a prime example. Sputnik motivated President Eisenhower to create DARPA in 1958 to bridge the gap between these two groups.

DARPA's mission, shown in Figure 3, is to find the people and ideas on the Far side, and accelerate those ideas to the Near side as quickly as possible.

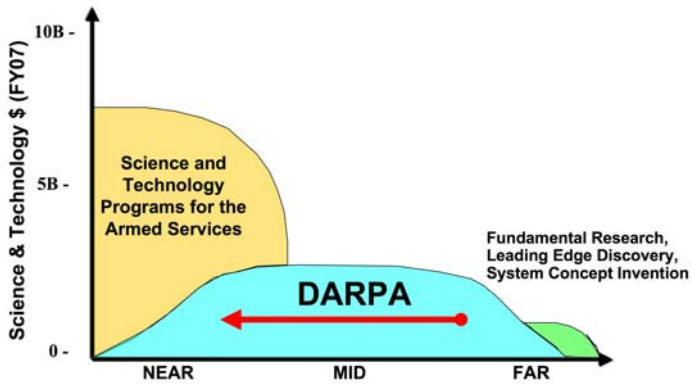

Figure 3: DARPA's role in science and technology.

These new capabilities often stem from developments at the component technology level, such as those promoted by DARPA's Core Technologies thrust (Section 3.9). Hence, DARPA mines fundamental discoveries – the Far side – and accelerates their development and lowers their risks until they prove their promise and can be adopted by the Services. DARPA's work is high-risk and high-payoff precisely because it bridges the gap between fundamental discoveries and their military use. Even though much of DARPA's work takes years to reach payoff, DARPA's flexibility and ability to change direction quickly allow it to react swiftly to emerging threats during a conflict. The inset discussion, "Shaping DARPA's Strategy" (p. 5) provides a more detailed discussion of how DARPA chooses its programs.

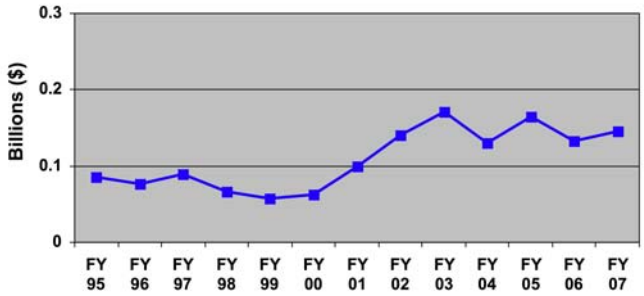

Figure 4: DARPA's Basic Research funding.

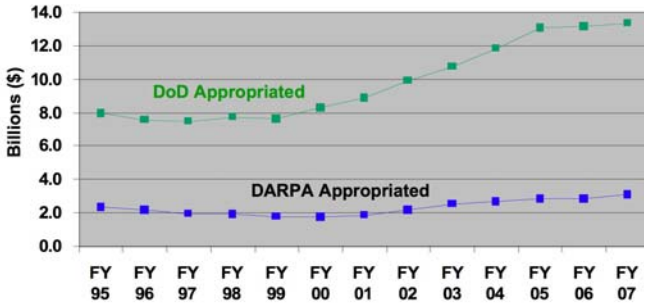

Figure 5: Total S&T funding in DoD and DARPA.

Basic research is primarily supported by the Service S&T organizations, such as the Office of Naval Research, and other federal agencies like the National Science Foundation, the National Institutes of Health, and the Department of Energy. Basic research creates new knowledge, whereas DARPA also creates new capabilities for national security by accelerating that knowledge and capacity into use.

DARPA uses its 6.1 funding to "get a seat at the table" with basic research performers so that DARPA can understand what is going on at the forefront of science and can mine that research for new Defense capabilities. Figure 4 shows DARPA's funding of Far Side basic research since FY 1994.

Shaping DARPA's Strategy

Basic Challenge and Focus: A basic challenge for any military research organization is matching military problems with technological opportunities, including the new operational concepts those technologies make possible. Parts of this challenge are extremely difficult because: (1) some military problems have no easy or obvious technical solutions; and (2) some emerging technologies may have far-reaching military consequences that are still unclear. DARPA focuses its investments on this "DARPA-hard" niche – a set of technical challenges that, if solved, will be of enormous benefit to U.S. national security, even if the risk of technical failure is high. Other factors also shape DARPA's investments:

- DARPA emphasizes research the Services are unlikely to support because it is risky, does not fit their specific role or missions, or challenges existing systems or operational concepts;
- DARPA focuses on capabilities military commanders might want in the future, not what they know they want today;
- DARPA insists that all programs start with good ideas and good people to pursue them; without both of these things, DARPA will not start a program.

Notable Features: DARPA's decision-making process is informal, flexible, and yet highly effective because it focuses on making decisions on specific technical proposals based on the factors discussed above.

There are two reasons for this. DARPA is a small, flat organization rich in military technological expertise. There is just one porous management layer (the Office Directors) between the program managers and the Director. With less than 20 senior technical managers and about 140 technical program managers, it is easy to make decisions. This management style is essential to keeping DARPA entrepreneurial, flexible and bold. DARPA's management philosophy is to pursue fast, flexible, and informal cycles of "think, propose, discuss, decide, and revise." This approach may not be possible for most larger government agencies, but it has worked well for DARPA.

The Basic Process: DARPA uses a top-down process to define problems and a bottoms-up process to find ideas, involving the staff at all levels. DARPA's management and program managers identify "DARPA-hard" problems by talking to many different people and groups. (See "DARPA's Outreach" on p. 6) This process includes:

- Specific assignments from the Secretary of Defense, Under Secretary for Acquisition, Technology and Logistics, or Director, Defense Research and Engineering;
- Requests for help from the Service Secretaries and Chiefs, Joint Staff, and Unified Combatant Commands;
- Discussions with senior military leaders on "What are the things that keep you awake at night?";
- Research into recent military operations to find situations where U.S. forces have limited capabilities and few good ideas;
- Discussions with Defense Agencies such as the Defense Threat Reduction Agency, the National Geospatial-Intelligence Agency, the Defense Information Systems Agency, and the Defense Logistics Agency;
- Discussions with intelligence community agencies such as the Central Intelligence Agency and the National Security Agency; and
- Discussions with other government agencies or outside organizations such as the National Science Foundation and the National Academy of Sciences.
- Visits to Service exercises or experiments.

During DARPA's program reviews, which occur throughout the year, DARPA's upper management looks for new ideas from program managers (or new program managers with ideas) for solving these problems. At the same time, management allocates funds for exploring highly speculative technology that has far-reaching military consequences.

Program managers get ideas from many different sources, such as:

- Their own technical communities;
- Suggestions from DoD advisory groups, such as the Defense Science Board and Service science boards;
- Suggestions from DARPA-sponsored technical groups, including the Information Science and Technology Study Group and the Defense Science Research Council;
- Suggestions from industry or academia, often in response to published Broad Agency Announcements or open industry meetings such as DARPATech;
- Surveys of international technology;
- Breakthroughs in DARPA or other research programs; and,
- Small studies and projects used to flesh out ideas, often referred to as "seedlings."

DARPA's strategy and budget is reviewed thoroughly by the Under Secretary for Acquisition, Technology and Logistics and Director, Defense Research and Engineering.

Vetting a Program: During reviews of both proposed and on-going programs, DARPA's assessment is often guided by a series of questions. These seemingly simple queries help reveal if a program is right for DARPA:

- What is the program trying to do?
- How is it done now and what are the limitations?
- What is truly novel in the approach that will remove those limitations and improve performance? By how much?
- If successful, what difference will it make?
- What are the interim technical milestones required to prove the hypothesis?
- What is the transition strategy?
- How much will it cost?
- Are the programmatic details clear?

Figure 5 shows DARPA's total S&T funding (Budget Activities 6.1, 6.2, and 6.3) in comparison to DoD's overall S&T budget. DARPA typically accounts for about 25 percent of DoD's S&T budget. This is in line with the common industry practice of devoting about 75 percent of R&D funding to product improvement but allocating 25 percent for new ideas, products, and markets.

By mining the Far side and bridging the gap between what *might be* done and what *is* done, DARPA attempts to prevent technological surprise for the United States, while creating technological surprise for our adversaries.

2.3. Shaping Programs

DARPA's senior management meets frequently with civilian and military leaders throughout the DoD to understand operational challenges, discuss with them what DARPA is working on that might help, and ask them the classic question, "What are the operational challenges that cause you the deepest concern? What are the problems that keep you up at night?" (See inset, "DARPA's Outreach.") These discussions, coupled with constantly monitoring the "Far side" for potential solutions, keep DARPA's strategy matched with DoD's hardest technical problems and greatest technical opportunities.

To keep current with the real-life facts-on-the-ground, several times a year DARPA's senior leadership and technical program managers visit military bases, commands, training centers, and other facilities to talk with warfighters and get a sense of their problems (Figure 6).

DARPA's Outreach

Among the individuals who have been briefed on major elements of DARPA's current strategy are:

- Vice President Richard B. Cheney
- Secretary of Defense Donald H. Rumsfeld
- Deputy Secretary of Defense Gordon R. England
- Secretary of the Army Dr. Francis J. Harvey
- Secretary of the Navy Dr. Donald C. Winter
- Secretary of the Air Force Michael W. Wynne
- Under Secretary of Defense for Acquisition, Technology and Logistics Kenneth J. Krieg
- Under Secretary of Defense for Intelligence Stephen A. Cambone
- Vice Chairman, Joint Chiefs of Staff, Admiral Edmund P. Giambastiani, Jr.
- Army Chief of Staff General Peter J. Schoomaker
- Chief of Naval Operations Admiral Michael G. Mullen
- Air Force Chief of Staff General Michael T. Moseley
- Commandant of the Marine Corps General Michael W. Hagee
- Commander, U.S. Special Operations Command, General Bryan D. Brown
- Commander, U.S. Strategic Command, General James E. Cartwright
- Commander, U.S. Central Command, General John P. Abizaid
- Commander, U.S. Pacific Command, Admiral William J. Fallon
- Commander, U.S. Joint Forces Command, General Lance L. Smith
- Commander, U.S. Air Force Space Command, General Kevin P. Chilton
- Commander, U.S. Pacific Fleet, Admiral Gary Roughead
- Commanding General, III Corps and Fort Hood, Lieutenant General Thomas F. Metz
- Deputy Under Secretary of Defense for Acquisition and Technology James I. Finley
- Under Secretary of the Air Force Dr. Ronald M. Sega
- Director, Defense Research and Engineering, John J. Young, Jr.
- Assistant Secretary of the Army for Acquisition, Logistics and Technology Claude M. Bolton, Jr.
- Assistant Secretary of the Navy (Research, Development and Acquisition) Dr. Delores M. Etter
- Director, National Security Agency, and Chief, Central Security Service, Lieutenant General Keith B. Alexander
- Director, Defense Threat Reduction Agency, Dr. James A. Tegnelia
- Commander, U.S. Marine Corps Forces Central Command and Commanding General, I Marine Expeditionary Force, Lieutenant General James N. Mattis

- US Army National Training Center
- US Navy Carrier Visits, CA
- US Marine Corps Warfighting Lab, Quantico, VA
- US Air Force Air Armaments Center, FL
- US Special Operations Command, Tampa, FL
- US Air Force Special Operations Command, Hurlburt Field, FL
- US Army Intelligence and Signals Command, VA
- US Air Force Test Wing, Edwards AFB, CA
- Naval Special Warfare Command, San Diego, CA
- Naval Surface Forces Command, San Diego, CA
- III Corps and Ft. Hood, TX
- Biannual Air Force Space Command Days
- Nellis Air Force Base, NV
- Edwards Air Force Base, CA
- Iraq, Afghanistan
- 29 Palms National Training Center, Fort Irwin, CA

Figure 6: DARPA's senior leadership and technical program managers have visited numerous military bases, commands, training centers, and other Defense facilities.

2.4. Major Accomplishments

For nearly five decades, DARPA's management methodology has been very successful at "bridging the gap."[5] Figure 7 shows icons that illustrate some of DARPA's preeminent accomplishments since the early 1960s.

DARPA was borne of the space age. The launch of Sputnik in 1957 also launched DARPA, so all the Agency's initial projects were space-related.

The Agency nearly ceased to exist when DARPA's space programs were transferred over to the National Aeronautics and Space Administration and the National Reconnaissance Office. But a new mission emerged to counter a new threat: intercontinental ballistic missiles. From approximately 1960 to 1970, DARPA was a driving force behind the United States' technology advancements in ballistic missile defense. In 1968, the Army Ballistic Missile Defense Agency was created, and the ballistic missile defense mission was transferred from DARPA.

DARPA began developing the technologies for stealthy aircraft in the early 1970s under the HAVE BLUE program, which led to prototype demonstrations in 1977 of the Air Force's F-117 tactical fighter that proved so successful in Operation Desert Storm. After the successes of the DARPA HAVE BLUE Stealth Fighter program, DARPA launched the TACIT BLUE technology demonstration, contributing directly to the development of the B-2 bomber deployed by the Air Force.

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5 In 2003, the Institute for Defense Analysis released its reports documenting the major contributions DARPA system projects made to the revolution in military affairs; these reports can be found at http://www.darpa.mil/body/mission.html .

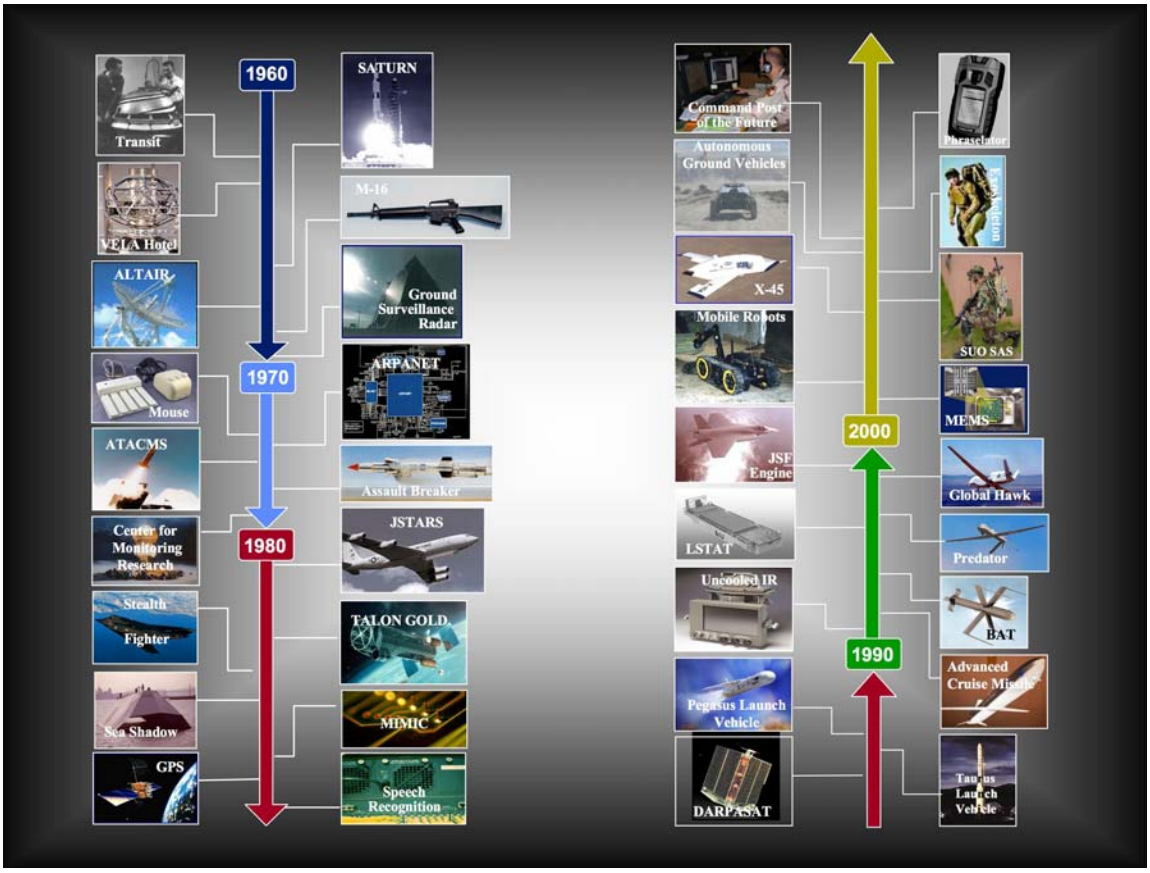

Figure 7: Key DARPA accomplishments spanning more than four decades.

The Global Hawk and Predator unmanned aerial vehicles (UAVs) have been prominent in Operation Enduring Freedom in Afghanistan and Operation Iraqi Freedom. DARPA started on the concept of a high altitude, long-range, extended loiter unmanned system in the 1970s with the TEAL RAIN program. After a number of significant technical breakthroughs, the Global Hawk high altitude endurance UAV transitioned from DARPA to the Air Force in 1998. The Tier 2 Predator medium-altitude endurance UAV evolved directly from DARPA's AMBER and Gnat 750-45 designs and was operationally deployed in the mid-1990s.

The most well known of all DARPA technologies is the Internet, which began in the 1960s-1970s with the development of the ARPANet and its associated TCP/IP network protocol architecture. DARPA's development of packet switching is the fundamental element of both public and private networks spanning the DoD, the Federal Government, U.S. industry, and the world.

DARPA's developments in distributed command and control, tied together by robust, secure, self-forming networks, have led to the Command Post of the Future (CPOF) being used today by the Army in Iraq. CPOF allows command and control centers to be wherever the commanders are, without regard to a fixed geographic location.

A crucial characteristic about several of these accomplishments, which holds true for many DARPA programs, is that it took a long time from an idea's conception to its use by the U.S. military. DARPA has shown itself very willing to repeatedly tackle hard technical problems, even in the face of previous failure, if the technology offers revolutionary new capabilities for

national security. Patience and persistence are required for those who pursue high-risk technology, but they are often rewarded with extremely large payoffs.

2.5. Future Icons

It is often said about organizations that past results do not necessarily indicate future success. Nevertheless, the following is a "short list" of ongoing DARPA research that promises major military benefits. In a few years these "Future Icons" may well take their places in the gallery of key DARPA accomplishments, illustrated in Figure 7. Each of these will be further discussed later in the corresponding sections identified in each description.

- **Networks**: self-forming, robust, self-defending networks at the strategic and tactical level are the key to network-centric warfare (Section 3.1).
- **Chip-Scale Atomic Clock**: miniaturizing an atomic clock to fit on a chip to provide very accurate time as required, for example, in assured network communications (Section 3.1).
- **Global War on Terrorism**: technologies to identify and defeat terrorist activities such as the manufacture and deployment of improvised explosive devices (Section 3.2).
- **Air Vehicles**: unmanned air vehicles that quickly arrive at their mission station and can loiter there for very long periods (Section 3.4).
- **Space**: The U.S. military's ability to use space is one of its major strategic advantages, and DARPA is working to ensure the United States maintains that defense advantage (Section 3.6).
- **High Productivity Computing Systems**: supercomputers are fundamental to a variety of military operations, from weather forecasting to cryptography to the design of new weapons; DARPA is working to maintain our global lead in this technology (Section 3.7).
- **Real-Time Accurate Language Translation**: real-time machine language translation of structured and unstructured text and speech with near-expert human translation accuracy (Section 3.7).
- **Biological Warfare Defense**: technologies to accelerate the development and production of vaccines and other medical therapeutics from 12 years to only 12 weeks (Section 3.8).
- **Prosthetics**: developing prosthetics that can be controlled and perceived by the brain, just as with a natural limb (Section 3.8).
- **Quantum Information Science**: exploiting quantum phenomena in the fields of computing, cryptography, and communications, with the promise of opening new frontiers in each area (Section 3.9.1).
- **Newton's Laws for Biology**: DARPA's Fundamental Laws of Biology program is working to bring deeper mathematical understanding and accompanying predictive ability to the field of biology, with the goal of discovering fundamental laws of biology that extend across all size scales (Section 3.9.2).
- **Low-Cost Titanium**: a completely revolutionary technology for extracting titanium from the ore and fabricating it promises to dramatically reduce the cost for military-grade titanium alloy, making it practical for many more applications (Section 3.9.3).
- **Alternative Energy**: technologies to help reduce the military's reliance on petroleum (Section 3.9.4).

- **High Energy Liquid Laser Area Defense System**: novel, compact, high power lasers making practical small-size and low-weight speed-of-light weapons for tactical mobile air- and ground-vehicles (Section 3.9.9).

2.6. Transitioning Technologies

Transitioning technology – getting technology from research and into use – is a contact sport. Many different types of organizations may need to be involved, i.e., S&T organizations like DARPA, the acquisition community, the warfighting/requirements community, and the firms that actually produce the product. This involvement requires personal contact between the people developing the technology and those destined to receive it.

The very nature of a technology strongly shapes how it transitions. For example, a component technology like a new material or microchip is likely to get to the warfighter when a prime contractor incorporates it into a system, without a Service acquisition program necessarily having decided on it *per se*. This means the key component decisions are made by industry – prime contractors and subcontractors.

On the other hand, a large system development program such as Global Hawk requires the warfighting community to establish a formal requirement for the system, thereby charging the acquisition community with actually purchasing it. New systems simply do not diffuse their way into military use, like a new material might.

The transition challenge is exacerbated for DARPA because its focus is on high-risk, revolutionary technologies and systems, which may have no clear home in a Service, are Joint, or threaten to displace current equipment or doctrine. Such factors tend to create resistance, or at least barriers to the use and adoption of a radical new technology.

Figure 8 is an illustration of DARPA's strategy to transition technology to the warfighter.

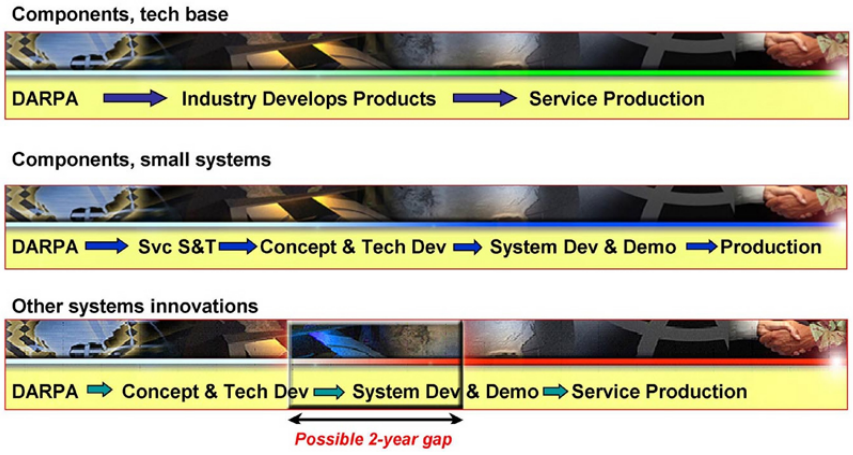

Figure 8: DARPA transition methods.

The first bar illustrates the majority of DARPA's transition activities. DARPA invests about 97 percent of its funds at organizations outside DARPA, primarily at universities and in industry. Over time, this investment leads to new capabilities in industry and steadily reduces the risks of the underlying technology. At some point, a company becomes sufficiently confident of the capability, value and technical maturity of a new technology for a predictable cost and schedule. It will then be willing to propose the technology to DoD users or acquisition programs. DARPA's investment reduces the risk of a technology to the point where firms themselves are willing to make it, use it, or otherwise bid it back to the rest of DoD.

Companies generally will not propose a new technology to a Service if they are not confident the Service will accept it. The second bar in Figure 8 shows how DARPA removes this impediment. To build potential Service customers for DARPA technology – someone to whom these companies can bid with confidence – DARPA deliberately executes most of its funding through

Working with USSOCOM

Over the last several years, DARPA has forged a close working relationship with USSOCOM based on the good strategic fit and synergy between the two organizations. USSOCOM has sophisticated operators who face difficult problems that might be solved with advanced technology and who can use experimental equipment in small quantities. DARPA is well-placed to supply that technology and is interested in getting feedback on its work. Both organizations are small and agile. In the short term, this relationship offers a good opportunity to test emerging technical solutions against difficult problems. In the longer term, it helps USSOCOM shape its view of what is and will be technically possible, and it influences what technology DARPA pursues.

To strengthen the systematic transition of its technology to USSOCOM, DARPA has a representative detached to the Command. She is posted at USSOCOM and works to bring USSOCOM and DARPA together across a range of programs and challenges. This can vary from co-investing in a program, to USSOCOM testing DARPA technology, to getting USSOCOM's inputs to strengthen DARPA goals and prototypes. USSOCOM is a partner or participant in numerous DARPA programs and has endorsed or influenced many others.

Among the recent fruits of this relationship are unmanned aerial vehicles, advanced runway lighting, sensor devices, and communication technology.

the Services. That is, a Service organization serves as DARPA's agent, signing the contracts with the research performers and monitoring the day-to-day technical work. This investment creates a cadre of people inside a Service who are familiar with a DARPA technology, who can vouch for it, and who can shepherd it into a Service acquisition program. Once the company is confident it can build a technology and a Service is willing to accept it, the technology transitions and DARPA's role in the development is, typically, forgotten.

DARPA occasionally builds prototypes of a large, integrated system such as Global Hawk. Such programs reduce the risks in a new system to the point where the warfighting community can be confident it will get a new and cost-effective capability. However, without proper planning such programs can run into a 2-year funding gap between the time the Service is convinced it wants the system and when the DoD financial system can effectively respond. To prevent these and other problems, DARPA tries to ensure transition of prototypes by negotiating a memorandum of agreement (MOA) with the Service adopting the system, such as the one for the Falcon Small Launch Vehicle. In general, for its Advanced Technology Development (i.e., "6.3") programs, DARPA requires that an MOA or a transition strategy be negotiated with a Service at some predetermined point during its development in order to proceed to its later stages.

DARPA has several initiatives to help transition technology:

- DARPA's *Service Chiefs Program* is a joint program between DARPA's Director and the Chief of Staff of each Service, and the Director of the National Geospatial-Intelligence Agency. Under the program, each Service and the NGA details young, talented officers to DARPA as interns on a two- to three-month basis to give them an in-depth look at DARPA's programs and way of doing business. The interns also help DARPA's program managers better understand existing military capabilities and combat operations. During the last 5 years over 140 officers from all the Services have participated in the program, which has proven valuable in transitioning DARPA technology to the Services. However, the real value of the program is long-term. As these young officers progress through their careers, being exposed to DARPA at an early stage should make them more open to new technology and hence be even more valuable to U.S. national security.

- *Operational Liaisons* from each military Service and the National Geospatial-Intelligence Agency are assigned to the Director's Office at DARPA. Their everyday job is to maintain DARPA's connection to real-life problems, while at the same time helping transition

DARPA technology to the Services. DARPA's Operational Liaisons organize meetings and other activities that bring DARPA program managers and warfighters together so the managers can better understand the warfighter's needs, and the warfighters can better understand upcoming technological opportunities. This individual brokering of connections is consonant with DARPA's general philosophy that technology transition is a contact sport. DARPA's Operational Liaisons are usually very senior both in rank and experience, come with a great set of contacts, and help reinforce the day-to-day linkages between DARPA's research programs and the needs and opportunities of the DoD.

DARPA has also detailed a representative to the U.S. Special Operations Command (USSOCOM) in Tampa, Florida, to maximize the flow of new technology to our Special Forces with a minimum of bureaucracy, an approach that has worked extremely well.

Please see Section 5 for contact information for these individuals.

3. Current Strategic Thrusts

Strategy is the evolving approach to pursuing a central mission through changing circumstances. Consequently, over time, DARPA changes much of what it is doing in response to the different national security threats and technological opportunities facing the United States.

While much of DARPA's work can take many years to reach fruition, in times of active conflict – such as today – DARPA's agility allows it to focus some of its resources on quickly meeting the needs of U.S. forces in combat. This can involve accelerating projects, harvesting the results of work done in the past but which were never fully implemented, or pursing new high-risk, high-reward ideas that can be quickly tested.

An important element of DARPA's work is to "red team" how an adversary would react. That is, how would an adversary respond to a new technological development by the U.S.? An expensive new technology that is easy and inexpensive to negate may not be that useful, whereas one that that is hard to counter may be extremely valuable. DARPA conducts its programs mindful that "the enemy gets a vote."

DARPA currently emphasizes research in nine strategic thrusts:

- Robust, Secure, Self-Forming Networks
- Detection, Precision ID, Tracking, and Destruction of Elusive Targets
- Urban Area Operations
- Advanced Manned and Unmanned Systems
- Detection, Characterization, and Assessment of Underground Structures
- Space
- Increasing the Tooth to Tail Ratio
- Bio-Revolution
- Core Technologies

3.1. Robust, Secure, Self-Forming Networks

The DoD is in the middle of a transformation to what is often termed "Network-Centric Operations." The promise of network-centric operations is to provide information superiority that enhances combat effectiveness so that the United States and its allies, having better information, can plan and conduct operations far more quickly and effectively than their adversary.

At the core of this concept are robust, secure, and self-forming networks. These networks must be as reliable, available, secure and survivable as the platforms and forces they connect. They must distribute huge amounts of data quickly and precisely across a battlefield, a theater, or the globe, delivering the right information at the right place at the right time. DoD's networks are becoming as important to its military success as its weapons platforms.

But in order for these networks to realize their full military potential, *people* can no longer be central to managing and administering them. The networks must be able to form, manage, defend and heal themselves, so they always function at the enormously high speeds that provide their advantages. And reducing the number of network management personnel will profoundly improve DoD's tooth to tail ratio.

Key challenges and opportunities in this area for DoD are shown in Figure 9. Tactical networks must locally link effects to targets and be agile, adaptive and versatile. Strategic and operational networks must globally link air, ground, and naval components for operational maneuver and strategic strike and enable knowledge and understanding, resourcing and sustainment throughout the force. And now, for the first time in military history, DoD has the opportunity to bridge the

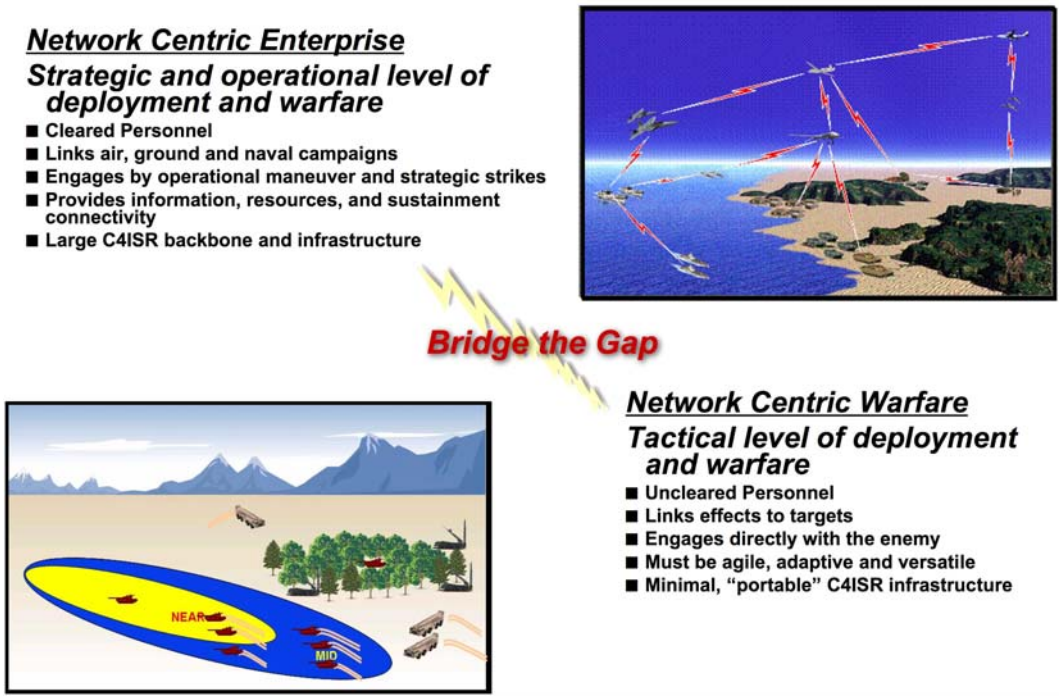

Figure 9: Bridging the Network-Centric Operations gap between strategic/operational and tactical levels of deployment and warfare

gap between these two families of networks, allowing the strategic and tactical levels to rapidly and effectively share information and insight.

DARPA is developing technologies for wireless tactical net-centric warfare that will enable reliable, mobile, secure, self-forming, ad hoc networking among the various echelons with the most efficient use of available spectrum.

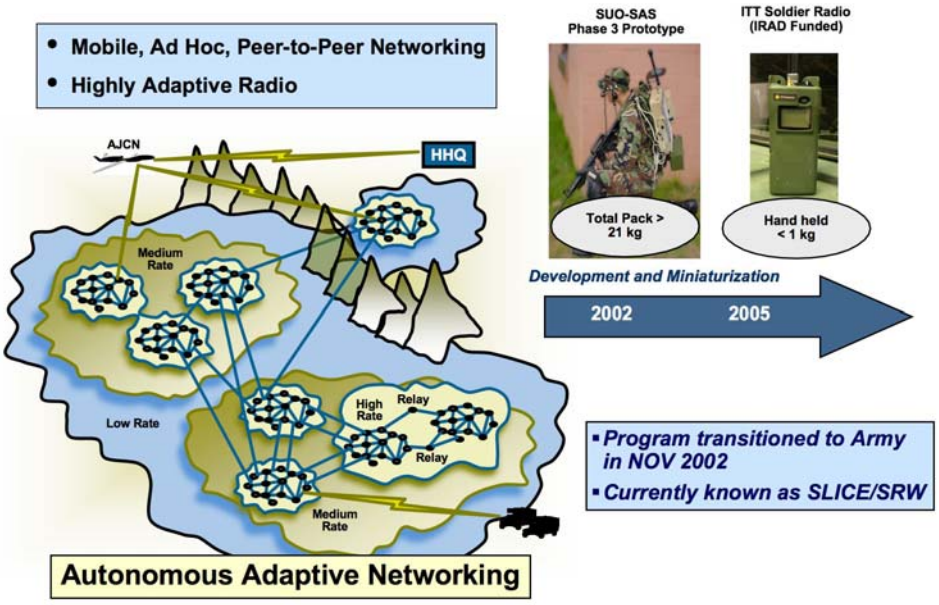

Figure 10: Small Unit Operations Situational Awareness System (SUO SAS).

A seminal networking program was the Small Unit Operations Situational Awareness System (SUO SAS) program (Figure 10). SOU SAS developed a self-forming, self-healing

communication system for dismounted warfighters operating in difficult and complex environments, such as urban and wooded terrains. It allows warfighters to covertly and securely communicate with fellow squad members, and automatically reports all squad member locations, enabling both mission planning and mission execution monitoring. SOU SAS technology and capabilities transitioned to the Army, which has made the technology more compact and portable. Today, SUO SAS is known as the Soldier Radio Waveform currently being integrated into the Joint Tactical Radio Systems Handheld, Manpack, Small Form Factor.

The next logical step was to connect tactical ground vehicles together. The Future Combat Systems Communications (FCS-C) program developed a mobile, self-healing ad hoc network designed for ground maneuver vehicles, on-the-move, operating in cluttered open terrain. Its performance is comparable to that of the Joint Tactical Radio Systems' Wideband Network Waveform, e.g., high data-rate (greater than five million bits per second), cross-banding mobile networking.

Radio interoperability has been a problem plaguing the Department of the Defense for decades. The FCS-C network was recently upgraded such that FCS-C would now operate as a gateway, rather than as a router network, allowing interoperability among various current and future communications radios via the network, not by using a radio (Figure 11). FCS-C Gateway has demonstrated that it is possible to have previously incompatible tactical radios (including coalition partner radios) talk seamlessly among themselves and to more modern systems by using the internet protocol layer of the network, thereby offering a potentially more affordable route for military communications interoperability in the future. The FCS-C Gateway system has been transitioned to U.S. Special Operations Command for their evaluation and use.

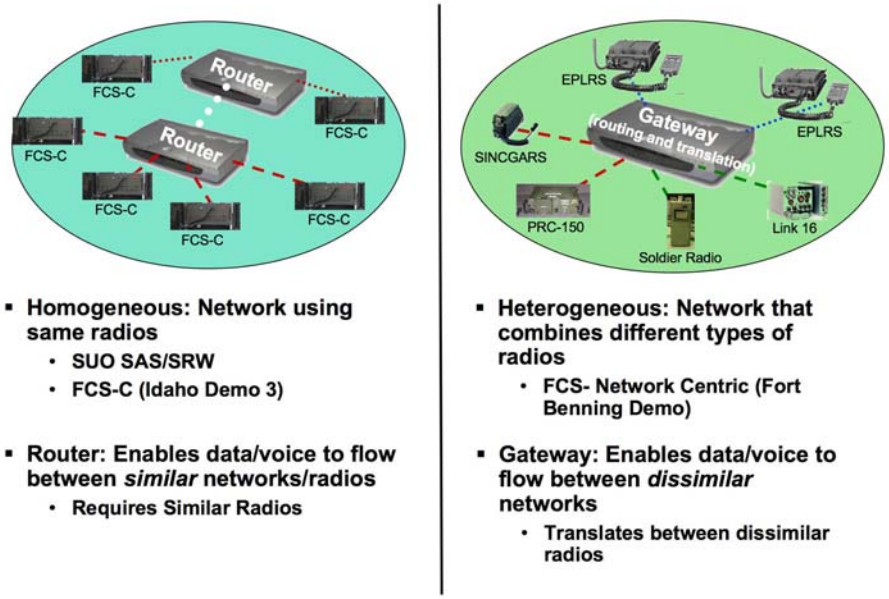

Figure 11: FCS-C Gateway enables network interoperability.

DARPA has also been developing autonomous network communications for the uniquely cluttered environment of cities. Urban clutter usually creates multiple signals from diverse reflections of the initial signal (multi-path), and the result is weak, fading voice/data from the destructive interference of all these multi-path signals with the unreflected signal at the receiver. Turning this problem into an opportunity, the Mobile Networked Multiple-Input/Multiple-Output program is actually exploiting multipath phenomena to improve communications between vehicles moving in cities without a fixed communications infrastructure. And the Networking in Extreme Environments program is exploring use of ultra wideband communications among dismounted Soldiers and unattended ground sensors.

Frequency spectrum is a valuable commodity. The neXt Generation (XG) Communications program will expand by 10-to-20 fold the amount of spectrum available to U.S. forces by giving

them access to unused, non-military spectrum via specialized electronic equipment (Figure 12). XG is designed to be implemented on a range of Joint Tactical Radio System (JTRS)- and non-JTRS-based systems, such as Enhanced Position Location Reporting System and similar commercial communications systems. Besides developing XG technology, DARPA is working with the Federal Communications Commission and the International Telecommunications Union to establish policies for its use.

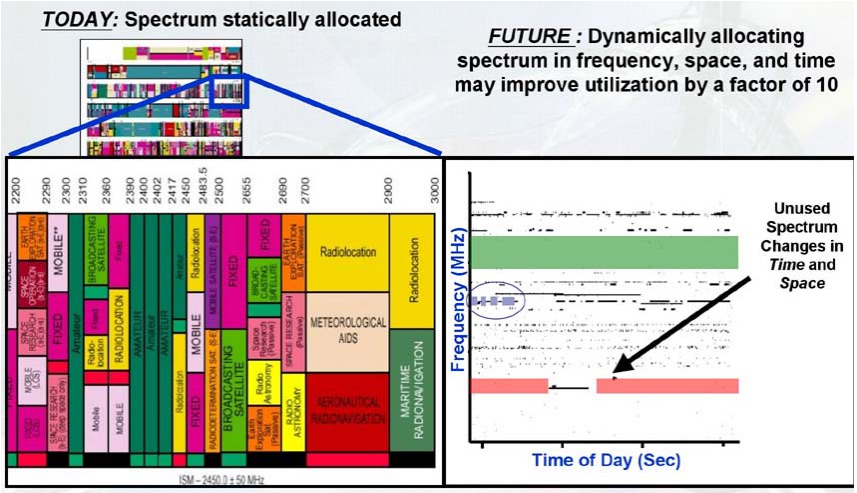

Figure 12: XG Communications program.

DARPA is working to bridge strategic and tactical networks with technologies that seamlessly connect strategic and tactical intelligence, objectives, mission plans, operational orders, and key knowledge and understanding to all components and levels of warfare. The Department's fiber optic network, called the Global Information Grid (GIG), has an integrated network data rate in the hundreds to thousands of megabits per second. To reach the theater's ground elements, the GIG's data must go through satellite systems that have integrated network data rates in the tens to hundreds of kilobits per second. This data rate mismatch creates problems in the timely delivery of information to the warfighter.

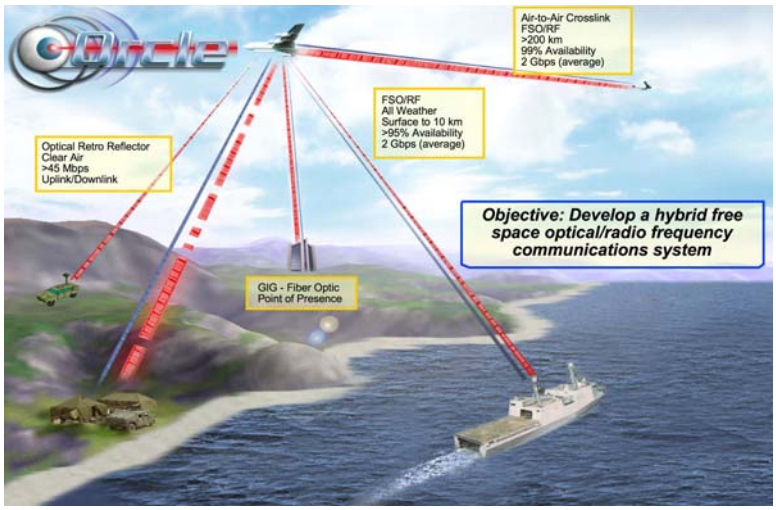

Figure 13: Optical and Radio Frequency Combined Link Experiment provides links to forces fixed and on-the-move.

In response, the Department has proposed using free-space optical satellite communications so the GIG and satellites capacities are better matched. Unfortunately, unlike radio frequency communications, clouds and other particulate scattering media degrade optical system performance when the satellite interfaces to the various theater elements on the ground. To counter this, the Optical and Radio Frequency Combined Link Experiment (ORCLE) program (Figure 13) will combine the high data-rate capability of laser communications, the high reliability of radio frequency communications, and clever network management to ensure compact, high quality of service, reliable, high bandwidth networked communications to the theater, even if some of the links are degraded by atmospheric or physical obstructions.

DARPA is creating a global strategic network capability by developing the extremely high bandwidth, high-speed, pervasive networks needed by DoD for global communications and data exchange. The Dynamic Multi-Terabit Core Optical Networks: Architecture, Protocols, Control

and Management program will leverage DARPA's photonics and secure networking programs to revolutionize the operation, performance, security, and survivability of DoD strategic networks (Figure 14). The program will develop the architecture, protocols, and control and management software for highly dynamic, multi-terabit global core optical networks with greatly enhanced performance, security and survivability to enable ultra-fast service set-up and tear-down, as well as very fast recovery from multiple network failures.

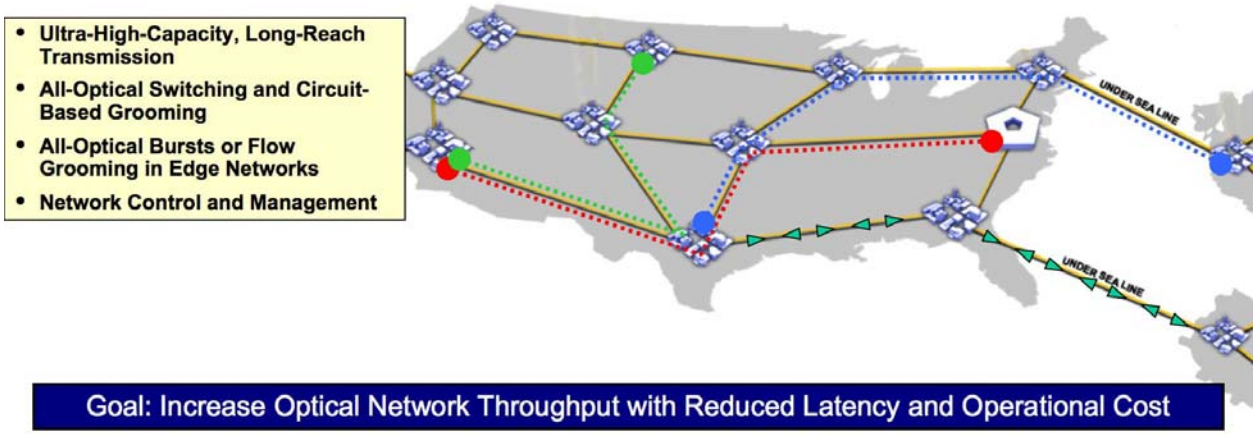

Figure 14: Dynamic Multi-Terabit Core Optical Networks: Architecture, Protocols, Control and Management.

DARPA is working to enhance net-centric warfare network capabilities, particularly in information assurance, by developing technologies to make networks secure, disruption-tolerant, and self-reconstituting. The heart of many networks is having identical time at all nodes. Today, in many cases, this time is provided by the Global Positioning System (GPS). Current and future threats will work hard to prevent our networks from using GPS as a time standard. To deal with possible loss of GPS, DARPA has been developing one of its Future Icons (Section 2.5), a microelectromechanical systems-based chip-scale atomic clock that will provide precise time for several days, all in a one cubic-centimeter package (Figure 15). In particular, the clock will allow a network node, such as the JTRS Ground Mobile Radio, to maintain synchronous operation within a tactical network, or will allow a Soldier to continue to talk with a Single Channel Ground and Airborne Radio System (SINCGARS) for several days without GPS.

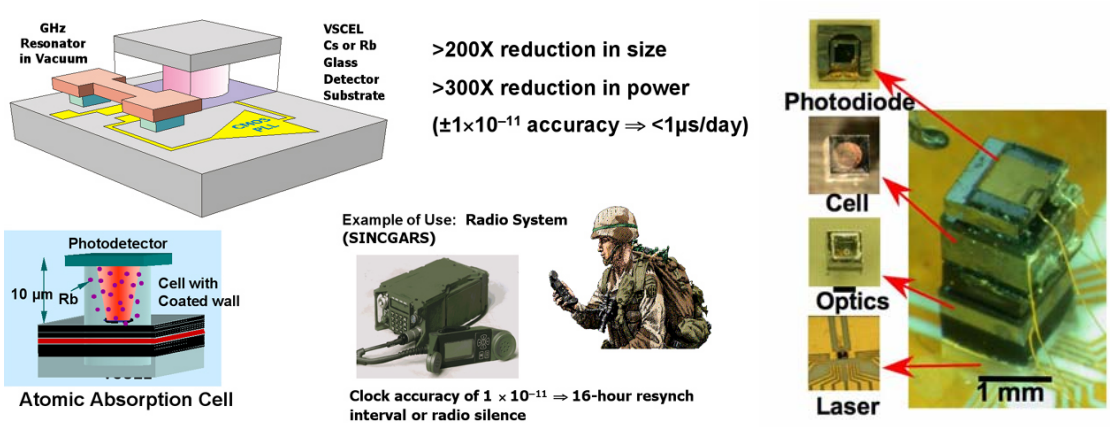

Figure 15: Chip-Scale Atomic Clock: ultra-miniaturized, low-power, atomic time and frequency reference units.

As the U.S. military adopts network-centric warfare, terrorists and other nation-states are likely to develop and employ malicious code to impede our ability to fight efficiently and effectively. The ever-growing sophistication of the malicious code threat has surpassed the ability of commercial industry to address this problem. For example, computer worms that have never been seen before ("zero-day worms") pose a specific threat to military networks because they can exploit previously unknown network vulnerabilities. The Dynamic Quarantine of Worms program is developing dynamic quarantine defenses for U.S. military networks against large-scale malicious code attacks, such as computer-based worms, by developing an integrated system that automatically detects and responds to worm-based attacks against military networks, provides advanced warning to other DoD enterprise networks, studies and determines the worm's propagation and epidemiology, and provides off-line rapid response forensic analysis of malicious code to identify its capabilities, modalities, and future behavior. The final system will quickly quarantine zero-day worms to limit the number of machines affected, as well as restore the infected machines to an uncontaminated state in *minutes*, rather than hours and days, which is today's state of the art.

As the DoD moves towards development and deployment of true mobile ad-hoc networks (MANETS), the ability to defend this type of network becomes more and more important. The Defense Against Cyber Attacks on Mobile Ad Hoc Network Systems (DCAMANETS) program will research, design, and prototype technologies to automatically detect cyber attacks and reconfigure MANETS to ensure mission success. This technology is intended to augment existing security systems and adds another dimension to the strategy of defense-in-depth. The program will develop defenses for MANETS, including automatic and dynamic quarantine response and forensics analysis of malicious code, that can sense failures and attacks and recover automatically in real-time. The DCAMANETS program will also develop the means to monitor and control the trustworthiness of distributed tactical applications used in network-centric warfare operations to ensure that future network-centric warfare systems are able to fulfill their combat missions.

3.2. Detection, Precision ID, Tracking, and Destruction of Elusive Targets

For many years, the Department of Defense has steadily improved its ability to conduct precision strike against both stationary and moving ground targets. The timely, accurate and precise delivery of bombs and missiles has given the U.S. military tremendous advantages. In recent years, America's adversaries have realized that, if they are to survive the United States' superior precision strike capabilities, they either have to move, hide, or "blend-in," especially in urban environments.

It is still difficult to detect, identify, track, and strike targets that are hiding, use evasive tactics such as frequent starts and stops, or that require a rapid reaction by U.S. forces in order to be destroyed.

To provide a focused response to these challenges, DARPA is assembling sensors, exploitation tools, and

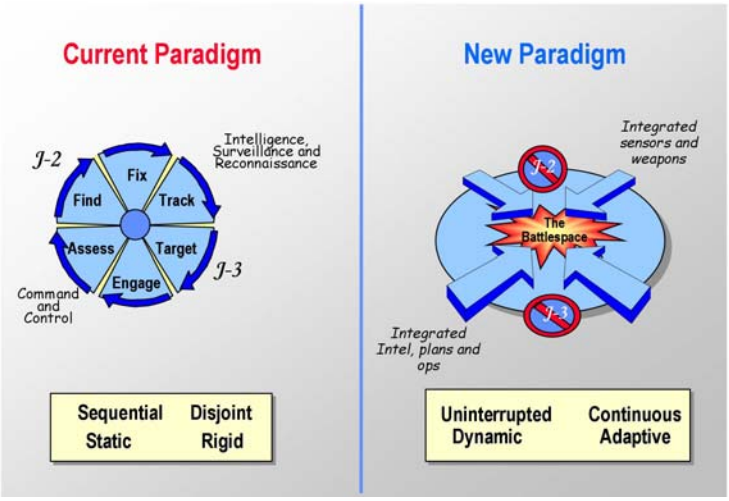

Figure 16: DARPA's goal: eliminate barriers between Intelligence (J-2) and Operations (J-3).

battle management systems to rapidly find and destroy ground targets in any terrain, in any weather, moving or stopped, with minimum accidental damage or casualties. To do this, we must seamlessly meld sensor tasking with strike operations to use platforms or a network of platforms that carry both capable sensors and effective weapons. This implies blurring or even erasing conventional barriers between the intelligence and operations functions at all levels of command (Figure 16). This is a difficult challenge requiring technical and organizational innovations to achieve a joint approach to striking ground targets.

Our strategy to address this mission anticipates network-centric warfare arriving in two stages. In the first stage, as detailed in Section 3.1, networks will connect more and more sensors, platforms, and weapons with a variety of communications links (Figure 17). In the second stage, computers and commanders will take advantage of the massive amounts of data available to increase the speed, accuracy, agility, and capability of our combat forces.

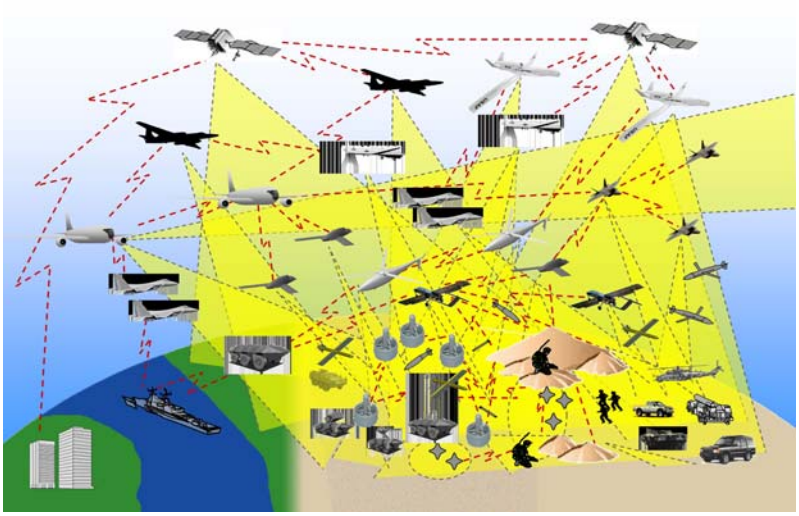

Figure 17: Networked operations.

For example, changes detected between images generated by DARPA's foliage-penetrating radar can be used to engage elusive targets. The radar operates at frequencies that penetrate the forest canopy. Algorithms, running either on an aircraft or by the network at a ground station, compare images taken at different times to detect changes that signify either departures or arrivals. Because radars operate in all weather and at long ranges, this technique can discover the location of potential targets over very wide areas.

Then, to identify targets in response to these cues, DARPA's ladar sensors can obtain exquisitely detailed, 3-D imagery. Figure 18 shows a ladar image of a tank beneath forest cover. By flying the ladar over a potential target, photons can be collected from many different angles. Those that pass through gaps between leaves, however few, can be collated together into a full image. New computational methods can match these data against 3-D geometric models of a variety of target types, even identifying gun barrels, rocket launchers, and other equipment that unambiguously indicate the military nature of the vehicle (Figure 18 depicts actual data from field tests).

DARPA is developing software tools to "stitch-together" information obtained from a variety of tactical sensors (e.g., moving target indicator radar, synthetic aperture radar, optical, video, and acoustic sensors), and then cue the sensors to obtain more information (Figure 19). For example, the change detections obtained from radar could cue the ladar sensor to watch a new arrival. Conversely, if Predator video lost a target because it entered a forest, the radar could be cued to search for the vehicle when it stops.

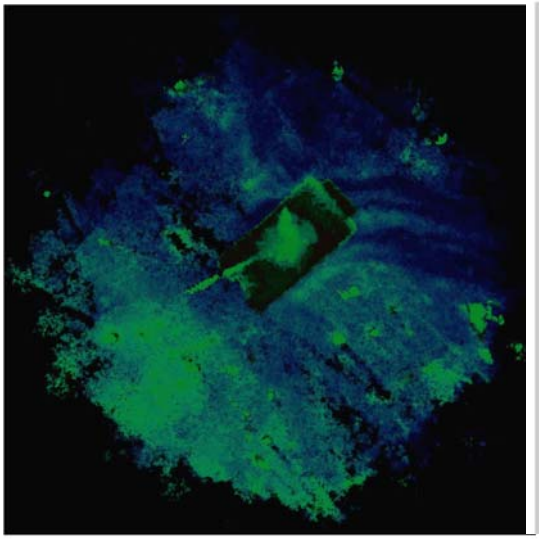

Figure 18: A composite image of a tank under trees formed from observations by a ladar sensor.

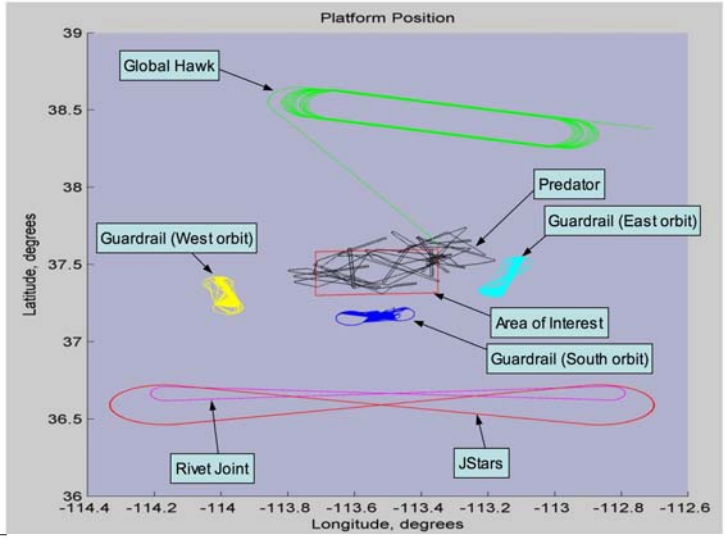

Figure 19: Decision aids help manage and adjust sensor routes to cover moving targets.

3.3. Urban Area Operations

Each year the world's urban areas increase in population and area. By 2025 nearly 60 percent of the world's population will live in urban areas. Given this, it is prudent to assume U.S. forces will continue to be deployed to urban areas for combat and post-conflict stabilization. Unstable and lawless urban areas give terrorists sanctuary to recruit, train, and develop asymmetric capabilities, including the possibility of chemical, biological, and radiological weapons of mass destruction (WMD).

Urban area operations can be the most dangerous, costly, and chaotic forms of combat. Cities are filled with buildings, alleys, and interlocking tunnels, which provide practically limitless places to hide, store weapons, and maneuver. They are hubs of transportation, information, and commerce, and they are homes for a nation's financial, political, and cultural institutions. Cities are densely packed with people and their property, creating an environment in which our adversaries can mix in and use civilians as shields to limit our military options. And insurgents don't just mix in, they *blend* in. Under these circumstances, warfighting technology that works so superbly in the open, and even in the rugged natural terrain of the traditional battlefield, is less effective in the urban environment.

Adversaries seek to fight in urban areas as a way to counter U.S. forces' superior detection and strike capabilities that work so well against fixed and mobile targets in open and semi-concealed terrain. By moving into cities, our adversaries hope to limit our advantages, draw more of our troops into combat, and inflict greater U.S. casualties, and cause mistakes that harm civilians and neutrals.

The Urban Area Operations thrust is aimed at creating technology to help make U.S. operations in cities as effective as operations in non-urban areas by seeking new urban warfare concepts and technologies that would make a smaller U.S. force conducting operations in an urban area more effective, suffer fewer casualties, and inflict less collateral damage.

If successful, these new urban warfare concepts and technologies would enable U.S forces fighting in or stabilizing an urban area to achieve the same or greater overall effect as a larger force using today's technology.

DARPA's Urban Area Operations thrust includes research in:

- **Improved urban intelligence, surveillance, and reconnaissance** to vastly improve U.S. capabilities to understand what is going on throughout a complex urban environment, including the ability to detect adversaries hiding in buildings and other structures, and to find hidden explosives or WMD.
- **Tagging, tracking and locating capabilities** to persistently monitor targets or equipment of interest; tag, track and locate enemy activities; track and detect weapons fabrication and movement; and precisely discriminate threat from non-threat entities against severe background clutter.
- **Weapons for urban operations** to develop ultra-precise, beyond-line-of-sight infantry weapons for use in congested urban areas.
- **Asymmetric warfare countermeasures** to develop technology to detect, prevent, or mitigate asymmetric attacks, such as suicide bomber attacks, improvised explosive device attacks, and WMD attacks – including radiological dispersal devices.
- **Pre- and post-conflict capabilities** to model and understand social indicators that precede the onset of hostility and conflict, coupled with tools to develop strategies to stabilize an urban area and assist U.S. civil affairs units.
- **Command, control, communications, and intelligence (C3I) for urban warfighting** to develop new approaches to all-echelon C2 and new intelligence analysis tools specifically suited for urban operations that allow warfighters to see and understand what is happening throughout the urban battlespace in real time.

A typical urban mission may require a U.S. team to pursue adversaries inside a multi-story building. Currently, the defenders have a major advantage by knowing the interior layout. But by using DARPA's Radar Scope (weighing less than 1.5 pounds and running on AA batteries), U.S. troops will be able to sense through over 12 inches of concrete to determine if someone is hiding inside a building or behind a wall.

The Advanced Soldier Sensor Information System and Technology (ASSIST) program will enhance the intelligence gathering capabilities of our ground troops by developing special sensors, networks, and databases that allow a patrol leader to directly add to, and tap into the collective experience of previous patrols, including the details of what has been encountered in specific neighborhoods. ASSIST will help intelligence analysts and front-line patrol leaders build and share knowledge of what's going on in various city neighborhoods.

Figure 20: Wasp micro air vehicle.

One miniature airborne sensor ideally suited for small unit operations (both in the open terrain and the urban environment) is the Wasp micro air vehicle, a small, quiet portable, reliable, and rugged unmanned air platform designed for front-line reconnaissance and surveillance over land or sea. Wasp serves as a reconnaissance platform for the company level and below by virtue of its extremely small size and quiet propulsion system. DARPA

has developed both land- and water-proofed-versions of Wasp. The air vehicle (Figure 20) has a 16-inch wing-span, weighs approximately one-half pound, fits in a backpack, and provides our warfighters with immediate surveillance capabilities. Wasp is capable of flying in excess of one hour, with a speed range of 20-40 miles per hour, and provides unobtrusive, real-time imagery from low altitudes. Wasp's current payload consists of two color video cameras (front and side), global positioning system sensor, altimeter, compass, and air speed sensor. The air vehicle's operational range is typically 2-4 kilometers, with a typical operational altitude of 50 - 500 feet above ground level. Wasp's ground control station is common to the Raven, Pointer, and other unmanned air vehicles in the arsenal. Wasp is hand- or bungee-launched by a single Soldier, and is recovered by either hard-ground landing or water-ditch. Wasp proto-types are currently under extended evaluation in-theater by the U.S. Marine Corps and the U.S. Navy.

Working with the Marine Corps

The senior leadership of the Marine Corps meets regularly with the DARPA Director to collaborate on future warfighting needs. DARPA has been working with the Marine Corps Warfighting Laboratory (MCWL) and Marine Expeditionary Force (MEF) Commanders to speed an array of technologies to the field.

MCWL and DARPA are currently working on several programs. The Tactical Iraqi Language Training Program uses voice recognition and game-like interfaces to teach troops basic Iraqi Arabic and culture. Generation II Boomerang shot detection systems rapidly identify enemy sniper locations. Bar Armor kits protect vehicles against rocket propelled grenade attack. Several Marine combat units have been linked with Army units and higher command echelons through the Command Post of the Future system. Marines have deployed DARPA handheld technologies to improve tactical situational awareness, including ground-based sensors, compact throwable networked cameras, and the Wasp micro air vehicle. Spiral development of the Wasp, based on user testing and pre-deployment training, has resulted in a capability valuable to Marine, Army and Special Forces; Wasp is currently undergoing extended system evaluation in Iraq.

DARPA's Distributed Operations Study has helped the Marine Corps identify technologies required to realize the Marine vision of future tactical forces. The study has resulted in close cooperation between DARPA and MCWL on advanced tactical mobility programs, improved vehicle and body armor protection, enhanced sniper rifles, next generation optics, rifle-launched sticking flares for marking targets, and tactical fuel cells to reduce the Marine's load.

One of the major threats to our forces in Iraq are snipers. DARPA's low-cost Boomerang shooter detection and location system provides a new force protection tool to the warfighter that tells Soldiers whether they are being fired upon, and where the shots are coming from. Soldiers can have great difficulty judging the origin and direction of gunfire in urban environments, especially when traveling in a convoy where road noise makes it difficult to even detect incoming fire. Boomerang saves lives by allowing Soldiers to react to incoming fires more quickly and effectively. Using results from the deployed Boomerang units, DARPA improved the system and upgraded units have been sent to deployed forces with superior system performance and results.

Figure 21: Command Post of the Future.

Another major threat to our forces in Iraq are Improvised Explosive Devices. One of DARPA's responses to this

threat, the Hardwire program, is pursuing a lightweight composite armor that embeds the steel wire reinforcement found in steel-belted radial tires in a polymer matrix wrapped around a low-cost ceramic. This novel material promises to be a moldable, comparable-cost, easily manufactured, lower-weight alternative to conventional steel armor, while providing the same or greater protection to our warfighters.

Command Post of the Future (CPOF) is a distributed command and control system (Figure 21) that provides commanders with planning and mapping tools, and allows command and control centers to be wherever the commanders are – without regard to a fixed geographic location. Deployed forces are currently using over 600 CPOF systems in Iraq. Soldiers say CPOF allows them to share information and respond more quickly, while providing greater flexibility and insight. CPOF is now an Army Program of Record.

Figure 22: Warfighters in a DARPA Training Superiority program classroom.

DARPA is adapting commercial gaming technology, coupled with feedback of Combat Training Center learning, to train U.S. warfighters in the unique combat skills they will need in the urban environment, such as ambush avoidance and tactical language skills. The Training Superiority program (Figure 22) is creating new PC-based software training systems that can be easily transported with the warfighter to theater, and that incorporate elements of human-tutor interactions and the emotional involvement of multi-user computer games.

3.4. Advanced Manned and Unmanned Systems

DARPA is working with the Army, Navy, Air Force, Marine Corps, and Special Operations Command toward a vision of a strategic and tactical battlespace filled with networked manned and unmanned air, ground, and maritime systems, and the technologies they need to navigate and fight. Unmanned systems provide autonomous and semiautonomous capabilities that free Soldiers, Sailors, Airmen and Marines from the dull, dirty, and dangerous missions which might now be better executed robotically, and enable entirely new design concepts unlimited by the endurance and performance of human crews. The use of unmanned aerial vehicles (UAVs) in Afghanistan and Iraq is the first step in demonstrating the transformational potential of such an approach.

DARPA's efforts have been focused in two areas. First, DARPA seeks to improve individual platforms so that they provide new or improved capabilities, such as unprecedented endurance or survivability. Second, DARPA is expanding the level of autonomy and robustness of robotic systems. Progress is measured in how well unmanned systems can handle increasingly complex missions in ever more complicated environments (Figure 23). Autonomy and robustness are improved by networking manned and unmanned systems into a more tightly coupled combat system that will improve our knowledge of the battlespace, enhance our targeting speed and accuracy, increase survivability, and allow greater mission flexibility.

Our A160 program (Figure 24) is developing an unmanned helicopter for intelligence, surveillance, and reconnaissance (ISR) missions, with long endurance – up to 20 hours. The A160 concept is being evaluated for surveillance and targeting, communications and data relay,

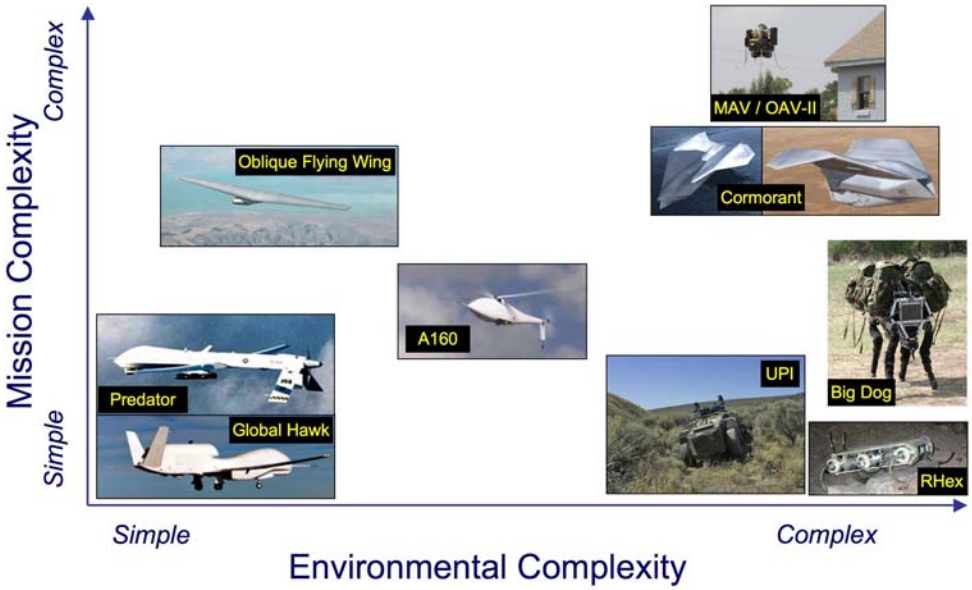

Figure 23: Unmanned Vehicles – the increasing challenge of autonomy.

crew recovery, resupply of forces in the field, and special operations missions in support of Army, Navy, Marine Corps, and other needs.

The Oblique Flying Wing program is demonstrating a transformational design concept for a new class of efficient supersonic aircraft. The oblique flying wing concept flies supersonically with one wing swept forward and the other swept backward. At low speeds, the wing changes to an unswept design for better subsonic efficiency. The oblique flying wing is known to have lower supersonic wave drag than conventionally designed symmetrically swept wings. In addition, when flying at low speeds, the unswept wing design has higher efficiency than swept wing designs. This combination of performance attributes will enable improved range, response time, fuel efficiency, and endurance for supersonic strike, ISR and transport missions. The goal of the program is to prove out the stability and control technologies required to enable the oblique wing concept by flying an X-plane that will demonstrate an asymmetric, variable sweep, tailless, supersonic flying wing.

Figure 24: A-160 vertical take-off and landing (VTOL) unmanned air vehicle (UAV).

The Micro Air Vehicle (MAV) Advanced Concept Technology Demonstration (ACTD) developed a backpackable, fully autonomous, vertically launched-and-landed ducted fan UAV capable of providing electro-optical or infrared hover-and-stare support to the dismounted Soldier. The MAV air vehicle is small (less than 14-inch duct outer diameter), flies autonomously, has an endurance of 55 minutes at sea level, and can operate at altitudes over 10,000 feet. These capabilities make it ideal for operations in the complex/urban terrain and extreme conditions typical of restricted military environments. Now part of the Army's FCS program, the MAV

ACTD program demonstrated important military capabilities through experimentation and flight tests.

Working with the Army

DARPA continues to work with senior Army leaders, including those from the Training and Doctrine Command and the Office of the Assistant Secretary of the Army for Acquisition, Logistics and Technology, to identify, develop and transition technologies for U.S. Soldiers. This partnership is evaluating new DARPA technologies in the field to support the Army's move toward a distributed, network-centric force with the lethality, mobility, and survivability of the current heavy force, but that is lighter, more rapidly deployable and easily supportable.

Today, the Army is using mobile, distributed, collaborative command and control technology from the Command Post of the Future program in Iraq. DARPA's Bar Armor is currently protecting troops in theater. Soldiers are evaluating the NetFires missile system, the Boomerang sniper detection system, and a glove that can rapidly cool down those suffering from the desert heat. Hardwire, a lightweight armor program, may provide a near-term solution to the heavy armor currently required to protect vehicles such as HMMWVs from small and medium-caliber munitions. DARWARS Ambush!, a convoy training program, provides a rapid and efficient learning tool for Soldiers. And DARPA continues to develop persistent surveillance and unmanned ground and air platforms, like the Micro Air Vehicle, for the Army's Future Combat Systems program.

The Heliplane program is developing a revolutionary air vehicle that can take-off, land, and hover vertically like a helicopter and cruise with the speed and efficiency of a fixed-wing aircraft, offering two- to three-fold improvement in forward flight characteristics over conventional helicopters. The Heliplane demonstrator aircraft will be tailored to a Combat Search and Rescue mission with a 400 mile per hour cruise speed, a 1000 pound payload, and an unrefueled range of 1000 nautical miles. Unlike a helicopter that relies on a rotor for both hover and cruise, the Heliplane adapts lifting mechanisms to achieve high efficiency throughout its flight envelope: a rotor in hover and slow-speed flight and a fixed wing combined with turbofan engines for high-speed flight. Rotor power is achieved through a reaction drive tip-jet that eliminates the complexity and weight of a transmission and the requirement for a tail rotor.

The Unmanned Ground Combat Vehicle/PerceptOR Integration (UPI) program is increasing the capabilities of unmanned ground vehicles (UGVs) to navigate in mission-relevant, cross-country environments. The program utilizes two highly mobile 6.5 ton, 6×6 wheeled, skid-steered, hybrid electric UGVs integrated with a state of the art perception and sensor system. The UPI program is demonstrating how these platforms can perform reliably and autonomously in obstacle-rich terrain, and is also developing tools to allow the vehicles to plan their path using terrain data.

The DARPA Grand Challenge 2005, held in October 2005, accelerated the development of autonomous ground vehicles to replace manned military vehicles in dangerous missions. It demonstrated that autonomous ground vehicles can travel significant distances, such as from one city to the next, at militarily relevant speeds. The 132-mile Grand Challenge course consisted of rugged desert roads typical of the terrain found in operational environments, and vehicles

Figure 25: The winner, 2005 DARPA Grand Challenge – Stanford's Stanley (6h 53m – 19.2 mph).

could use only onboard sensors and navigation equipment to find and follow the route and avoid obstacles. Five teams completed the course, and four finished under the required 10-hour time limit, with Stanford's "Stanley" the winner at six hours, 53 minutes (Figure 25). One team's vehicle remained in autonomous mode overnight on the desert route and completed the route the next day without any human intervention other than to give the vehicle permission to move.

The next step is the Urban Challenge, which is designed to accelerate the development of autonomous ground vehicles capable of operating safely in traffic. The final event in November 2007 will demonstrate if autonomous vehicles can travel 60 miles in under six hours through urban traffic.

3.5. Detection, Characterization, and Assessment of Underground Structures

Our adversaries are well aware of the U.S. military's sophisticated intelligence, surveillance, and reconnaissance assets and the global reach of our strike capabilities. In response, they have been building deeply buried underground facilities to hide various activities and protect them from attack.

Figure 26: Cave entrance.

These facilities can vary from the clever use of caves to complex and carefully engineered bunkers in both rural and urban environments (Figure 26 and Figure 27). They are used for a variety of purposes, including protecting leadership, command and control, hiding artillery and ballistic missiles launchers, and producing and storing weapons of mass destruction.

To meet the challenge posed by the proliferation of these facilities, the Counter-Underground Facility program is developing a variety of sensor technologies and systems – seismic, acoustic, electromagnetic, optical, and chemical – to find, characterize, and conduct post-strike assessments of underground facilities. Specifically, the program is working on tools to answer the questions, "Where is the facility? What is this facility's function? What is the pace and schedule of its activities? What are its layout, construction, and vulnerabilities? How might it be attacked? Did an attack destroy or disable the facility?"

Figure 27: Underground facility.

To answer these and other questions, DARPA is developing ground and airborne sensor systems with two-orders-of-magnitude improvement in sensor system performance, with emphasis on advanced signal processing for clutter rejection in complex environments.

For example, the Low-Altitude Airborne Sensor System (LAASS) is demonstrating the use of airborne electromagnetic, acoustic, and gravity sensors to rapidly find underground

facilities and map out their backbone structure. In proof-of-concept testing, LAASS exhibited excellent performance, and DARPA has begun prototype development.

To help the DoD in the near-term, technologies from LAASS and other activities in DARPA's Counter-Underground Facility program have been evaluated and inserted in systems development efforts by a number of agencies responsible for understanding and prosecuting hard and deeply buried targets. Some of these technologies have been taken to Iraq for further testing and use.

While large, developed facilities have long been recognized as strategic threats, there is increasing need to find and characterize small underground structures. These include caves that serve as hiding places and tunnels for smuggling weapons and infiltrators across borders. Caves and tunnels provide secret entry into sensitive areas, such as Baghdad's International Zone, and may even contain prisons, weapons laboratories, or nuclear power plants.

DARPA has developed several technologies under the Remote Interconnected Tunnel Assessment (RITA) and Cross-Border Tunnel programs to aid in the search and prosecution of these threats, especially when exploited by terrorist organizations.

3.6. Space

The national security community, and the U.S. military in particular, use space systems for weather data, warning, intelligence, communications, and navigation because they provide great advantages over potential adversaries. American society as a whole uses space systems for many similar purposes, making them an integral element of the U.S. economy and way of life.

These advantages – and the dependencies that come with them – have not gone unnoticed, and there is no reason to believe they will remain unchallenged or untested forever. As the Rumsfeld Commission explained, "An attack on elements of U.S. space systems during a crisis or conflict should not be considered an improbable act. If the United States is to avoid a 'Space Pearl Harbor,' it needs to take seriously the possibility of an attack on U.S. space systems."[6]

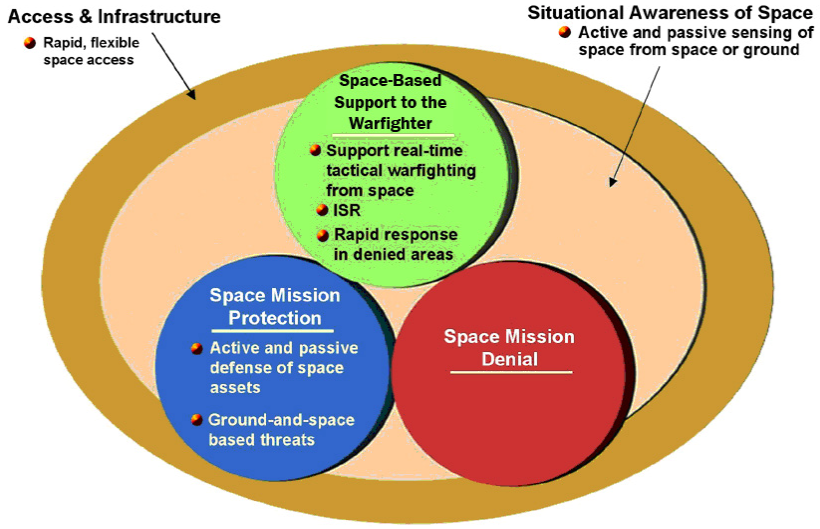

Figure 28: DARPA's space thrust.

6 Honorable Donald H. Rumsfeld, Chairman, Rumsfeld Commission, *Report of the Commission to Assess United States National Security Space Management and Organization* (January 11, 2001).

DARPA began as a space agency, when the shock of Sputnik caused Americans to believe the Soviet Union had seized "the ultimate high ground." DARPA maintains an ambitious effort to ensure that the U.S. military retains its preeminence in space by maintaining unhindered U.S. access to space and protecting U.S. space capabilities from attack. Figure 28 depicts DARPA's space strategic thrust with five elements:

- *Access and Infrastructure:* technology to provide rapid, affordable access to space and efficient on-orbit operations;
- *Situational Awareness:* the means for knowing what else is in space and what that "something else" is doing;
- *Space Mission Protection:* methods for protecting U.S. space assets from harm;
- *Space Mission Denial:* technologies that will prevent our adversaries from using space to harm the U.S. or its allies; and
- *Space-Based Support to the Warfighter:* reconnaissance, surveillance, communications, and navigation to support military operations down on earth – extending what the United States does so well today.

The Falcon program (Figure 29) is designed to vastly improve the U.S. capability to promptly reach orbit. The Falcon program includes launching the first of a series of new, low-cost, small launch systems that could be used to deliver new hypersonic test vehicles to near-space, and satellites into orbit. These new systems will enable an affordable and responsive launch vehicle capability for payloads in the 1000-pound class (Figure 30), reducing the cost of launch by over 50 percent. By the end of 2009, Falcon will have conducted flight tests of hypersonic test vehicles, which will focus the nation's hypersonic technology development and spur progress in this critical area for our nation's defense.

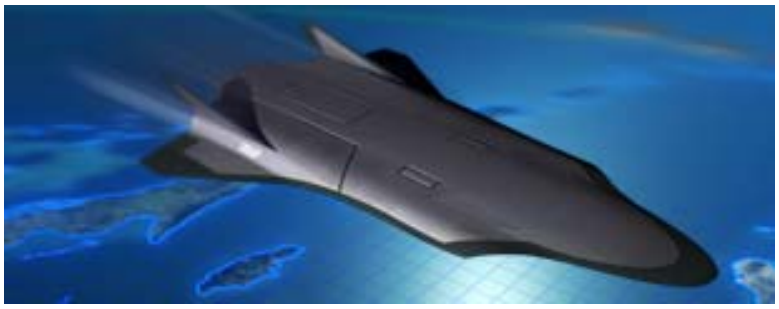

Figure 29: Falcon program's Hypersonic Cruise Vehicle.

Figure 30: Falcon Small Launch Vehicle (SpaceX's Falcon I) to be launched from Kwajalein Atoll, Marshall Islands.

Propellant on-board today's spacecraft is limited to the amount carried at launch. This reduces the useful payload on orbit because significant fractions of launch mass must be devoted to providing a lifetime of on-orbit fuel. Limited fuel also constrains on-orbit maneuvering, reducing the ability to relocate spacecraft in response to new needs or threats. In short, the inability to either refuel or repair spacecraft on-orbit sets a undesirable limit on their lifetime.

To address this problem, the Orbital Express program will demonstrate the

feasibility of using automated spacecraft to refuel, upgrade, and extend the life of appropriately designed on-orbit spacecraft. This will lower the cost of doing business in space and will provide radical new capabilities for military spacecraft, such as high maneuverability (which will make our satellites more difficult to track, hide from, or attack), autonomous orbital operations, and satellites that can be reconfigured as missions change, threats evolve, or as technology advances.

The F6 (Future Fast, Flexible, Fractionated, Formation-Flying Spacecraft) program takes a technically aggressive approach to combining separately launched space payloads and spacecraft subsystem elements. F6 will develop methods for satellite payloads and subsystem elements to operate in close formation, dividing mission requirements between nodes of the formation. Satellite systems could be repaired or upgraded by placing a new, wirelessly connected element into the formation. The systems could be less vulnerable to attack or failure because the components are physically separated. This capability also promises improved reliability and reduced risk from launch failures.

The Space Surveillance Telescope program will enhance our space situational awareness by developing a large-aperture optical telescope with very wide field of view, using curved focal plane array technology to detect and track very faint objects in space, e.g., new and unidentified objects that suddenly appear with unknown purpose or intent.

With respect to space mission protection, nuclear detonations in low earth orbit present a threat to orbiting satellites. The radiation from a space detonation can be trapped by the earth's magnetic field, increasing the number of energetic particles in the radiation belts and quickly degrading or destroying satellite electronics. The Radhard by Design program will develop design techniques for radiation hardened integrated circuits that can be produced in standard commercial foundries. Also, the Sleight of Hand program seeks to reduce this risk by using high power very low frequency radio transmissions to accelerate the decay of the energetic particles out of the belts.

The U.S. national security community and American society depend on communications satellites, and we must be prepared for adversaries that might try to jam them and deny us their use. DARPA's Novel Satellite Communications program is working to dramatically improve the hardening of our communication satellites against jamming by developing algorithms that fully exploit a new approach – demonstrated in recent years by DARPA – to dramatically improve anti-jam capabilities for all types of communications satellites.

DARPA's Integrated Sensor Is Structure (ISIS) program is the most powerful U.S. moving target indicator radar for air and ground targets ever conceived. Using the enormous platform surface area available on a stratospheric airship, ISIS will incorporate an extremely large antenna (approximately 1600 square meters) directly into the structure of the airship. A single ISIS stationed over Baghdad today would provide total airspace knowledge and unprecedented ground vehicle tactical tracking across more than 80 percent of Iraq.

3.7. Increasing the Tooth to Tail Ratio

U.S. force structure is on a transformation path to operational units that are rapidly deployable and with capabilities that are flexible and effective across a range of missions, from combat to stability operations. Deployed forces require a robust and extensive support infrastructure that is growing even larger given current capabilities. The support infrastructure (the "Tail") holds back the ability of the Operational units (the "Tooth," or sometimes referred to as the "Tip of the Spear") to achieve full rapid deployability and be within the decision loop of enemy forces. For

example, as information and communications increase in importance to modern combat and stability operations, more personnel are needed to operate the computers, software applications, and networks that support the front-line forces. Development of new information technology capabilities offers an opportunity to increase the existing forces' tooth to tail ratio by reducing the number of personnel required for support operations and making them available for other duties as needed by the Combatant Commanders.

From the personal computer to the Internet and beyond, DARPA has been a key catalyst behind much of the information revolution. Information Technology (IT) is a powerful tool for warfighters because it increases their tooth to tail ratio: IT is a substitute for layers of bureaucracy that would otherwise be needed to process information and handle the routine chores required for many warfighting tasks, while enabling warfighters to do things they never could before. DARPA is continuing this tradition, focusing on revolutionary new information technologies that will help the U.S. military make better decisions faster and with fewer support personnel.

Figure 31 shows the major themes of this strategic thrust:

Theme	Approach
Reduce Manpower and Empower People	Automation Through Cognition
Accelerate Development and Deployment of New Systems	High-Productivity Computing Systems
Global Operations	Language Processing

Figure 31: Major themes supporting enhanced decision-making.

- *Cognitive Computing* – Reducing manpower by providing computers that "know what they are doing" and can learn;
- *High Productivity Computing Systems* – Speeding up the development and deployment of new weapon systems by more complete and rapid design and testing; and
- *Language Processing* – Improving our global operations by providing local knowledge and interaction with the local population by removing language and culture barriers through superb machine language translation, thereby reducing the need for human translators.

Cognitive Computing

Computer systems are essential to military logistics and planning, command and control, and battlefield operations. Information superiority has greatly increased U.S. military effectiveness, but it has also increased the warfighter's cognitive burden in an already stressful environment. Moreover, as DoD's computing systems have become pervasive, they have also become

increasingly more complex, fragile, vulnerable to attack, and difficult to maintain. The computing challenges facing the DoD in the future – autonomous platforms that behave reliably without constant human intervention, intelligence systems that effectively integrate and interpret massive sensor streams, and decision support systems that can adapt rapidly – will depend on creating more flexible, competent, and autonomous software.

DoD needs revolutionary new computer technology to overcome these challenges. DARPA has embarked on an ambitious mission to create a new generation of computing systems – *cognitive computers* – to dramatically reduce military manpower and extend the capabilities of commanders and warfighters. Cognitive computing systems can be thought of as systems that "know what they're doing." DARPA's cognitive computing research is developing technologies that will enable computer systems to learn, reason and apply knowledge gained through experience, and respond intelligently to new and unforeseen events.

Success will have enormous benefits for our military. In the real-time environment of military operations, cognitive systems that can learn, reason, and draw on their experience to assist their user will help make the difference between mission success and failure. Cognitive systems will give military commanders and their staffs better access to a wide array of rapidly changing information, reduce the need for skilled computer system administrators, and dramatically reduce the cost of system maintenance.

For example, today's computers handle low-level processing of large amounts of raw data and numeric computations extremely well. However, they perform poorly when trying to turn raw data into high-level actionable information because they lack the capabilities we call "reasoning," "interpretation," and "judgment." Without learning through experience or instruction, our systems are doomed to repeat mistakes, and their performance will not improve. The DoD needs computer systems that can behave like experienced executive assistants, while also retaining their ability to process data like today's computational machines.

Working with the Air Force

DARPA and the Air Force have a strong working relationship, including quarterly meetings between the DARPA Director and the Secretary of the Air Force, and a particularly close and productive relationship with the Air Force Space Command. This has led to several new DARPA programs in space, targeting, and in-flight data exchange. As the Executive Agent for Space, the Air Force continues to integrate its operational missions with DARPA's technology development. These efforts are tackling the most difficult challenges to ensure that the United States maintains free and rapid access to space, and that U.S. space assets are protected from attack.

To improve our ability to strike mobile targets, DARPA and the Air Force's Air Combat Command are developing fast, precision-strike technologies to prosecute time-critical targets and perform battle damage assessment. In supporting the work in precision strike, DARPA is currently working on technology to vastly improve the exchange of data in-flight – technology that was first operationally validated in Afghanistan in 2001. DARPA has also established a working relationship with the Air Mobility Command to investigate technologies for in-transit visibility. In September of 2006, the Air Force and DARPA signed a Memorandum of Agreement (MOA) for the ORCLE program (see p. 16). This MOA provides for joint Air Force-DARPA program funding, an aerial demonstration, and subsequent transfer of ORCLE to Air Force warfighters. Looking forward, DARPA is working closely with the Air Force to enable capabilities for long-range strike, including a new class of weapons and vehicles.

In response, the Personalized Assistant that Learns (PAL) program is creating revolutionary technology for commanders and warfighters – the first comprehensive system that will dramatically empower commanders to understand, at a glance, all aspects of the current military situation. PAL will radically reduce manpower and labor required in command posts and in the field, and will automate the massive number of administrative and analytical tasks of today's

command centers. PAL systems will automatically adjust to new environments and users, help commanders adapt to evolving situations and priorities, and enable new command center personnel to become effective more quickly (Figure 32).

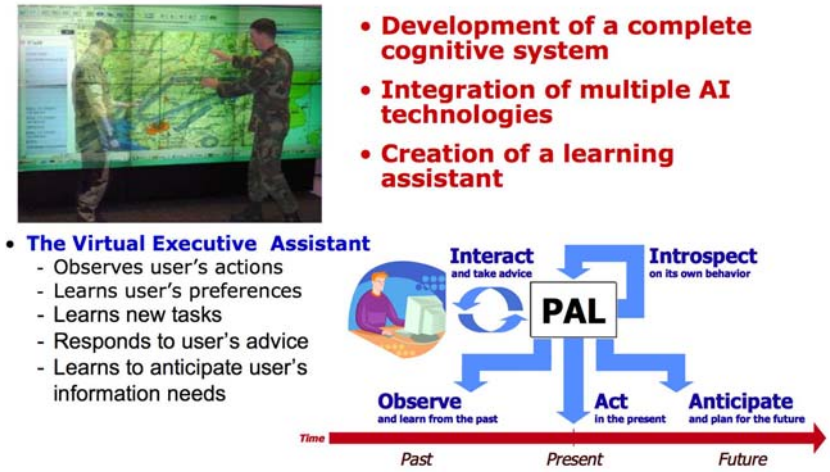

Figure 32: Personalized Assistant that Learns (PAL).

PAL is a national research initiative, combining the efforts of 21 universities and research laboratories across the United States. PAL has already produced a wide range of research breakthroughs in machine learning, knowledge representation and reasoning, communications and interaction, and computational perception. Selected PAL technology is now ready to be applied to military command and control, and has a well-established transition plan to all of the Services.

Learning technology developed under PAL has been applied to data from Command Post of the Future (CPOF) operations in Iraq in order to learn models of command activities. CPOF messages were analyzed to identify topics of interest (e.g., checkpoints, routes, and mortar attacks) and the individuals involved in handling them. A PAL algorithm learned to recognize points where a CPOF user changed his focus of attention. PAL learning technology also identified relationships among CPOF objects (e.g., objectives, activities, units, maps, and reports) by examining the networks of users that shared them.

These successful applications of PAL technology to CPOF data represent first steps towards learning and characterizing the operational patterns of a command center. By using patterns to anticipate users' needs, a cognitive assistant would help users handle additional tasks, as well as tasks of greater complexity, by gathering needed information in advance, coordinating teams, and managing message traffic.

The Transfer Learning program addresses the important problem of being able to learn knowledge from specific instances in such a way that it can be re-used and applied to new situations. The technology will enable computers to use skills, techniques, and knowledge learned from one task to provide superior performance on novel tasks. The inability to transfer learning has been the Achilles Heel for previous technologies, such as expert systems and neural networks, and this program will help prevent today's and tomorrow's programs from becoming trapped in such a *cul de sac*.

High Productivity Computing Systems

One of DARPA's Future Icons (Section 2.5) is the High Productivity Computing Systems program, which is pursuing the research, development and demonstration of economically viable, high productivity supercomputing systems for national security and industrial users. The major goal is to produce, by the end of the decade, extremely high performance computing systems that can be easily programmed and used by experts and non-experts alike. These innovative systems will address the difficulties now limiting the productivity of high-end computing systems by emphasizing programmability, portability, scalability, and robustness as

well as high performance goals of achieving multiple petaflops and thousands of global updates of memory per second (Figure 33). High productivity computing systems will help with the design and development of advanced vehicles and weapons, planning and executing military operations, cryptanalysis, image processing, maintaining the nuclear stockpile, and will be a key enabler for research in security-related fields.

Accomplishments:

- Established benchmarks to guide architecture development
- Matured Phase II concepts and investigated risk mitigation technologies
- Initiated high productivity language development

Plans:

- Build prototype
- Develop and follow a strategy to transition from three new programming languages to one
- Ensure strong involvement of mission partners

Bench-mark	Description	Current*	Future
Global High-Performance LINPAC (G-HPL) (PF/s)	Sustained execution speed @ local nodes	~.2	1—10
STREAM (PB/s)	Data Streaming mode - data processing rate	~.1	4 - 8
Global Random Access (GUPS/s)	GUPS - Random Access across entire memory system	~1 - 35	8K - 96K
Bisection B/W (PB/s)	Max transfer rate between all nodes	~.001 - .01	3 - 5

* These values reflect IBM's custom-built Blue Gene system and are substantially higher than commercially available systems

Figure 33: HPCS accomplishments, plans, and performance objectives.

Language Processing

Improved real-time translation of foreign languages at both the strategic and tactical levels is another important way computers can assist our warfighters. Real-time language translation would help U.S. forces understand the adversary and the overall social and political climate, thus decreasing the chances of costly mistakes due to misunderstandings and increasing the chances of success. Today, translation of important information is accomplished by linguists, and it is a slow process due to the amount of data that must be translated and the limited number of qualified linguists available.

At the strategic level, the goal of the Global Autonomous Language Exploitation (GALE) program is to translate and distill foreign language material (e.g., television shows and newspapers) in near real-time, highlight the salient information, and store the results in a searchable database (Figure 34). GALE is working to achieve this very ambitious goal by 2010.

At the tactical level, there are an insufficient number of translators to support each patrol or vehicle checkpoint. Our warfighters need automatic, on-the-spot speech translation to take advantage of what they may be told by locals about insurgents or suspicious activities, and in order to train or conduct missions with Iraqi units. The Spoken Language Communication and Translation System for Tactical Use (TRANSTAC) program has successfully demonstrated the

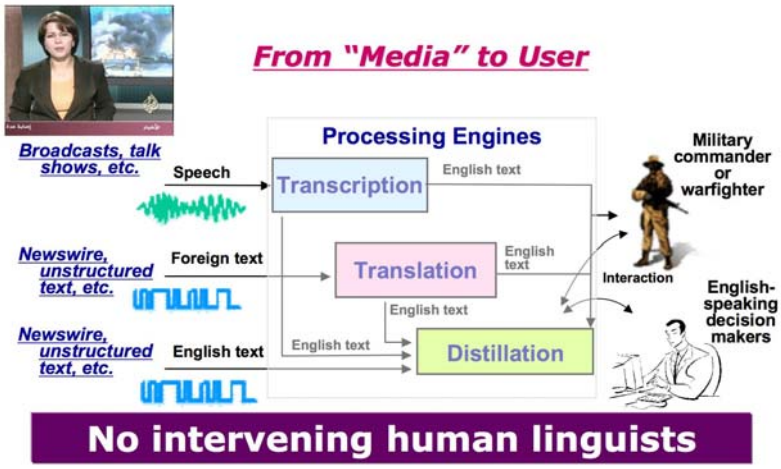

Figure 34: Global Autonomous Language Exploitation.

first two-way speech translation system to translate Iraqi Arabic into English, and vice versa. TRANSTAC works on basic questions and answers about people, medical screening, civil affairs and force protection.

3.8. Bio-Revolution

DARPA's strategic thrust in the life sciences, called Bio-Revolution, is a comprehensive effort to harness the insights and advances of modern biology to make U.S. warfighters and their equipment safer, more capable, and more effective. This thrust stems from several developments.

For more than a decade, the United States and many other nations have made enormous investments in the life sciences – so much that it has become commonplace to say that the world is entering a "golden age" of biology. One would be hard-pressed to find a better example of the Far side than the plethora of fundamental new discoveries in the life sciences reported every day. DARPA is mining these new discoveries for concepts and applications that could enhance U.S. national security in revolutionary ways.

DARPA's programs to thwart the threat of biological attack brought significant biological expertise into the Agency. This expertise led towards a major exploration of the national security potential of cutting-edge research in the life sciences.

Figure 35: Bio-inspired "Big Dog" quadruped robot is being developed as a "mule" that can traverse difficult terrain.

The Bio-Revolution thrust has four broad elements:

- *Protecting Human Assets* refers to DARPA's work in biological warfare defense (BWD) and combat casualty care. DARPA's comprehensive and aggressive BWD program began in the mid-1990s in response to a growing awareness of the biological warfare threat to the United States. Advances in BWD will protect the warfighter not only from biological warfare agents, but also from the infectious diseases they regularly encounter overseas. DARPA is also developing advanced combat casualty care technologies to greatly improve the chances of our wounded surviving battlefield injury.

- *Biology to Enhance Military Systems* refers to creating new systems with the autonomy and adaptability of living things by developing materials, processes, and devices inspired by living systems. This is yielding legged robots (Figure 35) that can outperform wheeled vehicles in unplanned terrain, new optics based on eyes, and room temperature infrared sensors inspired by insect sensors that are lighter, more sensitive, and less costly than conventional sensors. The idea is to let nature be a guide toward better engineering.

- *Maintaining Human Combat Performance* is aimed at maintaining the warfighter's peak physical and cognitive performance once deployed, despite extreme battlefield stresses such as heat and altitude, prolonged physical exertion, and sleep deprivation.

- *Restoring Combat Capabilities after Severe Injury* describes the revolutionary technology DARPA is developing to restore full function after severe injuries. Examples include techniques to accelerate healing, and revolutionary new prostheses for combat amputees.

In the BWD arena, current drug and vaccine development takes years or even decades. This slow process leads to a biodefense strategy of stockpiling therapeutics based on the latest projections of the threat. To completely change this paradigm, DARPA has begun to pursue research to find ways to provide millions of doses of a therapeutic within weeks of identifying a new pathogen.

DARPA is currently investing in three areas in to make this rapid bug-to-drug vision a reality:

- *Protein design processes* focuses on custom design of therapeutic proteins, such as vaccine components and antibodies, through mathematical prediction of structure and function, with the goal of devising an antidote to an infectious agent within 24 hours. This is a core technology program in Bio-Info-Micro (Section 3.9.2) that directly contributes to this strategic thrust.

- *Rapid vaccine assessment* will develop an artificial human immune system-on-a-chip consisting of human immune cells and micro-scale immune structures. If successful, this technology will facilitate rapid screening of candidate vaccines *within weeks* instead of years.

- *Accelerated manufacturing of pharmaceuticals* could revolutionize the scale and speed of vaccine and pharmaceutical manufacturing. Today, even if the ideal vaccine or antibody were known and available, we currently cannot manufacture large-scale quantities of these therapeutics quickly enough to deal with newly engineered diseases, whether caused by hostile action or naturally occurring. The Accelerated Manufacturing of Pharmaceuticals program is exploring several difficult but plausible solutions for manufacturing millions of doses of a complex new therapeutic within 12 weeks.

To revolutionize the treatment of severe bleeding on the battlefield, the Surviving Blood Loss program is developing therapies to allow injured troops to survive an otherwise fatal blood loss for up to six hours, until definitive care can be provided. Early experiments with rodents showed that a dose of estrogen, given immediately after an severe hemorrhage, prevented 75 percent of the group from going into shock and dying, whereas the *entire* control group died. Similarly, experiments using hydrogen sulfide to put hemorrhaged rodents into a significantly lowered metabolic state showed a 100 percent survival rate. These preliminary results show the great promise of this research area to save lives among the severely injured.

Today's Soldier often must carry a heavy load. In DARPA's Biodynotics program, the Big Dog project (Figure 35) applied biological principles that animals use to move and crawl across different terrain types to develop a bioinspired robotic "pack mule" that can carry 150-200 pounds over any terrain and under any conditions a human could tolerate. The vision is that Big Dog would enhance warfighters' capability by carrying supplies.

The vision of the Revolutionizing Prosthetics program, another of DARPA's Future Icons (Section 2.5), is simple but bold: to develop technologies for limb prostheses that are fully functional, neurologically controlled, and have normal sensory capabilities. This will allow

wounded, active-duty Soldiers to rapidly return to service with artificial limbs that work as well as the ones they had. Our vision includes not only regaining fine motor control, such as the ability to type on a keyboard or play a musical instrument, but also the ability to sense an artificial limb's position without looking at it, and to actually "feel" precisely what the artificial limb is touching by relaying sensations through residual nerves. (This program is also leveraging developments in a core technology program, Human Assisted Neural Devices.)

Three key breakthroughs are needed for this vision: (i) an unequivocal demonstration that motor signals from the brain can be decoded; (ii) a demonstration that the perception of feeling can be created in the brain – success here is important because sensory feedback is crucial to be able to feel objects that are being grasped so that the prosthesis is experienced as an arm instead of as a tool; and (iii) development of microsensors that send and receive signals to and from the nerves without causing nerve damage – eventually enabling detection and/or input of motor or sensory signals into a Soldier's remaining peripheral nerves. Four years from now, DARPA plans to deliver for clinical trials an upper limb that is not only functionally superior, but one that is controlled by the brain and provides full sensory feedback to the patient.

3.9. Core Technologies

While the eight DARPA strategic thrusts described above are strongly driven by national security threats and opportunities, a major portion of DARPA's research emphasizes areas largely independent of current strategic circumstances. These core technologies are the investments in fundamentally new technologies, particularly at the component level, that historically have been the technological feedstocks for new systems enabling quantum leaps in U.S. military capabilities.

In fact, these technologies often form enabling chains. Advanced materials have enabled new generations of microelectronics, which, in turn, have enabled new generations of information technology, which is the enabling technology for network-centric operations (see Section 3.1).

3.9.1. Quantum Science and Technology

Until recently, quantum effects in many electronic devices did not have overriding significance. However, with shrinking device sizes, quantum effects not only have to be taken into account but can dominate how devices perform. DARPA is conducting research aimed at technology built around exploiting quantum effects to achieve revolutionary new capabilities.

For example, The Quantum Entanglement Science and Technology (QuEST) program is exploring the research necessary to create new technologies based on quantum information science. Research in quantum entanglement has the ultimate goal of demonstrating the potentially significant advantages of quantum mechanical effects in communication and computing. QuEST is a broad-based program that will continue to explore fundamental open questions, the discovery of novel algorithms, and the theoretical and experimental limitations of quantum processing, as well as the construction of efficient, practical applications.

3.9.2. Bio-Info-Micro

For the past several years, DARPA has been exploiting and developing the synergies among biology, information technology, and micro-/nanotechnology. Advances in one area often benefit the other two, and DARPA has been active in information technology and microelectronics for many years. Bringing together the science and technology from these three areas produces new insights and new capabilities.

An example is one of DARPA's Future Icons (Section 2.5), the Fundamental Laws of Biology program. Every biological system, whether as complicated as the human body or as simple as a virus, lives by means of complex interactions within a complex environment. Up to now, scientists have been able to characterize even the simplest biological system only by rigorously collecting vast amounts of data through detailed observations, which often takes years or decades. The Fundamental Laws of Biology program is working to develop a new basis for doing biological research by bringing an increased mathematical discipline to biology, including creating new mathematics to reveal unanticipated features and relationships. The goal is to discover the fundamental laws of biology that extend across biological scales, and that can be used to make predictions.

Working with the Navy

DARPA maintains its solid relationship with the Navy through regular information exchanges among senior leadership. These include recent visits between the Director and the Secretary of the Navy, Chief of Naval Operations, Combatant Commanders, and the Chief of Naval Research. DARPA integrates these important inputs with those from other senior Interagency information exchanges to create the best possible synergy for potential maritime programs and provide responsive support to the warfighter.

Memoranda of Agreement (MOAs) established between DARPA and Naval leadership maintain commitment to future revolutionary technologies. MOAs signed since 2005 include use of software agents to search for anomalies or suspicious patterns in international high-interest shipping; development of high-efficiency shipboard lighting; high-performance corrosion-resistant materials; revolutionary training aids; language translation and exploitation; and micro air vehicles. Work continues with the Navy in efforts to dramatically reduce costs and increase capabilities in submarine and shipbuilding through programs in ship-wide integrated computing networks; friction drag reduction; and wide bandgap high-power electronics.

For the future, technologies related to the Navy's unique antisubmarine warfare mission will continue to be a priority, as well as distributed sensors, self-forming communication networks, extremely capable autonomous vehicles/vessels, and the ability to maintain persistent surveillance on high-value targets of interest – while delivering the right information to the right decision-maker at the right time.

3.9.3. Materials

The importance of materials technology to Defense systems is critical and long-standing: many fundamental changes in warfighting capabilities have sprung from new or improved materials. The breadth of this impact is large, ranging from stealth technology, which succeeds partly because materials can be designed with specific responses to electromagnetic radiation, to information technology, which has been enabled by advances in materials for electronic devices.

In keeping with this broad impact, DARPA maintains a robust and evolving materials program. DARPA's approach is to push new materials opportunities and discoveries that might change how the military operates. In the past, DARPA's work in materials has led to such technology revolutions as high-temperature structural materials for aircraft and aircraft engines, and the building blocks for the world's microelectronics industry. The materials work DARPA is supporting today builds on this heritage.

DARPA's current work in materials includes the following areas:

- *Structural Materials and Components*: low-cost and ultra-lightweight materials designed for structures and to accomplish multiple performance objectives in a single system;
- *Functional Materials*: advanced materials for non-structural applications such as electronics, photonics, magnetics, and sensors; and
- *Smart Materials and Structures*: materials that can sense and respond to their environment.

For example, the Structural Amorphous Metals (SAM) program is advancing a new class of bulk materials with amorphous or "glassy" microstructures that have previously unobtainable combinations of hardness, strength, damage tolerance and corrosion resistance. Calcium-based SAM alloys are being developed for ultralight space structures, aluminum-based alloys are being targeted for efficient turbine compressor blades, and iron-based alloys show outstanding corrosion resistance in marine environments. In a joint effort with the Navy, the Naval Advanced Amorphous Coatings program is exploiting these corrosion-resistant alloys as early-applied coatings with the goal of certifying them for unrestricted use on Naval ships.

Figure 36: Exoskeleton.

Smart materials enable a wide range of new structural concepts. They will also help our Soldiers carry ever-heavier and more cumbersome loads into combat – particularly when we account for body armor, which is critical in the close quarters of urban warfare. The Exoskeleton program (Figure 36) has been developing and demonstrating the critical technologies such as power, control, and actuation that will lead to a self-powered external structure to enable a Soldier to carry over 100 pounds of additional payload without feeling the weight. They will also enable future systems such as a morphing aircraft, which will change its shape like a bird to optimize military performance.

For titanium, DARPA has demonstrated a production process that offers the potential for radically reducing the price of titanium to less than four dollars per pound for military-grade quality metal. This program, one of DARPA's Future Icons (Section 2.5), is now moving from the feasibility stage to a prototype operation. This will be a true paradigm shift as to the use of titanium, as occurred with aluminum once it was no longer a precious metal but could be produced economically.

3.9.4. Power and Energy

Portable sources of electric power are critical to today's military. To Napoleon's dictum that an Army moves on its stomach, today's modern warfighting forces could add, "…and on energy." Developing portable, efficient, and compact power supplies has important ramifications for increasing our military reach, decreasing our logistics burden, and improving the overall efficiency of our warfighting forces – especially for distributed and net-centric operations.

The goal of the Mobile Integrated Sustainable Energy Recovery (MISER) program is to develop technologies that can use military waste to run military generators. Because seven pounds of plastic waste has energy equivalent to a gallon of JP-8, the logistics savings and advantages of success could be dramatic. And, the Palm Power program is demonstrating the use of fuel cells to reduce the logistics burden of batteries by a factor of 10.

The Very High Efficiency Solar Cell program is aimed at developing photovoltaic devices with efficiencies exceeding 50 percent. The program has a novel design architecture that allows integrating previously incompatible materials technologies to maximize performance across the solar spectrum. The program is evaluating the potential of engineered bio-molecules to guide the

assembly of inorganic materials in a manner not achievable with current technology, which offers the prospect for dramatic cost reductions in key materials

To help reduce the military's reliance on petroleum-based fuels to power its aircraft, ground vehicles, and non-nuclear ships, DARPA's BioFuels program is working to develop an affordable surrogate for military jet fuel (JP-8) derived from oil-rich crops produced by either agriculture or aquaculture including, but not limited to, plants, algae, fungi, and bacteria.

3.9.5. Microsystems

DARPA is shrinking ever-more-complex systems into chip-scale packages, integrating microelectronics, photonics, and microelectromechanical systems (MEMS) into "systems-on-a-chip" that have new capabilities. It is at the intersection of these three core hardware technologies of the information age that some of the greatest challenges and opportunities for DoD arise. Examples include integrating MEMS with radio frequency electronics and photonics; integrating photonics with digital and analog circuits; and integrating radio frequency and digital electronics to create mixed signal circuits. The model for this integration is the spectacular reduction in transistor circuit size under Moore's Law: electronics that once occupied entire racks now fit onto a single chip containing millions of transistors.

For instance, the Navigation-Grade Integrated Micro Gyroscope program is developing tiny, low-power, rotation-rate sensors capable of achieving performance commensurate with requirements for GPS-denied navigation of small platforms, including individual Soldiers, unmanned (micro) air vehicles, unmanned underwater vehicles, and even tiny (e.g., insect-sized) robots. The program will harness the advantages of micro-scale miniaturization to yield tiny (if not chip-scale) gyroscopes with navigation-grade performance.

Another example is the new photonic components, such as optical wavelength converters, optical switches, optical waveform generators, and optical buffers, that were developed under the Data in the Optical Domain Network (DOD-N) program. DOD-N has, for the first time, shown a path to an optical network that eliminates electrical-to-optical-to-electrical data conversion at each data router, thereby increasing the projected network data throughput by over a factor of 10. Combined with new network management strategies that dramatically reduced the amount of buffer memory required at each network node, DOD-N will enable new optical networks that can meet the growing DoD need for bandwidth, while also minimizing latency.

Microscale chemical and biological sensors are also being developed by scaling macro-equipment to micro-scale systems for lower power and higher performance, as seen in faster response times, lower false alarm rates, and higher probability of detection. The Micro Gas Analyzer program is shrinking the equivalent of a chemical laboratory gas chromatography, mass spectrometer that is the size of a large laser printer to one-cubic-centimeter by exploiting micromachining. In addition, another program is producing small tunable infrared semiconductor laser diodes to enable a compact laser photoacoustic spectrometer for detecting and identifying chemical warfare agents using the resonant acoustic signature of chemical molecules. Both of these programs will allow fast, low false alarm identification of hazardous agents in a form factor that will enable distributed deployment across a battlefield or throughout a DoD facility.

Microwave sensors will extend the performance of future radar, electronic warfare, and communications systems, and the advanced power electronics will reduce the size and weight of the power conversion stations in future aircraft carriers and contribute to realizing tactical electromagnetic weapons.

As successful as this progress has been, the future lies in exploiting advances in nano-science and nanotechnology, where matter is manipulated at the atomic scale to develop new capabilities and to integrate various technologies to create still-more-complex capabilities in ever smaller and lower-power packages. DARPA envisions adaptable microsystems for enhanced radio frequency and optical sensing; more versatile signal processors for extracting minute signals in the presence of overwhelming noise and intense enemy jamming; high-performance communication links with assured bandwidth; and intelligent chips that allow a user to convert data into actionable information in near-real-time.

Taken together, these capabilities will create information superiority by improving the ability of the mobile warfighter to collect, process, manage, and act on information – ultimately allowing U.S. forces to think and react more quickly than the enemy in a rapidly change battlespace.

An example of the move to integrated micro-systems is the 3-D Electronics program. Conventional 2-D circuits are limited in performance by the long signal interconnects across ever larger circuits and by existing circuit architectures. By moving to three dimensions (Figure 37), we can shorten the signal paths and introduce additional functions in each layer of 3-D stacked circuits that will change the way designers can exploit circuit complexity.

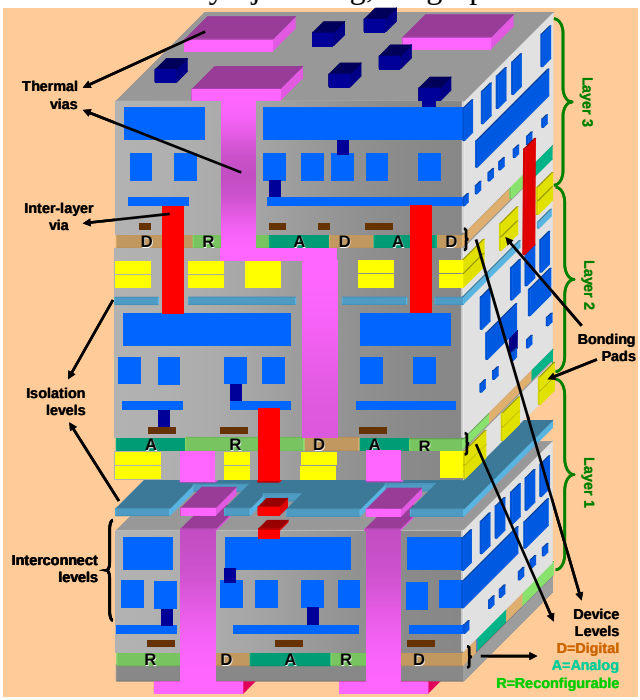

Figure 37: Schematic of 3-D circuit employing advanced functionality in each layer and reducing the length of critical signal paths.

As an example of how this integration approach is impacting system architecture, the Vertically Interconnected Sensor Array program is revolutionizing how focal plane arrays are coupled to their readout electronics by putting the electronics directly behind each pixel. New wafer-level processing technology makes it possible to construct these 3-D stacks, which will dramatically increase the performance and reduce the footprint of the focal plane.

Advanced materials are important drivers in developing new, advanced microsystems. An example is the progress being made in wide bandgap semiconductor devices for ultraviolet emitters, microwave sensors, and high-power electronics. The ultraviolet emitters are being integrated into a compact, low-cost, biosensor based on multi-wavelength fluorescence for a new class of early warning biosensor systems. The microwave sensors will extend the performance of future radar, electronic warfare, and communications systems.

3.9.6. Information Technology

The DoD is undergoing a transformation within network-centric operations – to turn information superiority into combat power. DARPA's information technology programs are building on both traditional and revolutionary computing environments to provide the kind of secure, robust, efficient, and versatile computing foundation that our network-centric future requires. We will create radical new computing capabilities to make the commander and the warfighter more effective in the field.

DARPA's work in information technology is closely intertwined with its strategic thrust in Increasing the Tooth to Tail Ratio. It is a core technology that supports an even broader set of problems and opportunities.

A key area in information technology is embedded systems – special purpose computer systems contained in the device they help control, enabling advanced intelligent functionality such as flight controls, radar, and electronic countermeasures. Embedded computing is critical across a broad range of military applications, from handheld, fielded systems and intelligent weapons systems to airborne information and command centers. Embedded applications face stringent limitations on size, weight and power, while requiring maximum performance and reliability. Current DoD embedded computing systems are point-solutions, tailored to a specific, static, and inflexible set of mission requirements. These implementations lead to one-of-a-kind systems that are costly to develop and unable or extremely expensive to adapt to changing requirements.

DARPA is pursuing technologies to overcome these limitations. This includes technologies for efficiently designing embedded systems, for high performance, flexible embedded processing, and for recovering and maintaining investments in software. These technologies are essential to providing embedded systems that can be efficiently implemented and adapt to changing missions. In its Polymorphic Computing Architecture program, DARPA is developing a class of flexible processors which can reconfigure dynamically, as required by the mission.

3.9.7. Mathematics

DARPA's mathematics program develops new mathematical tools for a broad continuum of DoD missions. The program is rooted in the tenet that DoD needs are best addressed by integrated teams of mathematicians and subject matter experts. This enables the rapid exploitation of new mathematical techniques to create novel technologies, as well as translating technological needs into research problems for the mathematics community.

Current program themes include topological and geometric methods, inverse methods, multiresolution analysis, representations, and computation that are applied to design and control complex systems, extract knowledge from data, forecast and assess risk, develop algorithms, and perform efficient computations. Potential applications include signal and image processing, biology, materials, sensing, and design of complex systems. For example, the Topological Data Analysis program is developing mathematical concepts and techniques to determine the fundamental structure of massive data sets along with the tools to exploit that knowledge. The result will be easy-to-use algorithms that find and display hidden properties of massive data sets and allow greater and faster understanding of the phenomena they represent.

By promoting interaction among the most creative thinkers in mathematics with leaders in disparate fields such as physics, biology, material sciences, and engineering, the programs seek to understand and intertwine fundamental mathematics with applications for the full spectrum of DoD needs. Today's applied mathematics and computational research programs help achieve cutting-edge technical superiority, while the basic mathematical research programs are securing the foundation for advanced science and technology programs.

3.9.8. Manufacturing Science and Technology

The DoD requires a continuous supply of critical, defense-specific materiel and systems. To ensure reliable, robust, and cost-effective access to these items, manufacturing technologies that can meet DoD's needs must be available in the DoD industrial base.

As an example, the Maskless Direct-Write Nanolithography for Defense Applications program will develop a maskless, direct-write lithography tool that will address both the DoD's need for affordable, high-performance, low-volume integrated circuits and the commercial market's need for highly customized, application-specific integrated circuits. This program, based on writing circuits versus printing them, will also provide a cost-effective manufacturing technology for low-volume nanoelectromechanical systems and nanophotonics initiatives within the DoD. Maskless lithography tools, installed in the Trusted Foundry and in commercial foundries, would enable incorporation of state-of-the-art semiconductor devices in new military systems, and allow for the cost-effective upgrade of legacy military systems.

3.9.9. Lasers

Lasers are a core technology that has been important to the Department for over 40 years. Lasers have multiple military uses, from sensing to communication to electronic warfare to target designation. And since the technology was first demonstrated, DoD has maintained a steady interest in developing, evaluating, and deploying lasers for a wide range of speed-of-light weapon applications. Starting in the early 1960s, DARPA has been involved in lasers and laser technology development for the DoD, and continues its work today in this crucial area.

For example, DARPA is currently working on lasers to arm platforms. The High Energy Liquid Laser Area Defense System (HELLADS) program is a Future Icon (Section 2.5) that is developing a high-energy laser weapon system (~150 kilowatt) with an order-of-magnitude reduction in weight compared to existing laser systems. With a weight goal of less than five kilograms per kilowatt, HELLADS will enable integration of high-energy lasers onto tactical aircraft and unmanned air vehicles, and will significantly increase engagement ranges compared to ground-based systems. If successful, HELLADS will lead to a truly practical, small-size, low-weight tactical laser weapon. This sort of weapon will transform offensive and defensive operations, and provide a tremendous advantage to U.S. forces.

Advanced semiconductor device concepts are also opening new systems opportunities. For example, the Super High Efficiency Diode Sources (SHEDS) program has broken new ground in the efficiency of semiconductor diode lasers that will be used as the front end pump source for tactical high power laser systems. The program has more than doubled the efficiency of the laser diodes from 35 percent to nearly 80 percent overall. This increase in efficiency will dramatically reduce the waste heat in a tactical laser system, enabling a reduction in both form factor and input drive power.

4. Strategy and Programs in Context

4.1. Strategic Thrusts Supporting Quadrennial Defense Review Priorities

The Quadrennial Defense Review (QDR) identified priorities on which the Department is focusing,[7] and Figure 38 shows which of DARPA's strategic thrusts support these priorities.

QDR Priorities	Robust, Secure, Self-Forming Networks	Detection, Precision ID, Tracking, and Destruction of Elusive Targets	Urban Area Operations	Advanced Manned and Unmanned Systems	Detection, Characterization, and Assessment of Underground Structures	Space	Increasing the Tooth to Tail Ratio	Bio-Revolution	Core Technologies
Defeating Terrorist Networks	●	●	●	●	●	●	●	●	●
Defending the Homeland In Depth		●		●		●		●	●
Shaping the Choices of Countries at Strategic Crossroads	●	●		●	●	●	●		●
Preventing Hostile States or Non-State Actors from Acquiring or Using WMD	●	●	●		●		●	●	●

Figure 38: DARPA's Strategic Thrusts and 2006 QDR Priorities.

4.2. Programs and Budget Supporting DARPA's Strategic Thrusts

Figure 39 presents an overview of which DARPA's programs and budget support the Strategic Thrusts. The table shows the Budget Program Elements (PE) and Budget Project Numbers[8] principally funding each area. Details on individual programs can then be found by reading those sections of DARPA's Budget Estimates[9]. The table also shows the principal DARPA offices supporting each area; please refer to the websites of those offices for information on their programs.

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7 *Quadrennial Defense Review Report* (February 6, 2006)

8 Budget Project Numbers refer to a subset of programs grouped together under each Program Element to provide a somewhat finer level of financial detail. It does not mean "project" in the normal sense of the word.

9 Available online at http://www.darpa.mil/body/budg.html

Strategic Thrusts			
Strategic Thrust	**Principal Office(s)**	**Principal Budget Program Elements**	**Principal Budget Project(s)**
Detection, Precision ID, Tracking, and Destruction of Elusive Targets	IXO STO	Tactical Technology (0602702E)	TT-13
		Command, Control and Communications Systems (0603760E)	CCC-01
		Network-Centric Warfare Technology (0603766E)	NET-01
		Sensor Technology (0603767E)	SEN-01, SEN-02
Robust, Secure, Self-Forming Networks	IPTO STO	Information and Communications Technology (0602303E)	IT-03
		Cognitive Computing Systems (0602304E)	COG-01
		Tactical Technology (0602702E)	TT-04, TT-13
		Command, Control and Communications Systems (0603760E)	CCC-02
Urban Area Operations	DSO IXO STO TTO	Tactical Technology (0602702E)	TT-04; TT-06; TT-13
		Command, Control and Communications Systems (0603760E)	CCC-01; CCC-02
		Land Warfare Technology (0603764E)	LNW-01
		Network-Centric Warfare Technology (0603766E)	NET-01
		Sensor Technology (0603767E)	SEN-01
Advanced Manned and Unmanned Systems	TTO STO	Tactical Technology (0602702E)	TT-03; TT-07
		Advanced Aerospace Systems (0603286E)	AIR-01
		Land Warfare Technology (0603764E)	LNW-03
		Network-Centric Warfare Technology (0603766E)	NET-02
		Guidance Technology (063768E)	GT-01
Detection, Characterization, and Assessment of Underground Structures	STO	Sensor Technology (0603767E)	SEN-01
Space	STO TTO	Space Programs and Technology (0603287E)	SPC-01
Increasing the Tooth to Tail Ratio	IPTO	Information and Communications Technology (0602303E)	IT-02, IT-04
		Cognitive Computing Systems (0602304E)	COG-01; COG-02; COG-03
Bio-Revolution	DSO STO	Biological Warfare Defense (0602383E)	BW-01
		Materials and Biological Technology (0602715E)	MBT-02
Core Technologies			
Quantum Science and Technology	DSO MTO	Defense Research Sciences (0601101E)	ES-01; MS-01
		Electronic Technology (0602716E)	ELT-01
Bio-Info-Micro	DSO	Defense Research Sciences (0601101E)	BLS-01; MS-01
		Electronic Technology (0602716E)	ELT-01
Materials	DSO	Defense Research Sciences (0601101E)	MS-01
		Materials and Biological Technology (0602715E)	MBT-01
Power and Energy	MTO DSO STO	Materials and Biological Technology (0602715E)	MBT-01
		Advanced Electronics Technology (0603739E)	MT-15
Microsystems	MTO	Defense Research Sciences (0601101E)	ES-01
		Electronics Technology (0602716E)	ELT-01
		Advanced Electronics Technologies (0603739E)	MT-12; MT-15
Information Technology	IPTO MTO DSO	Defense Research Sciences (0601101E)	CCS-02
		Electronic Technology (0602716E)	ELT-01
Mathematics	DSO	Tactical Technology (0602702E)	TT-06
Manufacturing Science and Technology	DSO MTO STO	Electronic Technology (0602716E)	ELT-01
		Advanced Electronics Technology (0603739E)	MT-07, MT-15
Lasers	TTO MTO	Tactical Technology (0602702E)	TT-06

Figure 39: DARPA's Strategic Thrusts, the principal offices supporting those thrusts, and the Program Element and Project numbers in the Descriptive Summaries for FY 2007.

5. Additional Information

5.1. General

Additional information on DARPA's offices and programs is available at www.darpa.mil. In-depth information is contained in DARPA's budget requests at www.darpa.mil/body/budg.html.

A listing of current DARPA solicitations may be found at www.darpa.mil/baa/. Of special interest to small businesses may be DARPA's Small Business Innovation Research (SBIR) program; more information may be found at www.darpa.mil/sbir/.

The DARPA Director's March 29, 2006, testimony to the Subcommittee on Terrorism, Unconventional Threats and Capabilities of the House Armed Services Committee may be found at www.darpa.mil/body/news/current/DARPAHASC32906final.pdf.

DARPA program news releases can be found at www.darpa.mil/body/news/current/index.asp.

5.2. Special Assistant for Technology Transition

DARPA has a permanent full-time person focused on promoting technology transition. To do so, he works closely with the Operational Liaisons and Agency Representatives, who rotate in and out of DARPA.

Special Assistant for Technology Transition.....Mr. Christopher Earl (571) 218-4425
Chris.Earl@darpa.mil

5.3. DARPA Operational Liaisons and Representatives

DARPA's Operational Liaisons serve as points of contact for the Services. Service representatives with technical questions or needs are encouraged to contact the liaisons or a DARPA program manager working the area closest to a particular area of interest.

Army: .....COL Timothy Tritch (571) 218-4281,
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William.Hoker@darpa.mil
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Marines: .....LtCol Carl Kime (703) 526-4027
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National Geospatial-Intelligence Agency.....Mr. Fred Schnarre (571) 218-4597
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The operational liaisons may also be contacted via SIPRNET at [username]@darpa.smil.mil.

In addition, DARPA has a representative located at the U.S. Special Operations Command:

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Kathy.Macdonald@darpa.mil