GPS-Free Navigation
Greg Duckworth

In her opening speech, Dr. Alving mentioned GPS and the use of pseudo-GPS transmitters like the GPX anti-jam system.
DARPA's work with pseudolites has ably solved the problem of robust geolocation and navigation when one has unrestricted line of sight to overhead beacons.
We want to take our work a step further, however, and deal with cases of systemic denial of GPS and extreme environments such as below the earth in caves, in rubble, in buildings, or even in urban and natural canyons, where GPS-frequency signals just need not apply.

Our goal is to strengthen our geolocation and navigation capabilities to allow us to support a wider range of platforms and missions -- ground or air vehicles navigating in a cave, urban maneuvers like forces inside buildings or urban canyons, sensors and robots operating in rubble, and sensors in forward areas where GPS is easily denied and forward assets like GPX and complex anti-jam antennas are undesirable or impractical.
We want to do all this, and to support all current GPS users under conditions of system denial in the manner to which they have become accustomed.

You may note that throughout this talk I distinguish between navigation, which implies a moving platform and immediate use of the solution, and geolocation, which implies a stationary platform or post-mission reconstruction of locations.
I make this distinction because there may be unique observables or short-cuts to exploit for these specific cases.
For example, long integration times and slow update rates are appropriate for ground sensors where a day to get their bearings is still short in relation to the mission duration.

With that background, I am going to spend the rest of my time outlining some ideas of interest to DARPA.
These ideas are organized roughly by the additional equipment needed to support the user's receiver, which I characterize as: "More Stuff," "Free Stuff," and "No Stuff."
It is also important to note that, while I have nothing against inertial systems, they are not the focus here.
When appropriate, they should be used to smooth and interpolate the output of the direct, non-rate, non-inertial location measurement systems that are of specific interest here.

Let us begin with "More Stuff."
Like GPX, which augments the GPS system with local powerful GPS pseudolites to fight jamming, we may need reinforcements to strengthen our capabilities.
One possibility is to create other types of "beacons" that can penetrate the earth, rubble, and buildings, while minimizing multipath and other environmentally-induced distortions.

DARPA is open to any and all modes of signaling from strategically or tactically placed beacons- acoustics, seismics, magnetic and electric fields- both low-frequency quasi-static and RF, light, gravity, radioactivity, or even pheromones- anything that can get us this degree of penetration.
We also recognize that to completely overcome environmentally-induced complexity- since signals that completely ignore the environment typically won't have much resolution or may be very difficult to detect, it will probably be necessary to process these beacon signals with advanced signal processing for clutter reduction- lots of innovations are needed here.

For example, in the special case of post-mission reconstruction of location, it is possible to exploit the entire history of observations available to mitigate multipath issues.

Imagine if we could create an autonomous crawling, flying, bouncing, and/or rolling probe that could determine the connectivity and extent of caves in Afghanistan.

Just think of the impact this type of probe would also have had on the World Trade Center search and rescue if it had the ability to log where it had been within the tunnels and rubble, and localize with signals from victims heard by its other sensors in order to make their positions available to the searchers.

While we are dealing with "more stuff", it doesn't only have to be transmit beacons, and user receivers- we are also open to tag architectures for these harsh environments, in which a rescuer in burning building, or a sensor to be tracked, emits a signal and a constellation of receivers, hopefully not too many, hopefully not too close, is used to localize it.

The key is the ability to work in hard-to-penetrate, high multipath and clutter environments across the descent of man -- from buildings to rubble to caves.

More Stuff is great, especially if we need it to penetrate obstructions or resist jamming, but what if we can't add local beacons or tag receivers because the desired coverage area is too large, or in denied territory.

Solving the problem then becomes harder, but we may be able to take advantage of "Free Stuff" that we are currently neglecting.

This free stuff includes the panoply of man-made signals that bombard every square inch of this planet, but don't necessarily penetrate very far or very cleanly into buildings or underground.

This approach can take advantage of the electromagnetic signals around us, like television and radio broadcasts, SATCOM, or cellular communications, to counter GPS denial in the one little delicate part of the EM spectrum used by GPS.

For example, these man-made signals may be exploitable for self-localization of Unattended Ground Sensors placed deep in hostile territory.

It is easy for our adversary to jam the sensors' GPS receivers in this environment, rendering them worthless for their mission since they can't determine their locations.

A robust geolocation software receiver could share real estate with communications and MASINT functions and provide geolocation performance with no recurring cost or additional hardware. This could very well become one of the killer apps for software radios.

To exploit this "free stuff," we may need to invest in a little "more stuff."

For example, characterizing the source location and waveforms of these signals of opportunity may require some pre-characterization or extra infrastructure like reference receiver stations in or near theater to provide these characterizations to the user receiver.

We are flexible on this - if it's not too much, not too close.

We'll know it when we see it.

Finally, another real challenge is to get back to the "No Stuff" basics.

How can we exploit the signals that nature hands us to figure out where we and our gizmos are? History and nature have proven that the ancients and migrating and foraging fauna were able to find their way to the motivations of food, mates and a warm dry place to sleep.

This happened despite tremendous observation and process noise.

The motivation DARPA can provide isn't so basic, but we challenge you to figure out how to use our less evolved, but more intrinsically capable conventional and quantum sensors as well as powerful and accurate computing, to carry out navigation and geolocation.

With the daily miracles of new MEMS and atom optics interferometry-based sensors, we should reconsider having to see the heavens.
Can we sense and exploit the gravity signals due to the tidal pull of the sun and the moon, the details of the Earth's magnetic fields, or other more penetrating influences instead?
As you do this, please consider the obscured realms of the rat and the worm, as well as the exposed birds and herds, and consider that we may have much more patience than they do for some of our applications.

The speculative ideas that I have just outlined certainly pose significant sensor challenges to exploit extremely weak signals-- and signal processing challenges to combat multipath clutter.
DARPA needs your help to re-examine both the absolute and relative navigation and geolocation problems for GPS-denied air, surface, and buried environments.
I encourage you to bring your ideas for unique sensor and systems solutions to exploit the wide range of observables, over a wide range of observation times to me and Col. Greg Vansuch.
An RFI covering some of these areas was issued in February.
Please keep your eyes out for a BAA in the near future.

With that, I thank you for your attention, and look forward to hearing some brilliantly wacky responses combining performance, robustness, affordability and the potential for global coverage in as many of these difficult environments and applications as possible.