The 4G soldier — new developments in military mobile communications

DARPA is developing an independent router/repeater to bring broadband voice, video and data to soldiers in the field.

By Dr. Larry Williams and Allen Kupetz

The key to empowering the military with tactical broadband voice, video and data is 4G communications technology that requires a minimal amount of fixed infrastructure, is small and highly portable, and inexpensive enough to be standard issue for every soldier. The Department of Defense's (DoD's) Defense Advanced Research Projects Agency (DARPA) is concertedly working to develop a new type of device to meet these requirements.

New developments

The first-generation device developed for DARPA was named the *Handheld Multimedia Terminal* (HMT), and was based on the development of the Tactical Internet, a data channel also used for routing information to identify positions of friendly forces.

Ad hoc peer-to-peer wireless networking, or mobile mesh networking, can link battlefield forces without fixed infrastructure.

This technology allows each wireless terminal to function as an independent, intelligent router and repeater. The HMT technology was developed to support the simultaneous use of voice over IP (VoIP), data, and multimedia at high data rates in battlefield conditions with no infrastructure.

This technology exists today via prototype HMTs running voice, data, and video applications that have already been demonstrated to the U.S. Army. What a modern military wants and needs is dependable real-time intelligence, shared among networked devices that can help dispel the fog that war's inevitable chaos generates.

There are several DARPA/DoD projects operating simultaneously, all of which have a communications device component. These include the "Warfighter Information Network — Tactical" (WIN-T), "Future Combat Systems" (FCS), "Small Unit Operations/Situational Awareness System" (SUO/SAS), and the "Joint Tactical Radio System" (JTRS).

Whichever program yields the device that will be in every soldier's pocket, it will likely differ from today's radios in terms of size weight, and cost. Not only must the device be small and inexpensive for distribution and use by every soldier, but because it is meant for tactical use, it must operate with virtually no fixed infrastructure. Cell towers cannot be erected on the battlefield.

The JTRS program is an initiative to acquire a family of radios for all DoD components. The effort will replace older, hardware-intensive radios with software applications for waveform generation and processing, encryption, signal processing, and other major communications functions. The approach will support military operations across a spectrum of environments — from backpacks to ships.

The key technology supporting these initiatives is ad hoc peer-to-peer wireless networking (ad hoc p2p), also known as a *mobile mesh network*. Ad hoc p2p operates by taking a collection of mobile terminals (such as handheld devices and vehicular systems) that communicate directly with each other without the aid of established infrastructure.

Ad hoc networking provides a self-organizing and self-healing network structure. Multihop routing terminals act as routers and relays for each other, and extend the range and coverage of communications links between individual soldiers, troop transports and command centers.

Robust and rich capabilities

The military and DARPA have outlined specific capabilities for these devices. At a minimum, they will need:

- *Deployability with little or no fixed infrastructure*. Military engagements are often spontaneous, and a communications solution needs to be, as well. 4G Soldiers bring their networks with them, and take them away when they leave. Network setup automatically begins the minute troops exit a transport, helicopter or ship.

- *Geo-location well beyond the limitations of GPS*. Soldiers cannot afford to expose themselves on a battlefield to acquire GPS coordinates. GPS is also limited in that satellite signals cannot penetrate caves, underground bunkers or inside shielded buildings. Ad hoc p2p wireless has built-in geo-location using an extremely accurate form of triangulation. The 4G soldier can triangulate his or her position, or that of another soldier, based on mesh-enabled vehicles or other devices, even when hiding in caves or otherwise out of harm's way. Readings are faster than GPS (under a second) because soldiers don't have to wait for multiple satellites to acquire a fix.
- *Security*. The device security must address both communications security (COMSEC) and a way to protect the network from unauthorized use if the device is captured.

  Communications are more secure when mesh networks allow for route diversity. Meshed architectures also allow devices to transmit at lower output power to neighbors rather than "shouting" at a cell tower. This lowers the probability of detection and increases battery life. Should a device be captured, the 4G soldier can blacklist that device to maintain the integrity of the network.
- *Anti-jamming robustness*. The 4G soldier is neither dependent on a single frequency nor constrained to a military band. The meshed architecture is the best deterrent to jamming because noise can now be routed around problem areas. These self-forming, self-healing networks will have the ability to instinctively and proactively reduce the probability of jamming.
- *High-mobility connectivity*. Communications devices must operate while vehicles or soldiers are mobile, even at speeds in excess of 100 mph. 4G soldiers can receive real-time streaming video from aircraft, such as the Predator Drone flying over a battlefield. Multitap rake receivers minimize the effects of Doppler radar to maximize the impact of theater air assets.
- *End-to-end IP*. Modern soldiers grew up with computers and will demand the same applications and user interfaces available to civilians. The 4G soldier, using instant messaging, can send photos of enemy positions back to the Pentagon for analysis, and use voice over IP to communicate with non-military phones in an occupied city.

Design challenges and innovations

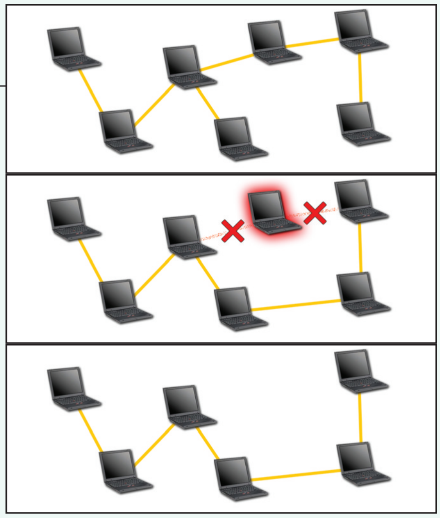
To meet these primary operational requirements and challenges, new communications systems need to operate on wide-ranging frequencies and bandwidths (from 20 MHz to 2.5 GHz at bandwidths from 500 kHz to 20 MHz), subject to the constraints of local spectrum management regulations and operational military imperatives.

The technologies within the device are very tightly related and highly complementary. Tight integration is exemplified by combining physical, media access, and link protocols, as well as a remoted intranet-forwarding table on the programmable modem hardware. This allows 4G soldiers' devices to constantly adapt to changes in their environments at rates faster than the environments change, continuously monitoring and controlling the system at the lowest possible level of the communication protocol stack capable of adapting to the changes.

The modem is the key component in maintaining connectivity under rapidly changing link conditions using a specialized packet-based waveform. The waveform is similar to today's IEEE 802.11 standard, but supports broader flexibility of operation.

The result of these differences, plus additional design features of the modem/waveform combination, provide up to 50 dB processing in signal acquisition in additional to the processing gain associated with adapting the data rate from 4 Mbps down to 16 bps. The affect of the embedded serial probe and multi-dwell acquisition results in significant improvements in the system's ability to acquire and maintain a signal.

The dual-receiver, single-transmitter configuration provides a novel solution to the problem encountered when a node loses track of transmission requests (RTS/CTS pair) while either transmitting or receiving data packets. In such cases, the node wanting to transmit would either add to packet collisions by initiating its own RTS, or wait in receive mode for a significant time for any outstanding reservations to clear. In the dual-receiver case, the node uses one channel to constantly monitor the reservation channel while using the second receiver to accept incoming data packets.



Ad hoc p2p networks are self-healing — they can route traffic around downed links.

As an adjunct to traditional link-layer protocols, the system performs neighbor discovery at the link level. Neighbor discovery results from either periodic broadcasts of neighbor discovery messages or by "ease-dropping" on other's transmissions. Placing this function at the link level reduces the amount of coordination between the intranetwork protocols hosted in a separate processor, and allows dynamic adjustments in connectivity without the need to update routing tables. It also allows the link layer to make local connectivity and data-rate decisions based in the frequency dependent characteristics of a channel.

Supporting an army

One of the program's challenges is to support thousands of users. Scaling of this magnitude is accomplished through a combination of tiered flat islands connected in a hierarchical structure.

Formation algorithms executed by distributed networking agents at the intranet level automatically self-organize the nodes. As each node activates, it listens for periodically broadcast neighbor discovery messages.

The newly activated node listens for a period of time to establish a list of potential islands with which it may seek affiliation. Upon determining the preferred island, the entering node sends an affiliation request.

The algorithms respond to this request according to programmable design policies that control the maximum number of nodes in any given island, weight of organizational association biases in member acceptance, and minimum data rate connectivity rules.

Once accepted, the entering node is notified immediately by message while other members are notified as part of the routing table updates. If no existing island is available or accepts the entering nodes, the node may establish itself as an island and potentially accept future members.

The distributed-agent algorithms also self-elect gateway nodes to act as bridges between tiers of connectivity, relying on alternate frequencies and higher processing gain data rates to achieve connectivity.

Advanced routing concepts tailored to highly mobile environments distribute routing information within the islands as routing table updates. The basic structure of these updates employs link-state methods within an island. However, between islands, the routing process employs data-hiding techniques to control the amount of overhead transmissions required over lower capacity inter-island links. Using this "near sighted" routing technique, overhead is typically held to less than 5 percent of the link bandwidth.

Multicast protocols increase the network efficiency by supporting "party conference" connections, characteristic of voice and data distribution patterns in military operations. These protocols form a reversable tree that transcends direct connectivity or node affiliation to create an "all-informed" party line activated by any member. Elastic virtual circuits improve reliability for information requirements demanding continual end-to-end connectivity in spite of the loss of intermediate nodes or links.

4G on the battlefield

All of the battlefield network devices — including those embedded in tanks or other vehicles — will instantly form, heal, and update the network as users come and go. That is, they will associate in an ad-hoc manner. Moreover, the devices will automatically and continuously optimize network connections as users merge in and out of the network at will. As intelligent elements, all of the devices will constantly reconfigure routing tables to determine the best network routes and, unlike cell-based solutions, network coverage and service levels will improve when soldier density increases.

The network resources are better utilized because networks are self-balancing, as well. The soldiers' subscriber devices can hop to distant network access points, away from points of congestion, shifting network capacity to meet demand. Network deployment will be fast and easy because it is towerless. While commercial versions of the technology will require some fixed infrastructure mounted on streetlights, billboards, and buildings, the 4G battlefield will be entirely mobile, with satellites or other communications systems providing the backhaul. And the network will disappear as fast as it was formed once soldiers leave the area.

This technology could function as a personal are network (PAN), local area network (LAN), or wide area network (WAN), simultaneously. This means that the same network can connect a soldier to the squad or platoon, to the battalion, and to a fully mobile division. It is the equivalent of a Bluetooth, 802.11, and 3G convergence, but in a single network, with a single device.

RF

About the Authors

Dr. Larry Williams is the chief engineer for ITT Industries Inc. (www.itt.com). Williams received his B.S. in physics from the U.S. Air Force Academy, his M.S. in systems engineering from the Air Force Institute of Technology, and his Ph.D. in electrical engineering from the University of Colorado. Before joining ITT, Williams was a senior staff scientist with Logicon Inc. He is also the principal investigator for the DARPA Small Unit Operations Situation Awareness System. Williams can be reached at larry.williams@itt.com

Allen H. Kupetz is the director of international business development for MeshNetworks Inc. (www.meshnetworks.com). He is also the founder of 4Gwireless.org, an organization that promotes the idea of 4G networking — wireless, ad hoc, peer-to-peer, mobile broadband networking.

Kupetz previously served as the telecommunications policy Officer for the U.S. Embassy in Seoul, Korea, from 1992 to 199. He has an M.A. in international relations from the University of Texas at Austin. He can be reached at akupetz@meshnetworks.com.