Radiation Detection System Integration Using Multiple-Input Multiple-Output Radios

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ABSTRACT

This study describes the application development of multiple-input multiple-output radios to provide persistent mobile ad hoc network (MANET) for the Department of Homeland Security. By using Man Portable Unit (MPU5) fifth generation radios (manufactured by Persistent Systems) with the Android Team Awareness Kit (ATAK), an Android smartphone geospatial infrastructure and military situational awareness application, the Remote Sensing Laboratory has developed a MANET connectivity to monitor deployed nuclear/radiological search operation assets. Network-capable radiation monitoring systems such as backpacks, vehicle-mounted sensors, and high-resolution high-purity germanium (HPGe) detectors have been integrated to facilitate surveillance operations, routine maintenance and status of health checks, radiation alerts and alarm monitoring, and adjudication.

This network connectivity application is particularly useful for maritime search operations. Shipboard search is conducted with backpack detectors and long dwell detector systems. Search techniques that involve the use of spectral anomaly detection algorithms applied to data from low-resolution gamma detectors, as well as the use of spatial interpolation tools, provide higher sensitivity to masked sources that may elude basic gross-count-rate-based algorithms. Small-vessel search techniques involve mounting large-volume mobile detectors on small boats and operating them in the same way as land-based mobile detection systems (i.e., searching for radiological/nuclear signatures emanating from nearby vessels or from targets on the water or shore). Data communication is difficult in a maritime environment because satellite communications may not be steady and multi-hop wireless networks with stations having backhaul infrastructure along coastlines may not be available. The MANET structure described in this study resolves data loss and network latency issues associated with maritime search operations.

Keywords: Mobile ad hoc network (MANET); Multiple Input Multiple Output (MIMO) Radios, software-defined radio (SDR), maritime search, Advanced Visualization and Integration of Data (AVID), Wave Relay

1. BACKGROUND

This article describes a study backed up by experimentation and data collection utilizing software-defined radio (SDR) technology to provide a persistent MANET environment to enhance the search capability (with special emphasis on maritime search) for the nuclear search program (NSP).

NSP at the Remote Sensing Laboratory Andrews (RSL-A) of the United States Department of Energy (DOE) National Nuclear Security Administration (NNSA) supports federal law enforcement mission partners in tactical responses (i.e., investigate, detect, interdict, diagnose, stabilize, and render safe threat items) to Weapons of Mass Destruction (WMD) threats. One of the most demanding operations is carried out onboard ships in maritime environments. Recently the United States Coast Guard (USCG) safety directives regarding Nuclear Emergency Support Team (NEST) direct involvement in maritime search has changed: NEST personnel shall not perform onboard search on offshore vessels, but will advise USCG, Customs and Border Patrol, or other responders on how to collect radiological data and assess and adjudicate the radiological anomaly, if any. This requires persistent surveillance and remote monitoring of large numbers of deployed network-capable detectors. Structured data communication is particularly difficult in a maritime environment where satellite communications may not be steady and multi-hop wireless networks with shore stations having backhaul infrastructure along coastlines may not be available. By using MPU5 radios with ATAK, the RSL-A could provide a mobile ad hoc network to monitor maritime assets onboard a ship during the search operation.

Multimodal sensor data enabling primary sensors in tactical deployment is in high demand for search operations. Decisional support tools and processes that depend on tactical field data seek more situational metadata from field operations in real-time. With increased numbers of networked and/or networkable individual sensors collecting multimodal data during search, surveillance, or safeguard/monitoring operations, there is more demand for higher data exchange speed, more connected users, and persistency of network capability with minimal data loss and latency. MPU5 multiple input, multiple output (MIMO) 3 x 3 radios are the appropriate solution to provide a sustained mobile communications network.

MIMO is an antenna technology for wireless communications in which multiple antennae are used at both the source (transmitter) and the destination (receiver). The antennae at both ends of the communications circuit are combined to minimize errors, optimize data speed, and improve the capacity of radio transmissions by enabling data to travel over many signal paths at the same time. Creating multiple versions of the same signal provides more opportunities for the data to reach the receiving antenna without being affected by fading, which increases the signal-to-noise ratio and error rate. By boosting the capacity of radio frequency (RF) systems, MIMO creates a more stable connection and less congestion.

Tactical search operations such as targeted search, maritime search, or forensic investigation are time-sensitive and take place in rapidly developing scenarios. Capturing essential elements of changing scenarios is of paramount importance. Contextual sensors support the curation of the natural flow of data elements to make real-time assessments. The integration of contextual sensor data managed by a data fusion architecture that consists of data acquisition from various sensors, intelligent sequencing, and juxtaposition of relevant data streams to accentuate the scenario is critical for these operations. Contextual sensing aided by smart data fusion provides a composite view of sequence of pertinent observations, facilitates split-second change detection, and captures additional circumstantial information that cannot be captured using individual sensors. Capturing large amounts of contextual data remotely demands a persistent mobile network in the field.

2. CONCEPT OF OPERATIONS

The following properties of MPU5 radios are important for creating a mobile ad hoc mesh network. The radios with a Wave Relay® mechanism are capable of:

- Installation and use of third-party applications directly on the MPU5
- Acceptance of external sensors directly into the MPU5 to process and distribute data without additional hardware
- Onboard hardware video encoding
- Connection to a monitor, mouse, and keyboard to create a command center in the field
- Control unmanned vehicles (e.g., Boston Dynamic's Spot Robot dog or similar agile and mobile robots)
- Easy connectivity with the ATAK Situational Awareness Suite

ATAK allows for precision targeting, intelligence gathering, situational awareness, navigation, and data sharing. It has a plugin architecture which allows developers to add functionality.

The Wave Relay system built into MPU5 radios allow compatible, networked assets like multimodal sensors, unmanned ground vehicles (UGVs), unmanned aerial vehicles (UAVs), and cameras to work under a common, standardized network. By sharing a common network, component elements can communicate with each other and share data. The integrated Android computer helps build a foundation for data fusion, artificial intelligence, edge computing, and in-network computing. Figure 1 describes the concept of operations for MPU5 radios.

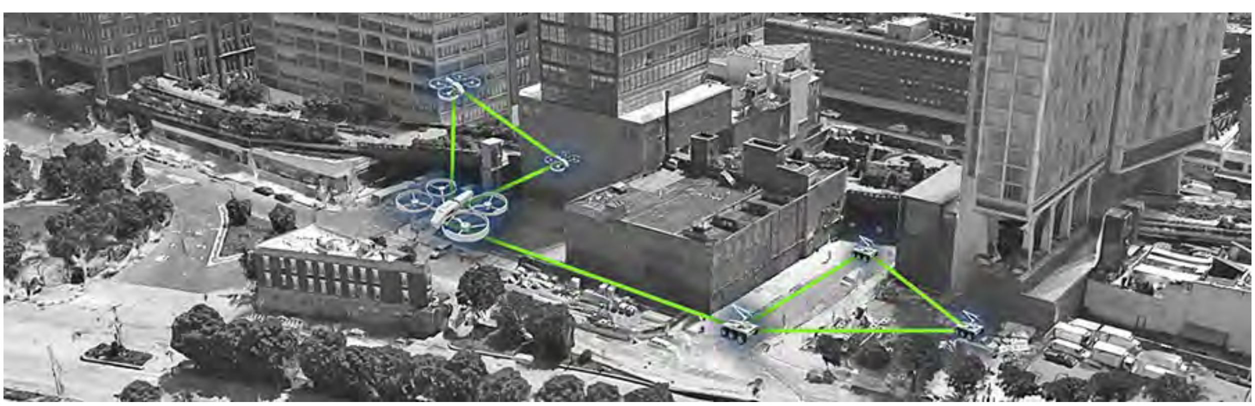

Figure 1. Pictorial description of concept of operations for MPU5 radios showing wireless communications between multiple ground and air assets.

3. APPLICATION IN MARITIME OPERATIONS

The Maritime Support Team (MST) is an important asset of NSP. MST lacks a backup communication system for dense data transmission/telemetry if the primary channels (defined below) fail or are unavailable. The MST needs to include ad hoc nodes to enhance the edge computing power that most sensors depend on. By utilizing MPU5 MIMO radios with three antennae, along with the ATAK, MST would be able to maintain a persistent mobile ad hoc network between maritime sensors and a mobile command and control center that is detached from the measurement platform, thereby providing a robust and expandable information exchange system.

The MST uses the following means as primary communications channels that heavily depend on onshore networking:

- Broadband air cards: usable dockside or at anchor within cellular range of shore. Air cards provide mobile broadband internet access via cellular networks.
- Satellite communication: Provide voice and data communication with the shore-based team and with other reachback assets (DOE Triage).
- Cellular phones/cellular Secure Terminal Equipment (STE).
- Team radios: Used for intra-team communications onboard the ship.

The limitations are that the system is not reconfigurable by excluding non-performing nodes, it is not expandable at will, and each individual sensor needs to be integrated individually to the current data acquisition/telemetry system.

MIMO devices such as an MPU5 (3 x 3) radio or STREAMCASTER 4400 ENHANCED (SC4400E, 4 x 4 MIMO radio) use advanced antenna technology. This study entails installing a data acquisition system for mobile radiation detectors (RSI Mobile system), man-portable backpack detectors (GEMINI), ORTEC/AMETEK HPGe gamma imaging system (PHDS' GeGI), and RSL-A Pedestrian Mapper for maintaining surveillance posture; performing routine maintenance and health checks; and integrating full motion video for collecting contextual data. The Wave Relay system built into MPU5 radios allows compatible, networked assets like multimodal sensors, UGVs, UAVs, and cameras to work under a common, standardized network. By sharing a common network, component elements can communicate with each other and share data. The integrated Android computer helps to build a foundation for data fusion, artificial intelligence, edge computing, and in-network computing. The NEST community, including Radiological Assistance Program (RAP) teams, are moving towards using MIMO radios for data communications. The technical features of MPU5 radios include: easy installation and use of third-party applications directly on the MPU5; acceptance of external sensors directly into the MPU5 to process and distribute data without additional hardware; and onboard hardware video encoding. These three features make these SDRs very attractive for NEST data/information communications.

4. DESCRIPTION OF MPU5 RADIO

The handheld MPU5 radio shown in Figure 2[1] is a small, compact, ruggedized radio system with physical dimensions [chassis only]) of 1.5 x 2.6 x 4.6 in. (3.8 x 6.7 x 11.7 cm). Environmentally it is IP68 Certified; IPx8 Waterproof 30 mins at 20m or 2 hrs at 10m rating; and IP6x Dustproof.[2] The MPU5 is the fifth generation Wave Relay platform. Leveraging multiple technologies such as MIMO and Android, the MPU5 is a tactical networking device that delivers enhanced performance, reliability, and network persistence that makes streaming of multiple video feeds and customized application packages with high-quality audio within a single device possible.[3]

Concept of MANET

MANETs have five key characteristics: self-forming, self-configuring, self-healing, dynamic topology, and limited resources.[4] MANET utilizes a route-configurable networking environment on top of a Link Layer ad hoc network. It consists of a set of mobile nodes connected wirelessly in a self-configured, self-healing network without having a fixed infrastructure. MANET nodes are free to move randomly as the network topology changes rapidly. Each node behaves as a router as it forwards information traffic to other designated nodes in the network.

Pros and Cons of MANET

Pros

1. Adaptable network topologies—Network topology can change randomly and rapidly with time; it can form unidirectional or bi-directional links.
2. Autonomous Behavior of communication nodes—Any node can act as a host and router, which reflects its autonomous behavior.

3. Minimum human interface—MANET requires less human intervention to configure the network because of the dynamically autonomous nature of ad hoc networks.

Cons

1. Limited bandwidth with variable capacity links—Wireless links have lower reliability, efficiency, stability, and capacity as compared to a wired network.
2. Energy consuming operation—Communication nodes need batteries and power supplies for sustained operation. Mobile nodes usually come with less memory and power, and have lightweight features.
3. Network security concerns—Wireless networks are more vulnerable to security threats. No centralized firewall can exist due to the distributed nature of the operation for security, routing, and host configuration.

The Wave Relay MANET is designed to maintain high bandwidth connectivity among mobile communications devices. The system is scalable so that it can incorporate a large number of meshed devices into the wireless network, where the component devices build the communications infrastructure. In highly dynamic environments, the system can maintain connectivity by rapidly rerouting data as necessary. It is the rerouting and node-hopping capability of the Wave Relay systems that make them technically attractive for emergency response. The Wave Relay MANET is a self-forming and self-healing network where nodes can physically move within the network without constraints. Information flows through the network and individual data paths can adjust and adapt at sub-second intervals. This unique approach creates an ideal environment for maximizing performance across the available communications medium.

Figure 2. MPU5 radio manufactured by Persistent Systems.

5. RESULTS

RSL-A has been performing radiological and nuclear emergency operations for more than six decades in support of the NNSA emergency response and consequence management program. One of the most important aspects of the operations is to provide a large cache of radiation monitoring and detection systems of various sensitivity (expressed in cps/μR/hr at specific energy) and selectivity along with trained technical personnel who can configure the deployed field elements into search, monitoring, and surveillance postures within reasonable time. The concept of operations heavily hinges on integration of data from the field to develop a common operating picture. To that end, RSL-A has developed an equipment-agnostic data acquisition and analysis package (from the same software platform)—Advanced Visualization and Integration of Data (AVID). AVID uses flexible data fusion algorithms to synchronize a large number of field-deployed equipment, providing time-stamped data with Global Positioning System (GPS) information. AVID is heavily dependent on cloud computing for storage and data extraction and manipulation purposes. MPU5 radios with MANET architectures have been successfully used to incorporate radiation monitoring data from several commercial off the shelf (COTs) and Government off the shelf (GOTs) equipment such as man-portable backpacks, vehicle-mounted mobile radiation detection systems, and high-resolution radioisotope identification devices (RIIDs). Figures 3 and 4 are examples of MPU5 integration with radiation monitoring systems.

Backpack. Man-portable backpacks are the workhorse of search and monitoring operations—typically a 3 x 3 sodium iodide crystal for gamma ray detection is carried in a backpack with five 1" diameter He-3 tubes maintained at 2.7 atmosphere pressure for neutron detection. This system has been configured with MPU5 radios that transmit the data to AVID, as shown in Figure 3. The system is capable of generating radiation alarm conditions if high radiation dose rate situation occurs and is also capable of identifying (the gamma ray emitting) sources/material by using an onboard radioisotope identification software algorithm. The background count rate changes as the system moves in urban areas; the alarm conditions are sensitive to the background count rates and are adjusted to minimize false alarm rates (typically once per hour), avoiding nuisance alarms cause by naturally occurring radioactive materials (NORM). The built-in GPS receiver within the backpack provides the position information as the searcher moves around in the area of deployment.

Figure 3. A backpack system set up to transmit radiation monitoring data to AVID by using MPU5 radio. The data received from two such systems is shown in Figure 4, with one of the backpacks causing radiation alarm.

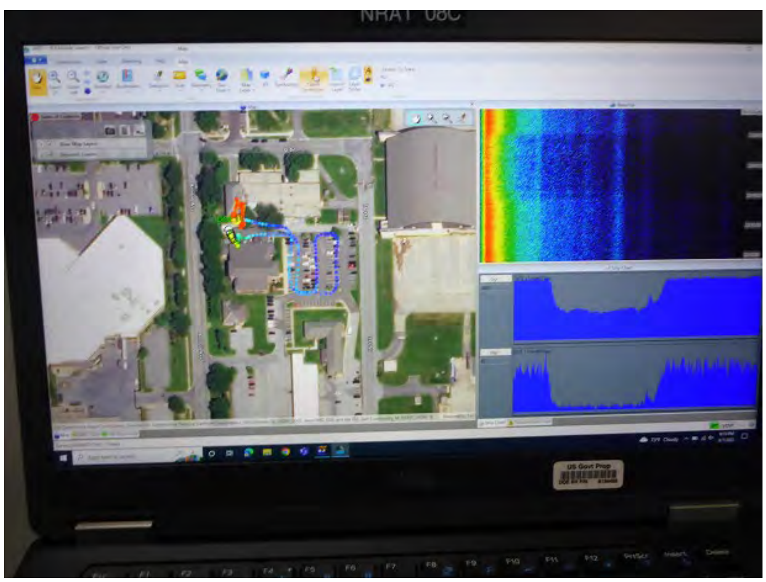

Figure 4. AVID shows the breadcrumb data from two field-deployed backpacks, one denoting a radiation ALARM on encounter with a small check source (< 10 μCi of activity).

Vehicle-mounted mobile radiation detection system. These are high sensitivity (typically 2500 cps/μR/hr) at nominal background. Eight large sodium iodide crystals (4" x 4" x 16") are used to form two identical packs of four crystals (commercially available from Radiation Solutions Inc., Canada) with product names RSX-4 and RS-705 controller.[5] The digital design using Field Programmable Gate Array (FPGA) and Digital Signal Processing (DSP) technology provides gamma energy spectra without any pileup effect, which results in better data quality. The unit is capable of working around high gamma flux area and counting up to 250K cps without deadtime and without gamma energy spectral distortion. These vehicle-mounted radiation detection systems can be operated from aircraft and can cover a very large area of radiologically affected land space from large standoff distances. Figure 5 shows the integration of MPU5 with a mobile radiation detection system to transmit the data to AVID, while Figure 6 shows the visual map from radiation monitoring data in the form of radiation breadcrumb data.

Figure 5. Vehicle-mounted system with two smaller modules of Radiation Solutions Inc. detection system RSX-1. The MPU5 is located in the middle of the picture. The data obtained from the system via AVID is shown in Figure 6.

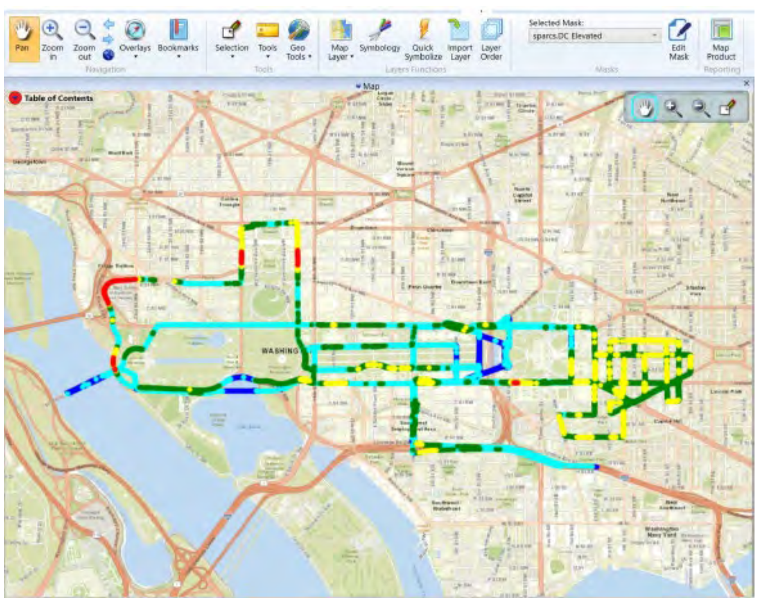

Figure 6. A color-coded gamma gross count rate is plotted by the AVID data acquisition system as the mobile system moves through urban area (Washington, DC in this case). There is a masking option, in which high count rate areas can be selectively chosen and the gamma energy spectral analysis can be performed. In this case, the region colored in red (higher count rate areas) were masked and a spectral analysis was done, as shown in Figure 7.

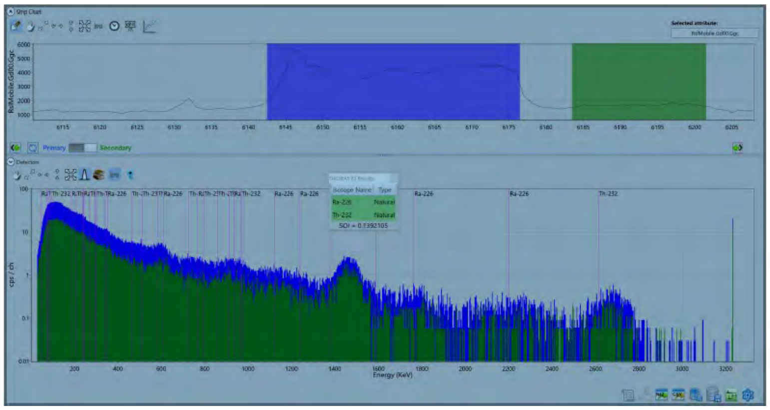

Figure 7. Gamma energy spectral analysis from the high count rate areas were performed to show that the elevated background rate was caused by NORM frequently found in pavement materials.

High resolution RIID using HPGe. HPGe gamma energy spectra are considered the gold standard for radioisotope identification process. A full width half maximum of 2 keV at the Co-60 peak at 1332 keV can be achieved (that is 0.15% resolution as compared to ~7% resolution seen from nominal sodium iodide scintillator, which is a factor of about 50 times better). One ORTEC Detective-X HPGe detector was coupled with an MPU5 radio to transmit second-by-second gamma energy spectral data to AVID, as shown in Figure 8.

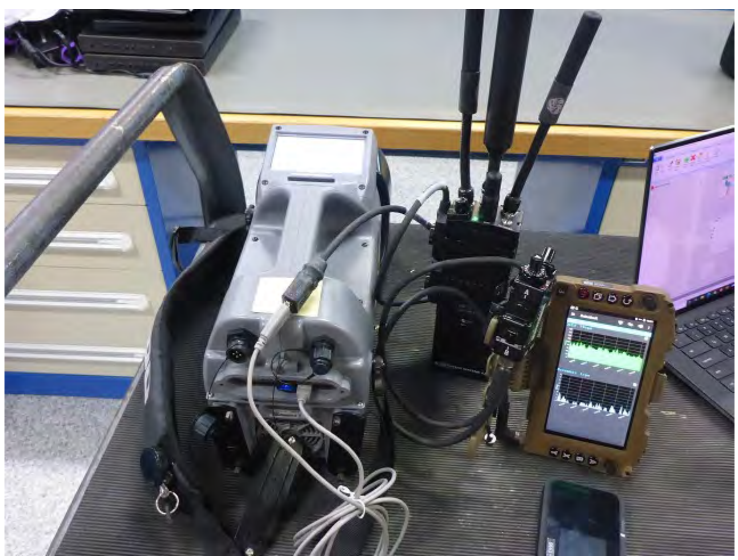

Figure 8. An HPGe radioisotope identification device is coupled with an MPU5 radio to transmit high-resolution gamma energy spectral data to AVID.

6. CONCLUSION

The MPU5 radio is a mobile ad hoc network radio capable of transmitting voice, data, and geographical position information throughout large areas, to include subterranean, urban, maritime, desert, or dense forest environment. The applications resident on these software-defined radios provide scalable mobile ad hoc networking capabilities between sensors and detached command-and-control centers. Sensors and data streams can be added or taken offline at will. Robust edge computing capabilities exist on board each MPU5 radio, where individual data acquisition systems and desired data transmission and receiving protocols can be programmed. The system provides the most dependable data communication and situational awareness tool covering very large geographic areas irrespective of terrain features.

7. ACKNOWLEDGEMENT

This manuscript has been authored by Mission Support and Test Services, LLC, under Contract No. DE-NA0003624 with the U.S. Department of Energy, National Nuclear Security Administration, NA-10 USDOE NA Office of Defense Programs (NA-10). The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The U.S. Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan). The views expressed in the article do not necessarily represent the views of the U.S. Department of Energy or the United States Government. DOE/NV/03624--1418.

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