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# EVALUATION OF RUGGED WIRELESS MESH NODES FOR USE IN EMERGENCY RESPONSE

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*During the summer of 2007 engineers at the Idaho National Laboratory (INL) conducted a two-day evaluation of commercially available battery powered, wireless, self-forming mesh nodes for use in emergency response. In this paper the author describes the fundamentals of this emerging technology, applications for emergency response, and specific results of the technology evaluation conducted at the Idaho National Laboratory.*

## I. INTRODUCTION

The Idaho National Laboratory (INL), a U. S. Department of Energy national laboratory, has worked closely with many military first response organizations for many years. Because of this relationship, there have been numerous occasions when the INL has been "challenged" by military first response organizations to provide engineered solutions to unique and sometimes common problems.

In any emergency response situation, communications between the first responder and response command personnel is critical to successfully and safely completing the response mission. Many times, this communications is only verbal; however, there are times when verbal communications alone are inadequate and other communication formats and techniques are required. In an ideal situation, the first responder would be able to not only "talk" with command personnel but they would be able to transmit real-time data and video to the commanders. This would allow the response commanders to review any data acquired by the responders and to view the incident scene with their own eyes.

During the summer of 2007, engineers at the INL were tasked by the U. S. Army to develop a prototype of a wireless network system that could provide the simultaneous transmission of data, video and voice. Toward that end, the INL collaborated with personnel from the Army and industry to conduct an evaluation of commercially available wireless mesh nodes. The results of that evaluation follow.

## II. WIRELESS MESH NODE TECHNOLOGY FUNDAMENTALS

A wireless mesh network (WMN) is comprised of two or more individual mesh nodes. It is used to route data, video and voice information from node to node. A multi-node network allows for continuous data path connections and signal re-routing around blocked or broken paths by relaying the signal from node to node until the desired destination is reached. Client devices refer to devices such as computers, sensors and cameras that are connected to the mesh network. A true mesh network allows information from any client device to be available at any node in the network. Figure 1 shows a typical mesh node system.

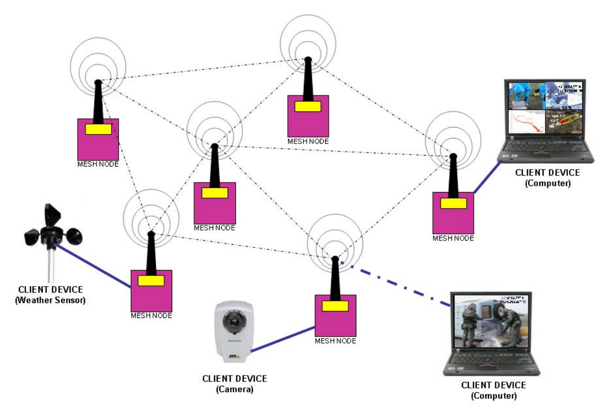


**Figure 1. Typical Wireless Mesh Node System.**

Mesh node networks are self-routing and self-healing. As nodes are activated in a network they automatically seek out other nodes within transmission range and form a wireless connection. The network will still operate even when a node stops working or a connection is blocked. This results in a very reliable network even in unpredictable environments.

As the cost of radio technology has dropped significantly since the mid 1990's, the capability of individual wireless mesh nodes has increased. It is now common for a single node to contain as many as three radios. Two radios for the up-link and down-link functions and a third radio to interface with client devices. Most modern wireless nodes also allow for a “hard-line” connection, via Ethernet cable, to a client device.

The increased data throughput capability of mesh node networks has allowed system designers to use the technology in real time video surveillance applications, border security enhancement or voice communication inside underground mines.[1]

## III. MESH NODE APPLICATIONS FOR EMERGENCY RESPONSE

Small, battery powered mesh node devices that can be quickly deployed are becoming a valuable tool for emergency response. These devices can be deployed by human or robotic means and provide a robust communications link between sensors and various groups during an emergency response.

Several wireless mesh node systems have been tested during emergency response situations. Portable wireless mesh node systems are very useful during emergency response operations, particularly when the existing infrastructure has been destroyed.

Mesh nodes were used during the response efforts for hurricane Katrina. Rajant Corporation’s mesh node equipment, known as BreadCrumbs, was used to restore some communications after the hurricane knocked out existing communications equipment. In Bay St. Louis, emergency rescue management teams now have wireless access to the internet as well as voice over Internet protocol (VoIP) and data coverage. The BreadCrumb wireless local area networks (LANs) have enabled the emergency management system (EMS), Highway Patrol, and Fire Department to send and receive emails, upload reports, and update activity blogs online.[2]

Mesh node systems were also used during the December 2004 tsunami relief efforts in Thailand. The tsunami caused severe interruptions in the existing communications infrastructure making relief efforts much more difficult. The use of rapidly deployed mesh node equipment, limited as it was, provided valuable communications links for emergency responders and survivors.

### III.A. Concerns Using Wireless Mesh Networks During Emergency Response

Past examples of wireless mesh node use during emergency response activities have brought to light several concerns. Some of these concerns are identified in research conducted by Kanchanasut, et al in 2007.[3] Concerns are broken down into two categories, technical and non-technical.

According to Kenchanasut, the wireless mesh network environment can have highly variable information loss rates and delay characteristics. Field tests indicate the packet loss rate could occasionally exceed 20%. Loss in the network is due to various reasons. These include the limited processing power of mobile nodes (e.g. running multimedia applications while also performing the routing function); node mobility; antenna orientation; transmission power; and radio channel access conflicts.

Information loss on the network effects the operations of all software components running over the network. The node management software, providing the capability for a node to connect to another node, is degraded if packet loss is too great. The quality of voice and video transmission are significantly affected. The sensor data can be lost. It also consumes more power when the network is very lossy as the applications and users have to re-transmit the lost information. Under normal operation, all applications work just fine. However, under severe packet loss conditions, minimal data rate communications such as text messaging are most reliable.

Non-technical concerns deal primarily with data security or data encryption. Medical information may have to be transmitted through an insecure network, making personal information privacy an issue. Authenticating emergency workers and classifying user privileges on a network for resource usage and control are also important. Physical signal interference or jamming may occur, either intentionally or unintentionally, while the rescue operations are being carried on causing command and control problems.

## IV. WIRELESS MESH NODE TECHNOLOGY EVALUATION AT THE INL

The evaluation of wireless mesh node technology was sponsored by the U.S. Army 20$^{th}$ Support Command with the purpose of finding the best wireless mesh node system capable of meeting the mission needs of the US Army’s Nuclear Disablement Team.

### IV.A. Description of Evaluation Technique

The evaluation took place on July 31$^{st}$ and August 1$^{st}$ at the INL. The INL is a Department of Energy research and development laboratory located in Idaho Falls, Idaho. Wireless mesh node systems from different vendors were evaluated using similar conditions to determine the system most capable of meeting the Army’s needs. Figure 2 shows the general topography of how the nodes were arranged for the evaluation.

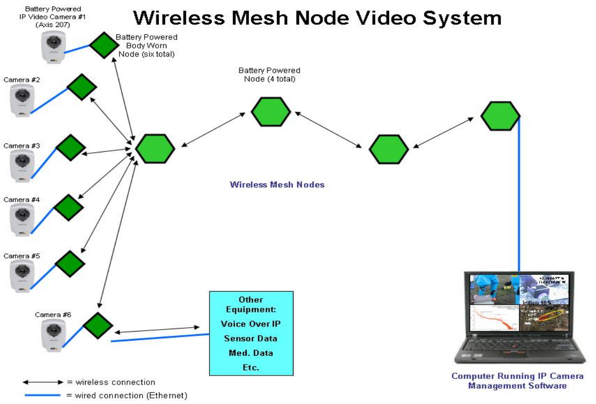


**Figure 2. General Topography of Node Evaluation**

Six helmet-mounted, battery powered IP cameras provided by the INL were attached via Ethernet cable (RJ45) to six body-worn, battery powered mesh nodes provided by the vendors. The cameras were Axis Model 207. Figure 3 shows the helmet mounted camera system during checkout prior to the evaluation.

**Figure 3. INL Developed Helmet Mounted IP Camera**

Data from a low-bandwidth radiation detection system was also sent through the network.

Four additional battery powered nodes (provided by the vendor) will be placed, or dropped, throughout the test area. One of these four nodes was attached to a computer using an Ethernet cable. The computer was used to simultaneously display the four camera images using a commercially available video surveillance software program. A computer projector was used to project the image onto the wall for easier viewing by all the evaluators. Figure 4 shows the projected view of four helmet cameras.

**Figure 4. Projected Images of Four Helmet Cameras**

Day one of the evaluation gave vendors the opportunity to test and configure their equipment with the equipment provided by the INL in an indoor, bench-top setting to ensure their system was ready for the field evaluation the following day. At the same time, INL and U.S. Army individuals used this day to become familiar with the equipment operation and features. Figure 5 shows day one evaluation of wireless mesh nodes.

**Figure 5. Day One Evaluation of Mesh Nodes**

During the field evaluation on day two, equipment from each vendor was evaluated exclusively with the provided INL equipment. Equipment features were evaluated using the list of features in section IV.B. The order in which vendor equipment was evaluated was chosen randomly. Nodes were evaluated inside buildings and outdoors. Serial and multi point-to-point configurations were evaluated. The body worn nodes were placed in a pouch on a tactical vest with the Ethernet cable running up to the helmet mounted camera. Figure 6 shows day two evaluation of wireless mesh nodes.

**Figure 6. Day Two Evaluation of Mesh Nodes**

### IV.B. Wireless Mesh Node Features Evaluated

Mesh nodes from Rajant, Corporation, 3eTechnologies International (3eTI), and AgileMesh, Inc. were evaluated based on the features listed below. Every attempt was made to test each vendor's nodes in a similar fashion.

For each of the vendor systems, the following features were evaluated:

- Image frame rate and resolution with four cameras operating at the same time
- Ease of node deployment and operation
- Ease of node configuration
- Size, weight and ruggedness of nodes/connectors
- Battery life
- LOS distance between body worn nodes and "drop" nodes
- Ease of node maintenance
- Security features
- Ease of node/system status monitoring
- Cost and availability of nodes

Engineers from the INL and U.S. Army conducted the actual equipment validation with technical assistance from the vendors as needed. Observers representing Department of Energy Security Forces, Department of Energy Radiological Assistance Program (DOE RAP), and Department of Energy Fire Department were present during the evaluation and provided feedback on each of the wireless mesh node systems.

After considering all of the results from the evaluation, the U.S. Army selected one of the vendors to continue further testing and development for providing a system capable of meeting their needs.

## V. RESULTS

The results presented are comprised of comments collected from the U.S. Army and observers participating in the evaluation. As this activity was conducted as an evaluation and not a specification based test, the results are presented qualitatively.

### V.A. Image Resolution and Frame Rate Results

Each of the mesh node systems evaluated were able to handle data throughput for four cameras set at VGA (640x480) images resolution. The frame rates for video images on all three systems varied widely as node connection topography changed. Latency in image was a minor problem with all three systems.

### V.B. Ease of Node Deployment and Operation

All mesh nodes had simple to use power switches and were relatively small and light weight. The AgileMesh system was the bulkiest of the three and created a large amount of heat and noise. With the 3eTI system, the body worn node and the drop node had different controls

### V.C. Ease of Node Configuration

All three node systems had a difficult time connecting to the helmet mounted cameras. This configuration effort is still somewhat of a "specialized knowledge" activity making the set-up of portable mesh node systems difficult for non-technical users.

### V.D. Size, Weight and Ruggedness of Nodes

Weight for each of the body worn node systems ranged from 2.5 lbs to 3.5 lbs. The Rajant Corporation node was packaged in the most rugged fashion and was most suited for wet decon. Rugged packaging was a significant concern for the U.S. Army.

### V.E. Battery Life

The battery life for each node was listed at roughly three hours. Actual battery life testing was not completed due to lack of time. The stated battery life by the vendor was used for overall system evaluation. The Rajant Corporation node was able to use an external battery to increase the stated battery life. Additional testing on the Rajant Corporation nodes in the future will validate battery life.

### V.F. LOS Transmission Distance Between Body Node and Drop Node

A long distance transmission test was set up were the body worn node with helmet camera was separated by approximately 3,000 feet from one of the drop nodes. The two nodes were in line of sight (LOS) with each other. Only the AgileMesh node system was capable of transmitting a clear video signal over that distance. The other two systems provided very limited connectivity.

### V.G. Ease of Node Maintenance

All three node systems require very limited maintenance. Battery charging and replacement was about the only maintenance activity required.

### V.H. Security Features

Only the 3eTI system was Federal Information Processing Standard 140 (FIPs) compliant. The Rajant Corporation system was in the process of certification. The AgileMesh system was not FIPs certified and there were no plans on submitting for certification. The U.S. Army stated they still have to establish the security requirement for their mesh node system.

### V.I. Ease of Node Systems Status Monitoring

Rajant Coporation used a very intuitive software program to monitor the status of network health and individual node connectivity. The software's graphical interface provided a clear and easily understood visual of the entire system and data rate between nodes. The AgileMesh system utilized a simple display right on the node that indicated the number of connections to that node and the signal strength. Channel selection was also easily made using a control on the node panel. The 3eTI node provided the least user-friendly means for monitoring system status.

### V.J. Cost and Availability of Nodes

Cost for individual nodes varied between $3K and $5K with AgileMesh being the cheapest and Rajant Corporation being the most expensive.

## VI. CONCLUSIONS

After evaluating each of the mesh node systems, the U.S. Army elected to continue evaluation of the Rajant Corporation node system. Several observations were made during the evaluation. The configuration of client devices for operation on the network proved to be more difficult than expected. This problem was evident with all three node systems evaluated. For portable mesh node systems to become more user friendly, this particular problem must be addressed. The helmet mounted camera system was deemed too large and heavy for extended use. Recommendations were made to split the system so that only the camera unit was placed on the helmet with the rest of the camera system in a pouch on the vest.

The transmission of instrument data from the radiation detection system was not a problem for any of the node systems. This emphasizes the fact that video still remains the largest portion of data throughput for a mobile mesh node system. Our evaluation indicates that video quality will vary depending on node location and signal environment.


## ACKNOWLEDGEMENTS

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