MANET Operational Field Test with the New York City Police Department (NYPD) Emergency Service Unit (ESU)

After Action Report

First Responders Group

October 2017

Homeland Security

Science and Technology

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Mobile Ad-hoc Networking (MANET) Operational Field Test with the New York Police City Department (NYPD) Emergency Service Unit (ESU)

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Prepared for: The First Responders Group
Office for Interoperability and Compatibility

Prepared by: Johns Hopkins University Applied Physics Lab

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Publication Notice

This document was prepared under funding provided by the U.S. Department of Homeland Security Science and Technology Directorate (Contract Number N00024-13-D-6400; Task Order 0372, Task Number S8906, Resilient Systems for Public Safety Communication). Points of view or opinions expressed in this document are those of the authors and do not necessarily represent the official position or policies of the U.S. Department of Homeland Security.

Acknowledgements

The authors would like to express their appreciation to the Department of Homeland Security (DHS) Science and Technology Directorate – First Responders Group (FRG) Office for Interoperability and Compatibility and our sponsor Mr. Cuong Luu. JHU/APL would also like to express sincere gratitude to the New York City Police Department (NYPD) Emergency Service Unit (ESU) for their participation. In particular, Lieutenant Michael Reilley, Detective John McKenna and officers from the ESU and Counter Terrorism Unit (CTU) provided invaluable insight, support and expertise to this effort.

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Disclaimer

Executive Summary

The Johns Hopkins University Applied Physics Laboratory (JHU/APL), under the direction of the Department of Homeland Security (DHS) Science and Technology Directorate (S&T), First Responders Group, Office for Interoperability and Compatibility, recently partnered with the New York City Police Department's (NYPD's) Emergency Service Unit (ESU) to conduct a field test to evaluate a Mobile Ad-hoc Networking (MANET) (Reference 1) system using Persistent Systems' commercially available units of the MPU5 smart radio. The MANET field test is a DHS S&T project aimed at providing local, state, and federal law enforcement with a situational awareness tool, similar to what the Department of Defense front line forces use, but adapted to meet specific requirements for first responders. A similar testing and evaluation was completed with the New York State Police (NYSP) Special Operations Response Team (SORT) on September, 27-29 2016 followed by a collaborative field test by the NYPD ESU on April 19-20, 2017. This report summarizes the NYPD ESU field test and associated outcomes. The results from the NYSP SORT field test are available upon request.

The MANET system includes several components: (an Android Tactical Awareness Kit (ATAK), the Microsoft Windows-based Tactial Awareness Kit (WinTAK), wireless smart radio system, tablet, Global Positioning System (GPS) capabilities, protective vest, antennas, and audio and video plug and play. The MANET system supports peer-to-peer communications and information sharing when other standard wireless communications (e.g., Land Mobile Radio (LMR), cell phone) means are limited or unavailable. The NYPD ESU field test used different scenarios within a condensed, urban environment to help determine what communications-based components are lacking, required, and recommended specific to local law enforcement needs. Earlier MANET systems proved to be effective with the U.S. military and other DHS components such as the U.S. Border Patrol to address their communication needs. DHS S&T is exploring this capability with the NYPD to help overcome such factors as wireless coverage dead spots and service congestion associated with existing network infrastructures.

Discussion and interviews with NYPD ESU personnel revealed the following top three needs for their critical response-related operations specific to the MANET system:

1) Providing audio communications for a no-notice deployment event, including connectivity to other radios within range, reasonable volume levels, and clear voice communication.

2) Providing video multicasting for the deployment event, including connectivity to other radios within range and clear video streams that provide an effective field of view.

3) Using ATAK to provide enhanced situational awareness via the Samsung Note3, including position location information (PLI) overlaid on a map for each radio involved in the event.

The NYPD ESU participants currently use a LMR network with one city-wide repeater frequency and three point-to-point frequencies with limited encryption mechanisms available. These frequencies only allow for voice communications. With responders walking through a realistic scenario for the field test, they evaluated the MANET system's ability to enhance situational awareness by providing location and real-time

video streams in addition to voice. The ESU identified the MANET system's communications range and relaying capabilities (as a means for range extension) in supporting voice, video, and situational awareness traffic as its overarching objective in the evaluation of this system.

The field test conducted on April 20, 2017, used operationally-relevant scenarios and took place at two venues in New York's Times Square: the Marriott Marquis Times Square and the Times Square subway station. During test execution, JHU/APL with support from Persistent Systems, monitored MANET system performance from both an operational and technical perspective using qualitative and quantitative means.

JHU/APL conducted extensive on-campus testing (at APL) prior to field test to determine a technical threshold that could be used as guidance to determine when links between inter-communicating MPU5s would terminate, which was then used to determine deployment of relay nodes prior to test implementation. The metric used as the technical threshold was each link's Signal-to-Noise Ratio (SNR). In supporting this objective, the JHU/APL test team established relay locations for the MPU5 smart radios during the pre-event engineering tests, conducted in March 2017, to ensure that the Tactical Operations Center (TOC) could receive uninterrupted voice, real-time streaming video (the most demanding service on MANET system capacity), and situational awareness information from the team at the farthest extent of each mission.

The JHU/APL team had the opportunity to interact with representatives of the NYPD ESU during the pre-event training and orientation, the field test, and afterward during the hot wash. This allowed for direct observation of how the equipment supports mission-specific needs of local law enforcement agencies, and helped determine its communication range capabilities for supporting voice, video, and geographic location capabilities in a complex urban environment.

In summary, feedback from the first responders was largely positive with stated appreciation of the software tool's ability to provide live video streaming and live location updates for personnel. The tool augmented voice communications since the team could see response team locations on a map, as well as a live video stream from the team lead. First responders also provided input regarding needed improvements and modifications to allow the equipment to meet their specific mission-based needs. For example, since the MANET system requires several radios to comprise a "mesh" network with multiple radios serving as relay nodes, and it is not feasible for NYPD personnel to carry radios for the sole purpose of serving as relay nodes, participants suggested a possibility of using drop boxes (i.e., pelican cases with radios pre-loaded) as the relay points. It was also noted that the current version of the MPU5 smart radio worked well with the use of a high gain multiple input, multiple output (MIMO) sector antenna (12 decibels relative to isotropic) (dBi)) connected to the top of the TOC – this enhanced their ability to sustain sufficient connectivity for voice and real-time video streaming.

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1 Introduction

The U.S. Department of Homeland Security (DHS) is committed to using cutting-edge technologies and scientific talent in its efforts to make America safer. The DHS Science and Technology Directorate (S&T) is tasked with researching and organizing the scientific, engineering, and technological resources of the United States and leveraging these existing resources into technological tools to help protect the nation. The DHS S&T First Responders Group Office for Interoperability and Compatibility (FRG/OIC) is interested in determining the effectiveness of the Mobile Ad-hoc Networking (MANET) System in an operational environment. The Johns Hopkins University Applied Physics Laboratory (JHU/APL) has been tasked to procure, test, and evaluate the operational utility of the technologies that comprise the MANET system, which includes the MPU5 Radio, Android Team Awareness Kit (ATAK) software and related supporting components such as antennas, cables, etc. The overarching objectives of this effort are to:

- Elicit basic *requirements* for state and local law enforcement as it relates to the ability to maintain situational awareness (SA) via a scalable peer-to-peer wireless network that integrates data, voice, and video in real-time operational settings.
- Evaluate the *deployment and utility* of the MANET system within the local and state law enforcement operational environments.
- Provide an *operational evaluation and recommendations* report (i.e., After Action Report).
- Utilize two different types of operational environments as test beds: 1) State Law Enforcement — New York State Police (NYSP) and 2) Local Law Enforcement — New York City Police Department (NYPD). This report is specific to the April 2017 NYPD (local) operational testing and evaluation of the MANET system.

1.1 Goal of this Report

The goal of this After Action Report (AAR) is to provide a high level overview of the implementation and outcomes of the April 2017 NYPD MANET field test. This Report also provides information to help determine to what extent the MANET system could enhance communications and situational awareness in an urban law enforcement environment, as well as to provide feedback to DHS and relevant technology developers.

1.2 Mobile Ad Hoc Networking (MANET) Capabilities

The MANET System (Figure 1) is comprised of the ATAK mapping engine software, the Samsung Note3 notebook, and the MPU5 smart radio manufactured by Persistent Systems, LLC. ATAK is a mobile geospatial collaboration smartphone app that allows teams to share information and access data to improve real-time SA. ATAK provides a wide variety of useful SA functions including mapping and navigation, range and bearing, text chat, force tracking, geospatial markup tools, image and file sharing, video playback, and many others. The Samsung Note3 end user device (EUD)

communicates with the MPU5 smart radio (described next) via the Universal Serial Bus (USB) Push Pull Android Tether Cable (CBL-DATA-2004) and is provisioned to run a customized version of the Android 4.4.2 operating system.

The MPU5 smart radio can be used to transmit data, video, and voice communications between several radio nodes and is designed for use in situations where Land Mobile Radio (LMR) communications and cell phone networks are not available. An overview of the features and functions of the MPU5 is shown in Table 1. The MPU5 radio can be outfitted with a variety of accessories, including various types of antennas, to customize the performance given the operational scenario. Persistent Systems, LLC, reports that the MPU5 is ruggedized to withstand extreme temperatures (-40°C to 85°C), as well as water immersion (20 meters depth for 30 minutes), shock, and salt fog (Reference 2).

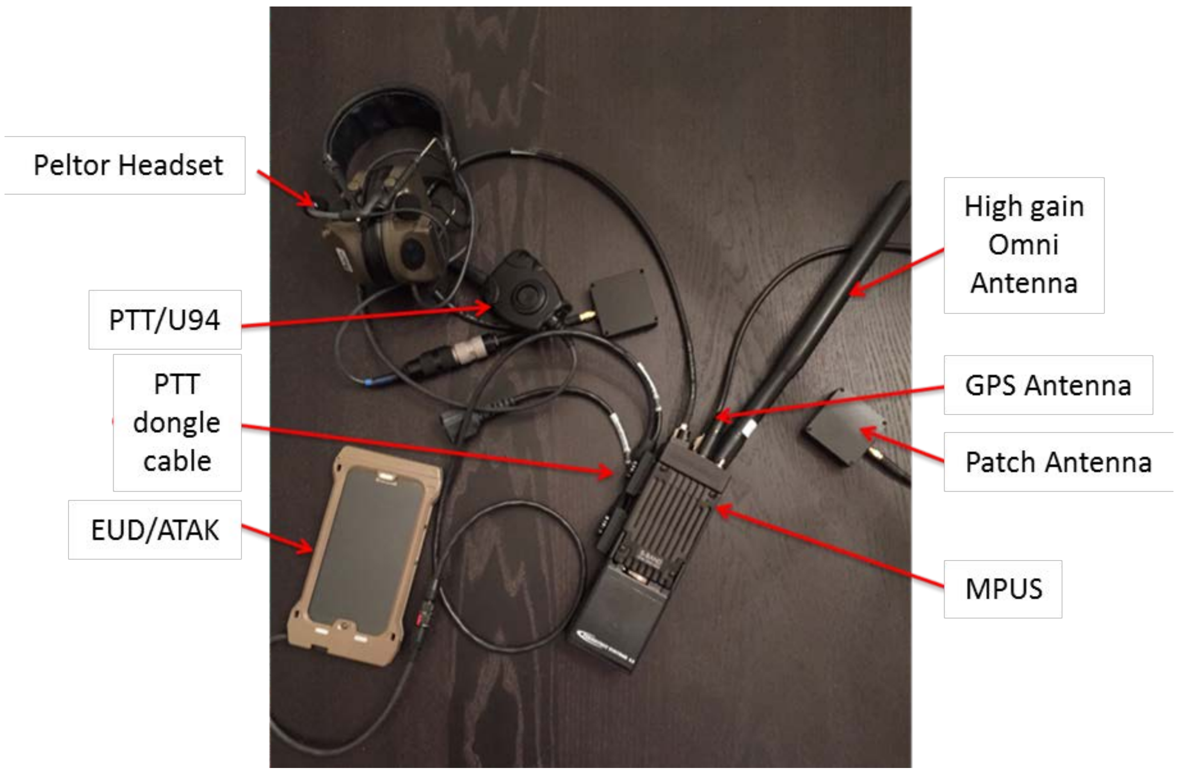


Figure 1: MANET System

Table 1: MPU5 Features and Functions (Reference 2)

MPU5 FEATURES	FUNCTIONS
Android™ Computer	1 GHz Quad Core Processor, 2 GB RAM, 128 GB Flash
HD Video Encoder	3G-SDI, Composite, HDMI Inputs
HD Video Decoder	Hardware based H.264 Decoding
Push-to-Talk Voice	16 Channels of Voice
RoIP Radio Interface	Tethers Legacy Radios into Network
USB	(3) USB Ports
10/100 Ethernet	Network Devices

MANET systems are typically deployed for dynamic networks where the networked nodes are designed to operate in a self-forming and self-healing manner. In the self-forming feature, each communicating node has the capability to discover and connect to other nearby nodes that operate with the same RF waveform, frequency and bandwidth. These intercommunicating nodes do not require any infrastructure to support their peer-to-peer mutual node discovery and operation. The self-healing features of MANET system enable the establishment of new routes among MANET nodes when communications links are lost due to wireless channel conditions or node mobility.

The overall interconnectedness of a public safety radio network (i.e., mesh network) is an important consideration for critical event deployments. Mesh networks are characterized as richly connected networks where the radio nodes can directly communicate with each other, therefore enhancing overall communications and situational awareness. Because critical events take place in a wide variety of environments and scenarios, an increased connectivity among radios represents an enhanced ability for any law enforcement personnel to directly engage in radio communications with all other personnel.

Lastly, "multiple input multiple output" (MIMO) is an antenna technology where multiple antennas reside on the same platform (in this case the MPU5 smart radio with three antennas) to leverage the multipath propagation effects of a wireless channel. Multipath propagation is the phenomenon where RF waves reach a receiver via multiple paths as a result of reflection from environmental obstacles such as terrain, foliage or buildings. MIMO technology aims to enhance throughput (an important consideration in providing broadband services) by leveraging multipath propagation.

2 NYPD Baseline Operational Requirements

The NYPD Emergency Service Unit (ESU) is a component of the NYPD Citywide Operations Bureau's Special Operations Division. The unit is uniquely trained and

equipped to perform tactical (Special Weapons and Tactics [SWAT]) and technical rescue duty for other department elements. Members of ESU are cross-trained in multiple disciplines for police and rescue work. In addition, its Canine Unit helps with searches for perpetrators and missing persons. ESU is always on patrol (all three tours, 365 days a year) with 10 Heavy Rescue trucks, each ordinarily manned by a police officer and a sergeant, and often more than twice as many smaller Radio Emergency Patrol vehicles containing two ESU police officers. There are also two or more citywide patrol sergeants or lieutenants in unmarked vehicles at all times to supervise and support ESU operations where needed.

The NYPD ESU identified their top three high level requirements as:

- System provides audio communications for the deployment event. This includes connectivity to other radios within range, reasonable volume levels, and clear voice communication.
- System provides video multicasting for the deployment event. This includes connectivity to other radios within range and clear video stream that provides an effective field of view.
- The ATAK provides situational awareness via the Samsung Note3 including location information overlaid on a map for each radio involved in the event.

The NYPD ESU identified their other baseline requirements as:

- Voice and data communications in a closed network with no dependency on commercial cellular infrastructure.
- Dependable system that can work across the city and penetrate buildings and underground areas and provide better SA with the use of video and ATAK.

3 Test and Evaluation: Summary of Plan

The NYPD ESU requested that the field test be conducted in buildings and subway stations as these were representative of their typical operational environments, and where frequent critical communications-related challenges occurred. The specific locations originally chosen by the NYPD ESU were near the Times Square in New York City (NYC): 1) Minskoff Theater, 2) 42nd St. subway station on 7th Ave., and 3) Marriott Marquis Hotel at Times Square. These locations were eventually changed due to availabilities of the facilities. The final locations for the three tests that were performed on 20 April were: 1) 42nd St. Subway Station, 2) Side-street on 42nd St., and 3) Marriot Marquis Hotel.

The general approach was based on utilizing a mission-relevant scenario, developed with input from NYPD ESU representatives, to conduct the MANET system field tests. The test was focused on integration of the MANET system with existing operational component (both technical and human). Test participants consisted of personnel from the NYPD ESU-1 located on 235 E. 20th St., NYC. A mobile ESU Tactical Operations Center (TOC) commander was pre-designated to serve as the incident commander to coordinate and monitor operations. A summary of the test and evaluation plan is provided in Appendix A: Detailed Test and Evaluation Plan. For the complete Test and Evaluation plan, please contact Ruth Vogel, at ruth.vogel@jhuapl.edu.

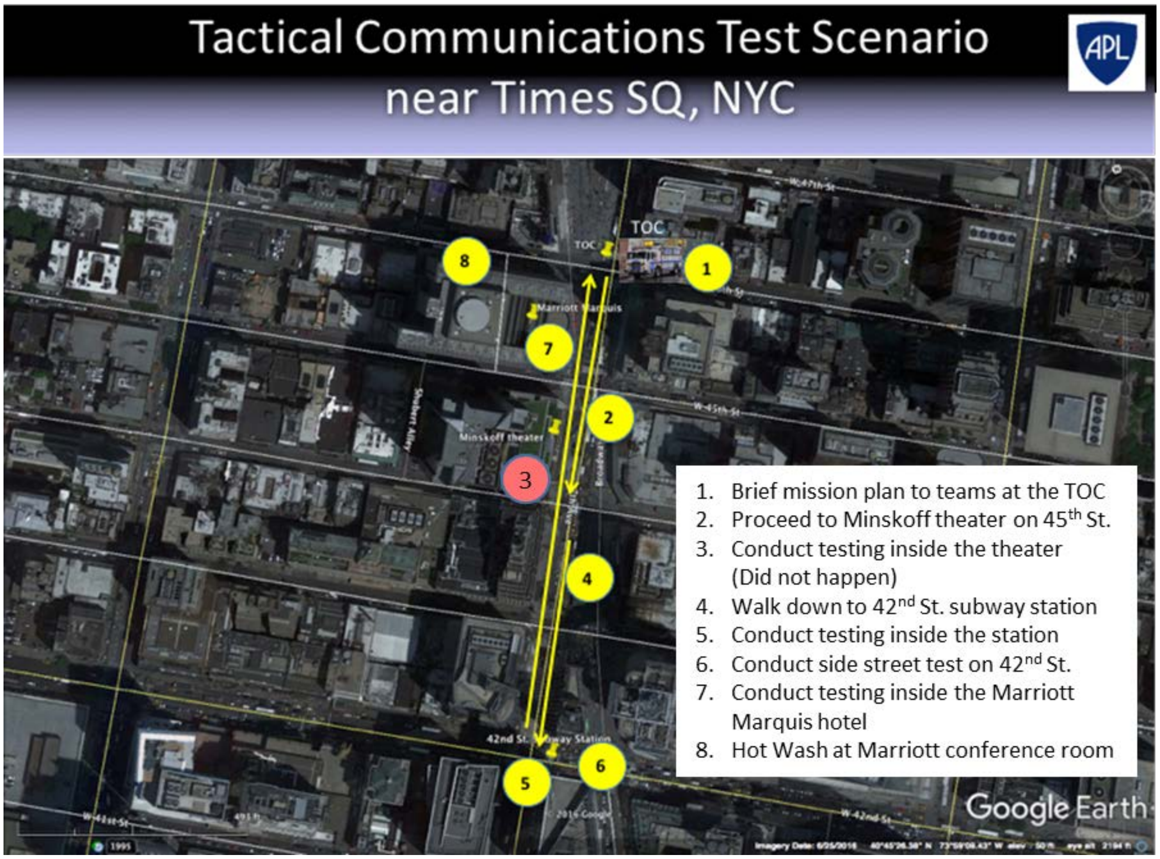


Figure 2: Test Scenarios near Times Square NYC, New York

3.1 Participants

- DHS S&T (leadership and observers)
- NYPD ESU officers
- NYPD Counter Terrorism Unit (CTU)
- Mobile TOC/Command Center
- TOC commander (Lieutenant from NYPD ESU)
- JHU/APL team
- Persistent Systems team provided technical set-up and MPU5 consultation support to JHU/APL. Persistent Systems did not participant in evaluation activities (i.e., data collection, analysis, evaluation and the development of this report)

3.2 Background

- Conduct a demonstration of the MANET communications system in the New York Subway. This is a basic capability demonstration.

- Conduct a demonstration of the MANET communications system to determine the ability of the systems to "reach around" large buildings and corners. This was a basic capability demonstration.
- Operational evaluation was based on a scenario in which a suspect was observed running past hotel security at the Marquis Marriott Hotel in Times Square. Suspect was subsequently reported as carrying a large duffle type bag while entering the express elevators for floors 20-49. NYPD ESU was tasked with a tactical search for the suspect and the bag.

3.3 Pre-Conditions

- A dry-run test was performed in March 2017.
- Results from the dry-run test, including further support of the established 20 decibels (dB) Signal-to-Noise Ratio (SNR) threshold value, were used to prepare for and configure equipment for the April field test.
- On-site MPU5 and ATAK training was provided for NYPD ESU personnel
- The TOC was configured as shown in Figure 3 below.
- All team members were equipped with an MPU5 radio and a EUD/ATAK.
- The van from the Counter Terrorism Unit served as a relay node.
- A non-functional inert simulated bomb bag was prepared by the CTU.
- A test at the Minskoff Theater was not performed due to a scheduling conflict with Theater related events.
- NYPD ESU obtained permission from the Marriott Marquis Hotel security manager to conduct a test.

3.4 Test Scenario Flow

As depicted in Figure 2, three tests were performed on 20 April 2017 at the following locations: 1) 42nd St. Subway Station, 2) Side-street on 42nd St., and 3) Marriot Marquis Hotel. The summary of the sequence of events were as follows:

0700: The NYPD ESU, JHU/APL and Persistent Systems met at the mobile TOC parked next to the Times Square, 46th St. and Broadway (Figure 4). Test team configured the TOC according to Figure 3. A van from the counter terrorism unit was parked next to the 42nd St. subway station and each ESU officer was provided with one MPU5 and an EUD/ATAK on their tactical vest. An MPU5 was mounted on the back of the vest and an EUD was mounted on the front.

0830: Onsite refresher training for the MPU5 and ATAK provided to all participants.

0845: Comms check performed by the TOC to ensure communications between the TOC and each team. Three video streams were received from Team-1. In addition, Teams 2, 4, 5, 6, and 7 were receiving the same video stream from Team-1 (Note: Team-3 did not have an EUD/ATAK).

0850: All teams briefed on the test scenario.

0907: All teams proceeded toward the 42nd St. subway station.

0915: Subway station test performed.

0935: Side-street test performed on 42nd St.

1000: All teams reconvened at the TOC.

1010: Marriott Marquis test performed.

1030: Marriot Marquis test concluded.

1100: Hot-wash held at the Marriott Marquis.

1200: NYPD field test concluded.

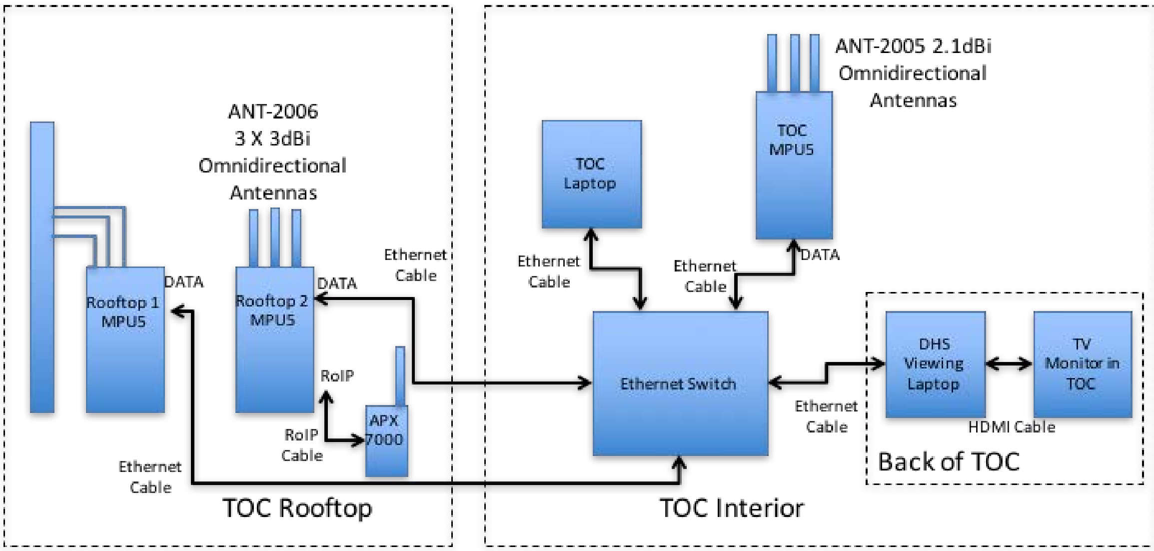


Figure 3: TOC Setup

3.5 Post-conditions

- Conduct a hot wash to elicit feedback and gain end-users' insight to better understanding NYPD ESU operational requirements.
- Collect MPU5 and EUD/ATAK equipment from all participants.
- Break down equipment and re-package for transport accordingly.

4 Implementation and Results

The field test, conducted on April 20, 2017 with the NYPD ESU, was based on an operational scenario relevant to the NYPD ESU routine operations and representative of their communications-related challenges for critical response events. During test execution, JHU/APL led efforts to plan for, configure, monitor and document the MANET system performance from both an operational and technical perspective using qualitative and quantitative means. Persistent Systems LLC, technology developer of the MPU5 radio, provided invaluable support to JHU/APL with technical configuration and equipment set-up for this event.

The ESU participants identified the MANET system's communications range and relaying capabilities (as a means for range extension) in supporting voice, video, and situational awareness traffic as its overarching objective in the evaluation of this system. In supporting this objective, the JHU/APL test team established relay locations for the MPU5 radios during the Dry Run engineering tests in March 2017 to ensure that the TOC could receive voice, real-time streaming video (the most demanding service on MANET system capacity), and situational awareness information from the team at the farthest extent of each mission (Team-1).

JHU/APL also conducted extensive on-campus testing (at APL) prior to the March 2017 Dry Run and the April 2017 Test to determine a technical threshold that could be used as guidance for when links between inter-communicating MPU5s would break. The metric used as the technical threshold was each link's SNR. For a communications link consisting of a transmitter and a received, SNR is a ratio between the power of the intended transmitted signal measured at the receiver and the background noise in the communications channel from other radiating phenomena. SNR is typically represented in logarithmic form as a dimensionless value known as decibels (dB) as noted in the following equation:

$$10log_{10}\frac{Received\ Power\ (in\ Watts\ or\ millwatts)}{Noise\ Power\ (in\ Watt\ or\ miliwatts)}.$$

Thus, an SNR of 10 dB means that the received power of the intended signal is 10 times as much of that of the noise power measured at the receiver. An SNR of 20 dB signifies a 100 times proportion between Received Power and Noise Power. During JHU/APL on-site campus testing and follow-on technical conversations with Persistent Systems technical representatives, it was established that 20 dB was the threshold SNR value for communications link signal strength between inter-communicating MPU5s to sustain voice, video, and SA services. The establishment of this 20 dB value was experiential (based on APL on-site test and NYC Dry Run) rather than translating to a specific service availability or data throughput. The primary objective of this effort was to determine a threshold value for persistence in voice, video, and SA services. Furthermore, the team scanned the operating frequency (2.227 GHz and 20 MHz bandwidth) with a spectrum analyzer prior to turning on the MPU5 radios to make sure that there were no interference signals. Once it was determined that this was true, the field test commenced.

The received power on a communications link is a function of the transmitter power, transmitter antenna gain, receiver antenna gain, operating frequency (2.227 GHz for the NYPD MANET testing), distance between transmitter and receiver, and other environmental factors such as terrain, vegetation, and buildings. As previously mentioned, the MPU5s are MIMO radios with three antennas each. The antennas may be omnidirectional where the energy radiated by the antenna in the horizontal plane is uniformly distributed in all directions. Another type of antenna is a MIMO sector antenna where the energy radiated by the antenna is focused directionally in a narrower sector in the horizontal plane (i.e., 120 degrees as was the antenna installed on the TOC vehicle's Rooftop 1 MPU5 unit for the April 2017 test). Appendix B: System Configurations includes further details on the configuration for this field test.

The MPU5's web management interface provides operators with the capability to log into radios connected to the MPU5 MANET. One of the views that the web management interface provides is the MANET Monitor. For each MPU5, the MANET Monitor view provides real-time updates of the SNR measured on the links to those MPU5s to which there is a direct connection. For each direct communications link, MANET Monitor provides Receive SNR (SNR measured at the MPU5 that is monitored or accessed) and Reverse SNR (SNR measured at the opposite node on the communications link). Therefore, the MANET Monitor provides a bi-directional view of SNR for each communications link. It should be noted that the MANET Monitor views that are presented in this section represent snapshots in time of the wireless communication link conditions between the individual MANET nodes. Wireless channels in complex urban and indoor/outdoor/subterranean environments accommodate a wide variety of occurrences and thus channel conditions, even among relatively stationary nodes, can be inconsistent. The views are included here to present insightful technical details that the MANET system provides the users.

During the test, the JHU/APL technical team at the TOC monitored the SNR values for key MPU5s (specifically Team-1's MPU5 or NYPD-1) to ensure there was at least one MPU5 to which there was a direct link with an SNR of at least 20 dB. Simultaneously, the JHU/APL technical team monitored the real-time video streaming from Team-1's EUD to the TOC to ensure continuous linkage and clarity, as well as voice quality from Team-1. Additionally, the MANET Monitor views for the Rooftop-1 and Rooftop-2 MPU5s were monitored and captured during the various execution phases of the tests.

4.1 Pre-Test Communications Check

On April 20, 2017, the NYPD ESU and JHU/APL team met at the mobile TOC parked next to the Times Square location (**Figure 4**) to finalize configurations and prepare for field test initiation.

Figure 4: Mobile TOC located at Times Square

Before proceeding to the 42nd St. subway station, a communications check was performed at the TOC to ensure all team members, including the TOC, were able to communicate with Push-to-Talk (PTT) voice and view the video streaming from Team-1's EUD on the ATAK video player.

The following tasks listed in Table 2 (checklist) were performed prior to the Subway demonstration.

Table 2: Checklist

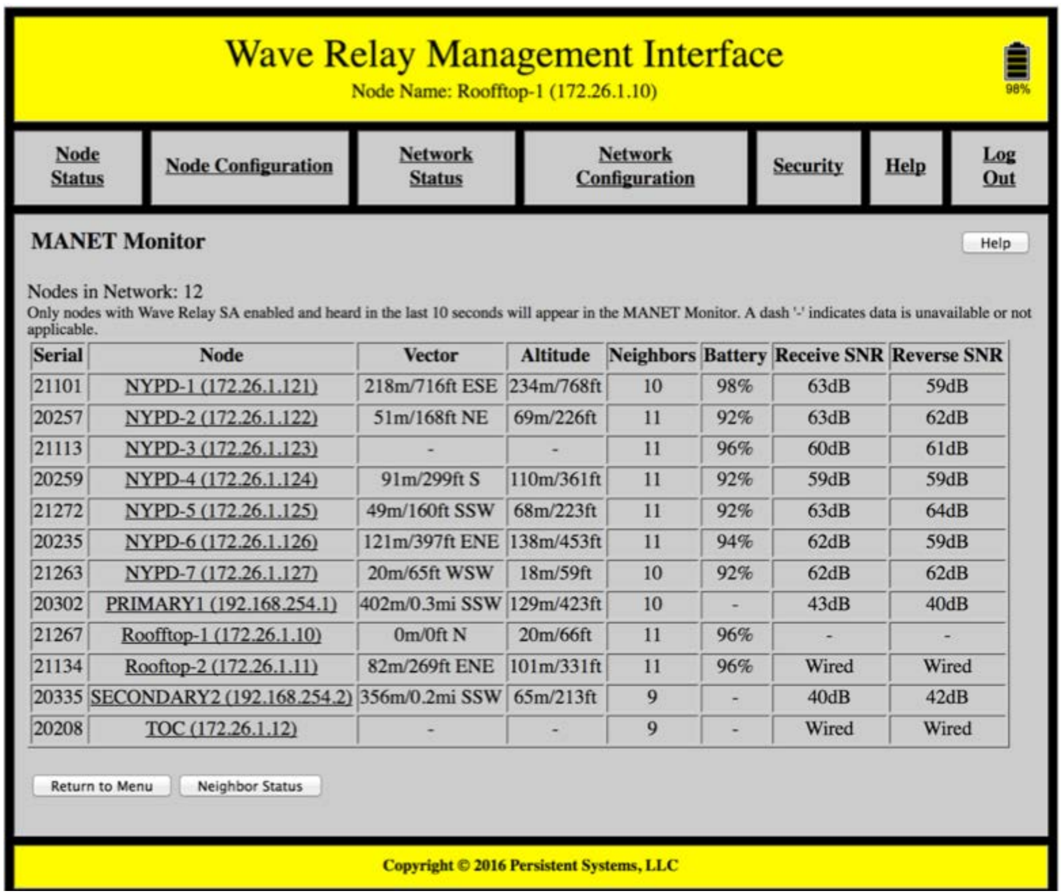
Item #	Action Item	Completed
1	Mount a sector antenna on the TOC roof and connect to the rooftop-1 MPU5. Make sure that the antenna is not point UP	
2	Perform Spectrum scanning (Max Hold) at 2227 MHz before powering on radios (save to system and take photo)	
3	Place the rooftop-2 MPU5 and three Omni-antennas (ANT-2006) with mag mount on the TOC roof	
4	Configure and connect the WinTAK laptop to mirror its display on the television monitor in the back of the Mobile TOC, then connect laptop to the Ethernet switch using a long Ethernet cable	

Item #	Action Item	Completed
5	Launch WinTAK and open the video player tab on the right side of the screen	
6	Mount MPU5 and EUD/ATAK on each team member (x7)	
7	All teams Power ON radios	
8	All seven team members to deploy in the Times Square area	
9	Wait ~30 seconds to boot up radios and lock onto Global Positioning System (GPS)	
10	TOC to re-check battery levels on all 11 radios using MANET monitor	
11	Replace any low batteries (lower than 50 percent)	
12	TOC to check SNR level between Team-1 and Rooftop-1 using MANET monitor	
13	TOC (Rooftop-1) to perform Bandwidth test to Team-1	
14	Perform Spectrum Analysis (Max Hold) once all radios on (save to system and take picture)	
15	TOC to check voice comm with each team (including with APX 7000 via RoIP)	
16	Log in to Rooftop-1 and download Visualization KML file	
17	Check MPU5's GPS locations using Google Earth	
18	Check video stream from Team-1's ATAK/EUD to TOC's laptop and the television monitor in the back of the TOC	
19	Place APX7000 in rear of TOC so leadership can hear voice commands	
20	Connect PC to the switch as a backup to the TOC's laptop	
21	Check video stream on all ATAK devices	
22	All systems ready	
23	Take screen shot of MANET monitor at end of subway test • Rooftop-1 perspective • Rooftop-2 perspective • Team-1 perspective	
24	Take screen shot of MANET monitor at end of hotel test • Rooftop-1 perspective • Rooftop-2 perspective • Team-1 perspective	

The communications check included performing a Throughput Test between Rooftop-1 (the intended primary TOC radio) and NYPD-1 (the team that would be deployed to the farthest extent for each test and streaming real-time video back to the TOC). During

this Throughput Test, some unexpected results were observed and JHU/APL requested Persistent System's assistance in understanding this occurrence. It was agreed that further testing beyond the scope of this project was needed. See Appendix B: System Configurations for additional information.

During the communications check, views from the MANET screen for Rooftop-1, Rooftop-2, and NYPD-1 were captured to establish a baseline of how strong the communications links were with all nodes in and around the TOC. The ATAK application running on the EUD periodically dropped breadcrumbs at the EUD locations. Therefore, the GPS coordinates of each team during various phases of the test were captured. Screenshots of these EUD breadcrumbs overlaid on Google Earth are provided in this section. These Google Earth overlay screenshots were placed next to the NYPD-1 MANET Monitor views and are from the same time (within less than a minute) when the MANET Monitor screenshots were captured (for each pre-test/test phase) to provide data correlation.



Wave Relay Management Interface

Node Name: Roofftop-1 (172.26.1.10)

98%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	218m/716ft ESE	234m/768ft	10	98%	63dB	59dB
20257	NYPD-2 (172.26.1.122)	51m/168ft NE	69m/226ft	11	92%	63dB	62dB
21113	NYPD-3 (172.26.1.123)	-	-	11	96%	60dB	61dB
20259	NYPD-4 (172.26.1.124)	91m/299ft S	110m/361ft	11	92%	59dB	59dB
21272	NYPD-5 (172.26.1.125)	49m/160ft SSW	68m/223ft	11	92%	63dB	64dB
20235	NYPD-6 (172.26.1.126)	121m/397ft ENE	138m/453ft	11	94%	62dB	59dB
21263	NYPD-7 (172.26.1.127)	20m/65ft WSW	18m/59ft	10	92%	62dB	62dB
20302	PRIMARY1 (192.168.254.1)	402m/0.3mi SSW	129m/423ft	10	-	43dB	40dB
21267	Roofftop-1 (172.26.1.10)	0m/0ft N	20m/66ft	11	96%	-	-
21134	Rooftop-2 (172.26.1.11)	82m/269ft ENE	101m/331ft	11	96%	Wired	Wired
20335	SECONDARY2 (192.168.254.2)	356m/0.2mi SSW	65m/213ft	9	-	40dB	42dB
20208	TOC (172.26.1.12)	-	-	9	-	Wired	Wired

Return to Menu | Neighbor Status

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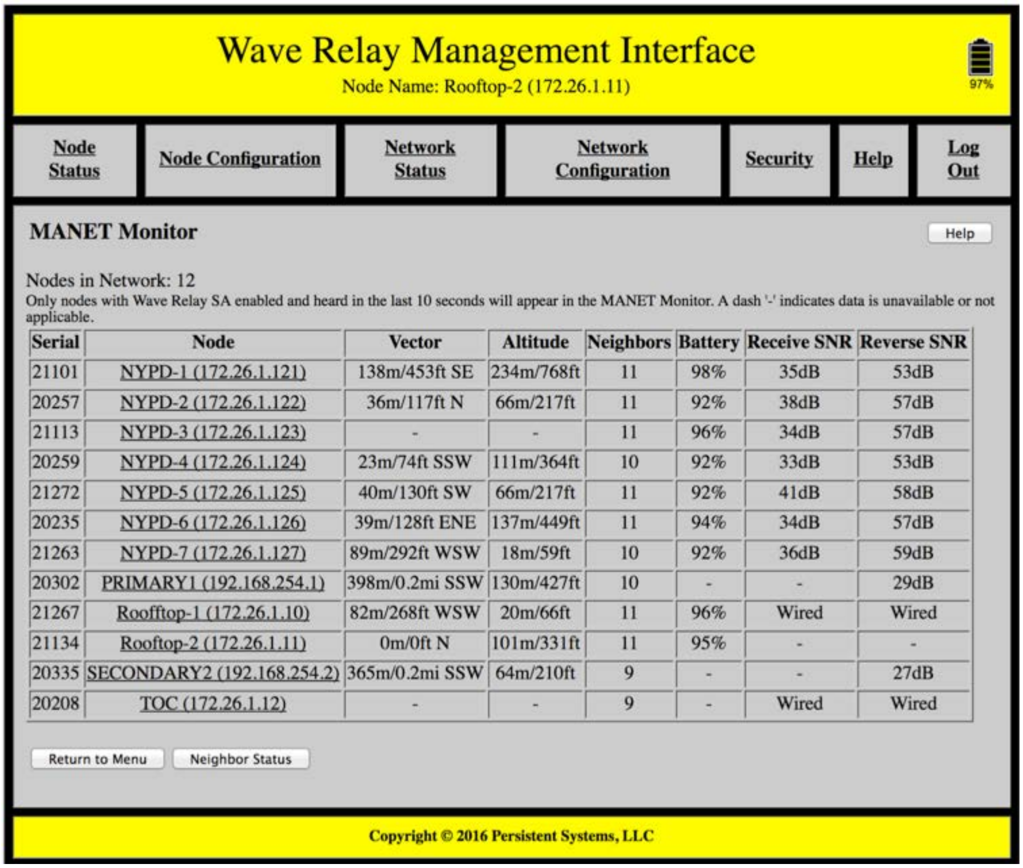
Figure 5: Rooftop-1 MANET Monitor View (Communications Check - 0854)

Figure 5 shows that Rooftop-1 with the 12 dBi MIMO sector antenna was connected to all nodes during the communications check. The CTU van (the location of PRIMARY1 and SECONDARY2) was parked next to the 42nd St. subway station on 7th Ave.



Wave Relay Management Interface

Node Name: Rooftop-2 (172.26.1.11)

97%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	138m/453ft SE	234m/768ft	11	98%	35dB	53dB
20257	NYPD-2 (172.26.1.122)	36m/117ft N	66m/217ft	11	92%	38dB	57dB
21113	NYPD-3 (172.26.1.123)	-	-	11	96%	34dB	57dB
20259	NYPD-4 (172.26.1.124)	23m/74ft SSW	111m/364ft	10	92%	33dB	53dB
21272	NYPD-5 (172.26.1.125)	40m/130ft SW	66m/217ft	11	92%	41dB	58dB
20235	NYPD-6 (172.26.1.126)	39m/128ft ENE	137m/449ft	11	94%	34dB	57dB
21263	NYPD-7 (172.26.1.127)	89m/292ft WSW	18m/59ft	10	92%	36dB	59dB
20302	PRIMARY1 (192.168.254.1)	398m/0.2mi SSW	130m/427ft	10	-	-	29dB
21267	Roofftop-1 (172.26.1.10)	82m/268ft WSW	20m/66ft	11	96%	Wired	Wired
21134	Rooftop-2 (172.26.1.11)	0m/0ft N	101m/331ft	11	95%	-	-
20335	SECONDARY2 (192.168.254.2)	365m/0.2mi SSW	64m/210ft	9	-	-	27dB
20208	TOC (172.26.1.12)	-	-	9	-	Wired	Wired

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Figure 6: Rooftop-2 MANET Monitor View (Communications Check - 0855)

From Figure 6, what is most noteworthy is that Rooftop-2 did not connect to the CTU van's MPU5's in the Receive direction because Rooftop-2 only had low gain (3.0 dBi) omni antennas.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	0m/0ft N	238m/781ft	11	68%	-	-
20257	NYPD-2 (172.26.1.122)	6m/18ft WNW	243m/797ft	11	93%	70dB	69dB
21113	NYPD-3 (172.26.1.123)	-	-	11	97%	79dB	77dB
20259	NYPD-4 (172.26.1.124)	92m/303ft N	149m/489ft	11	93%	64dB	64dB
21272	NYPD-5 (172.26.1.125)	173m/569ft NW	68m/223ft	11	93%	62dB	64dB
20235	NYPD-6 (172.26.1.126)	28m/91ft NE	255m/837ft	11	95%	69dB	69dB
21263	NYPD-7 (172.26.1.127)	213m/699ft NW	29m/95ft	11	93%	60dB	66dB
20302	PRIMARY1 (192.168.254.1)	411m/0.3mi SW	21m/69ft	9	-	27dB	31dB
21267	Rooftop-1 (172.26.1.10)	128m/420ft NNW	115m/377ft	11	96%	61dB	66dB
21134	Rooftop-2 (172.26.1.11)	204m/670ft NNW	36m/118ft	11	96%	54dB	35dB
20335	SECONDARY2 (192.168.254.2)	381m/0.2mi SW	80m/262ft	8	-	28dB	30dB
20208	TOC (172.26.1.12)	-	-	11	-	52dB	49dB

Figure 7: NYPD-1 MANET Monitor View (Communications Check - 0855)

As depicted in Figure 7, Team-1/NYPD-1 was able to establish a connection with all teams, the TOC, and CTU van with strong SNR values. The CTU van's MPU5s were the farthest nodes from TOC/Rooftop-1 (1100 feet). Of note, during this specific capture at the communications check, Team-1's radio (operating with 2.15 dBi omnidirectional antennas) was sustaining stronger links among the MANET nodes than Rooftop-2, which had three dBi omnidirectional antennas. Commonly in omnidirectional antennas, there is minimal energy radiated right below the antenna, so Rooftop-2's antennas did not radiate well to the MANET nodes located directly near the TOC on the sidewalk.

4.2 42nd St. Subway Station Test

The objective of the subway station test was to demonstrate the capability of the MANET system to support voice, video, and situational awareness in an underground environment. As previously mentioned, Team 1 was streaming real-time video to the TOC via MPU5 relays placed at the locations depicted in **Figure 8** below.

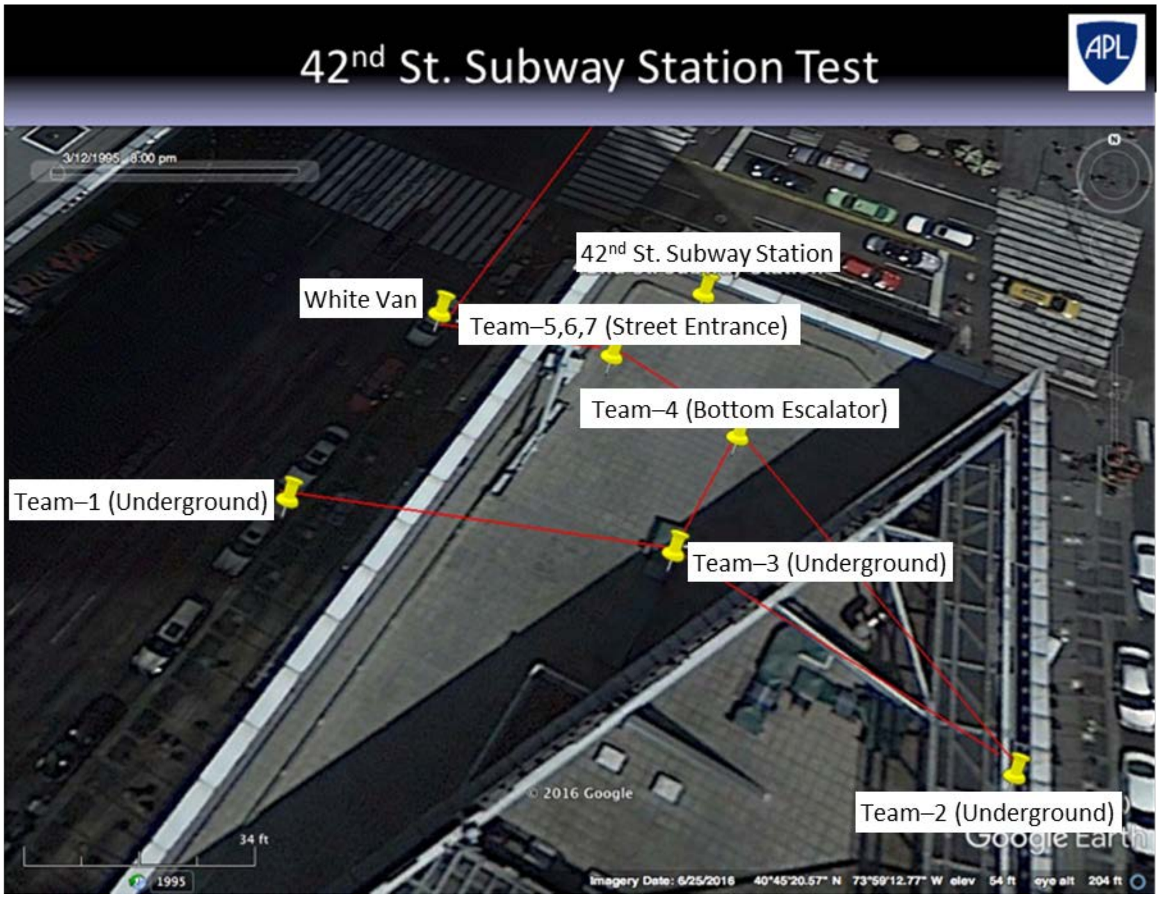
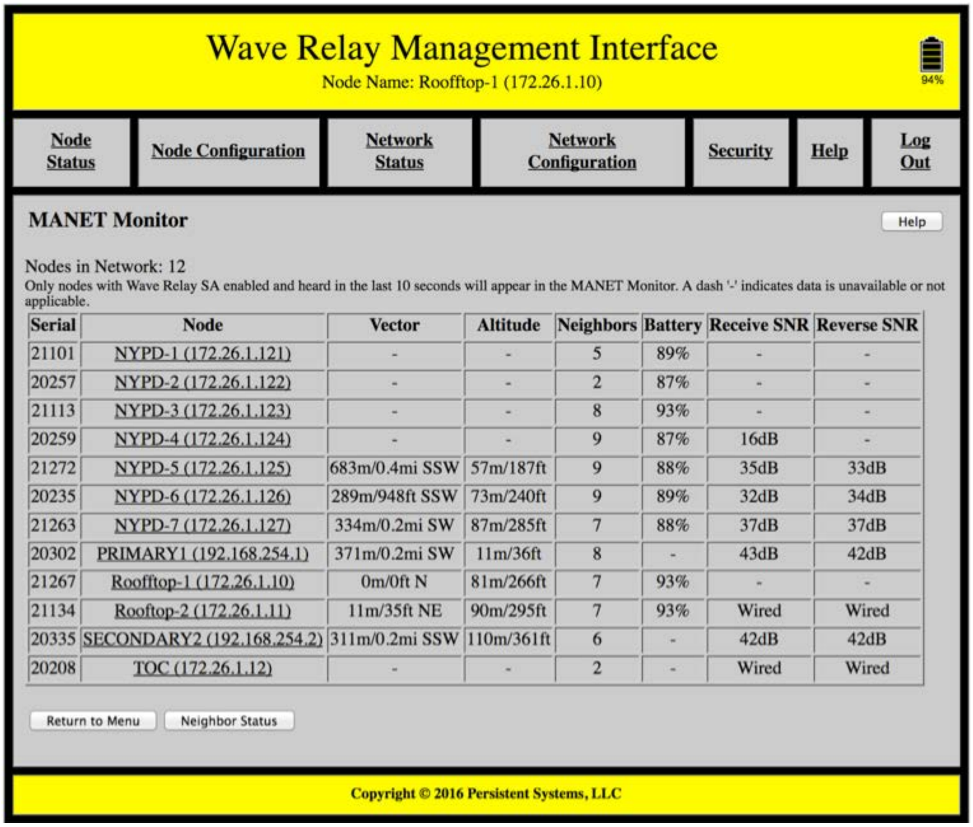


Figure 8: Subway Station Test Node Locations

The following MANET Monitor screenshots were collected at the end of the subway test when NYPD-1 (Team-1's MPU5) was at the subway platform.



Wave Relay Management Interface

Node Name: Roofftop-1 (172.26.1.10)

94%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	-	-	5	89%	-	-
20257	NYPD-2 (172.26.1.122)	-	-	2	87%	-	-
21113	NYPD-3 (172.26.1.123)	-	-	8	93%	-	-
20259	NYPD-4 (172.26.1.124)	-	-	9	87%	16dB	-
21272	NYPD-5 (172.26.1.125)	683m/0.4mi SSW	57m/187ft	9	88%	35dB	33dB
20235	NYPD-6 (172.26.1.126)	289m/948ft SSW	73m/240ft	9	89%	32dB	34dB
21263	NYPD-7 (172.26.1.127)	334m/0.2mi SW	87m/285ft	7	88%	37dB	37dB
20302	PRIMARY1 (192.168.254.1)	371m/0.2mi SW	11m/36ft	8	-	43dB	42dB
21267	Roofftop-1 (172.26.1.10)	0m/0ft N	81m/266ft	7	93%	-	-
21134	Rooftop-2 (172.26.1.11)	11m/35ft NE	90m/295ft	7	93%	Wired	Wired
20335	SECONDARY2 (192.168.254.2)	311m/0.2mi SSW	110m/361ft	6	-	42dB	42dB
20208	TOC (172.26.1.12)	-	-	2	-	Wired	Wired

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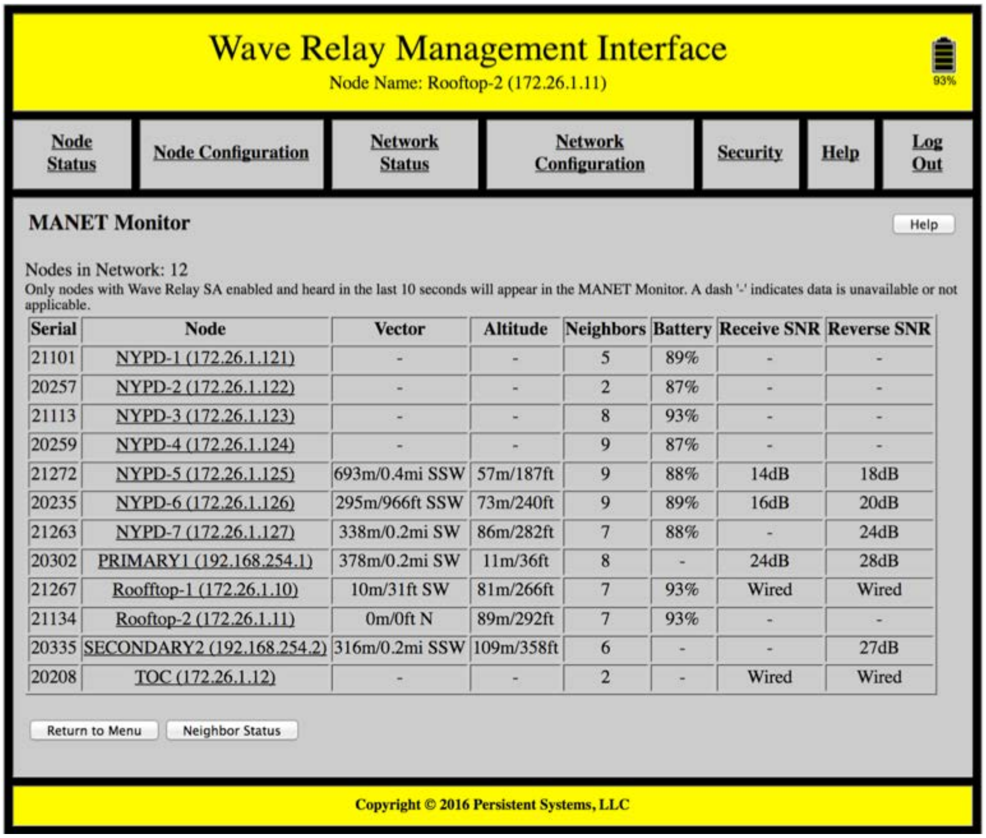
Figure 9: Rooftop-1 MANET Monitor View (End of Subway Test - 0921)

As depicted in Figure 9, Rooftop-1 could not connect directly to Teams-1, 2, 3, and 4 while they were underground at the platform. For this test, Teams 5, 6, 7, and the CTU van's MPU5s acted as relays for the TOC. The distance from the TOC to the CTU van was 1100 ft.



Wave Relay Management Interface

Node Name: Rooftop-2 (172.26.1.11)

93%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	-	-	5	89%	-	-
20257	NYPD-2 (172.26.1.122)	-	-	2	87%	-	-
21113	NYPD-3 (172.26.1.123)	-	-	8	93%	-	-
20259	NYPD-4 (172.26.1.124)	-	-	9	87%	-	-
21272	NYPD-5 (172.26.1.125)	693m/0.4mi SSW	57m/187ft	9	88%	14dB	18dB
20235	NYPD-6 (172.26.1.126)	295m/966ft SSW	73m/240ft	9	89%	16dB	20dB
21263	NYPD-7 (172.26.1.127)	338m/0.2mi SW	86m/282ft	7	88%	-	24dB
20302	PRIMARY1 (192.168.254.1)	378m/0.2mi SW	11m/36ft	8	-	24dB	28dB
21267	Roofftop-1 (172.26.1.10)	10m/31ft SW	81m/266ft	7	93%	Wired	Wired
21134	Rooftop-2 (172.26.1.11)	0m/0ft N	89m/292ft	7	93%	-	-
20335	SECONDARY2 (192.168.254.2)	316m/0.2mi SSW	109m/358ft	6	-	-	27dB
20208	TOC (172.26.1.12)	-	-	2	-	Wired	Wired

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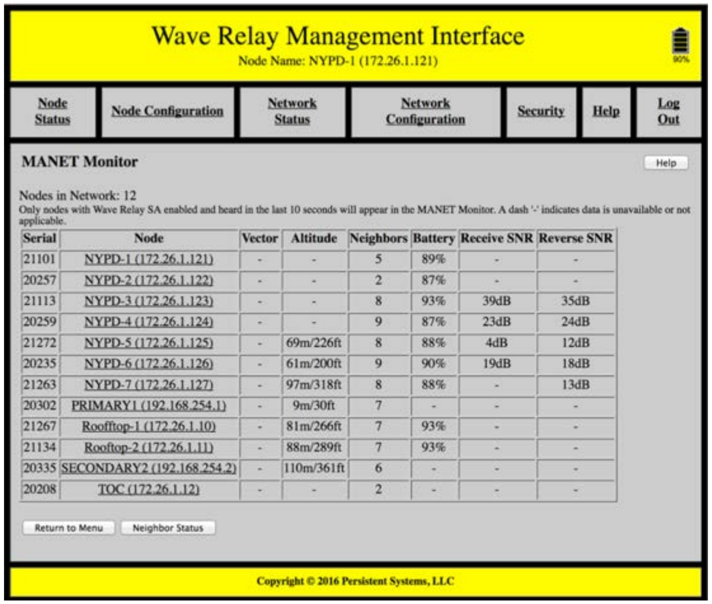
Figure 10: Rooftop-2 MANET Monitor View (End of Subway Test - 0921)

According to Figure 10, Rooftop-2 was not able to connect all units, and could only marginally connect the CTU van's MPU5s. This denotes that the connection between the CTU MPU5s to Rooftop-1 was the critical link to ensure communications with the TOC.



Wave Relay Management Interface

Node Name: NYPD-1 (172.26.1.121)

90%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	-	-	5	89%	-	-
20257	NYPD-2 (172.26.1.122)	-	-	2	87%	-	-
21113	NYPD-3 (172.26.1.123)	-	-	8	93%	39dB	35dB
20259	NYPD-4 (172.26.1.124)	-	-	9	87%	23dB	24dB
21272	NYPD-5 (172.26.1.125)	-	69m/226ft	8	88%	4dB	12dB
20235	NYPD-6 (172.26.1.126)	-	61m/200ft	9	90%	19dB	18dB
21263	NYPD-7 (172.26.1.127)	-	97m/318ft	8	88%	-	13dB
20302	PRIMARY1 (192.168.254.1)	-	9m/30ft	7	-	-	-
21267	Roofftop-1 (172.26.1.10)	-	81m/266ft	7	93%	-	-
21134	Rooftop-2 (172.26.1.11)	-	88m/289ft	7	93%	-	-
20335	SECONDARY2 (192.168.254.2)	-	110m/361ft	6	-	-	-
20208	TOC (172.26.1.12)	-	-	2	-	-	-

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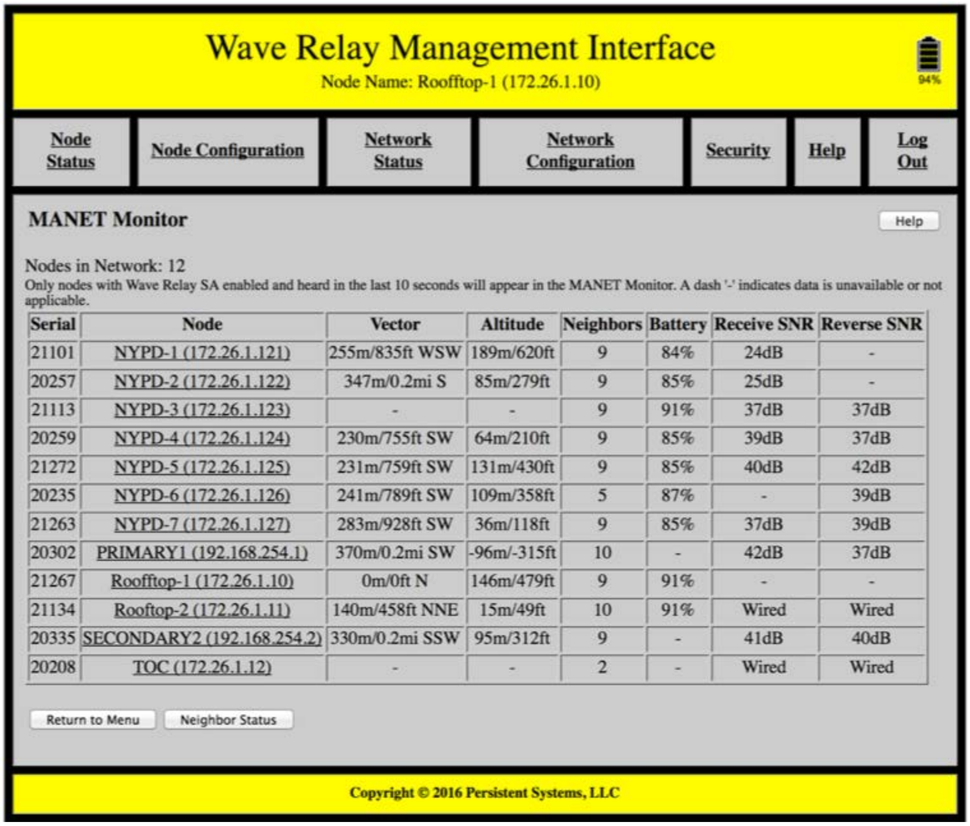
Figure 11: NYPD-1 MANET Monitor View (End of Subway Test -0921)

It can be seen from Figure 11 that inside the subway platform, Team-1 was able to connect to Teams 3 and 4, while Teams 3 and 4 were subsequently connected to Teams 5, 6, 7 at the subway entrance lobby. Team-1's connection to Team-6 is questionable based on the experiment-based finding that links usually drop for broadband services at the SNR value below 20dB. Furthermore, Team-3&4 were acting as relays for Teams 1 & 2 as Teams 1 & 2 went in opposite directions at the subway platform.

4.3 Side-Street Test on 42nd St.

After completion of the subway test, the Teams were repositioned on the side streets to determine the capability of the MPU5 system to provide connectivity around corners of city blocks. As depicted in Figure 12, Team 1 and Team 2 proceeded down 42nd St. to 8th Avenue and 6th Avenue respectively. Teams 3, 4, 5, 6, and 7 remained at the corner of 42nd St. and 7th Avenue to serve as relays.

Figure 12: Side-street Test on 42nd St.



Wave Relay Management Interface

Node Name: Roofftop-1 (172.26.1.10)

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	255m/835ft WSW	189m/620ft	9	84%	24dB	-
20257	NYPD-2 (172.26.1.122)	347m/0.2mi S	85m/279ft	9	85%	25dB	-
21113	NYPD-3 (172.26.1.123)	-	-	9	91%	37dB	37dB
20259	NYPD-4 (172.26.1.124)	230m/755ft SW	64m/210ft	9	85%	39dB	37dB
21272	NYPD-5 (172.26.1.125)	231m/759ft SW	131m/430ft	9	85%	40dB	42dB
20235	NYPD-6 (172.26.1.126)	241m/789ft SW	109m/358ft	5	87%	-	39dB
21263	NYPD-7 (172.26.1.127)	283m/928ft SW	36m/118ft	9	85%	37dB	39dB
20302	PRIMARY1 (192.168.254.1)	370m/0.2mi SW	-96m/-315ft	10	-	42dB	37dB
21267	Roofftop-1 (172.26.1.10)	0m/0ft N	146m/479ft	9	91%	-	-
21134	Rooftop-2 (172.26.1.11)	140m/458ft NNE	15m/49ft	10	91%	Wired	Wired
20335	SECONDARY2 (192.168.254.2)	330m/0.2mi SSW	95m/312ft	9	-	41dB	40dB
20208	TOC (172.26.1.12)	-	-	2	-	Wired	Wired

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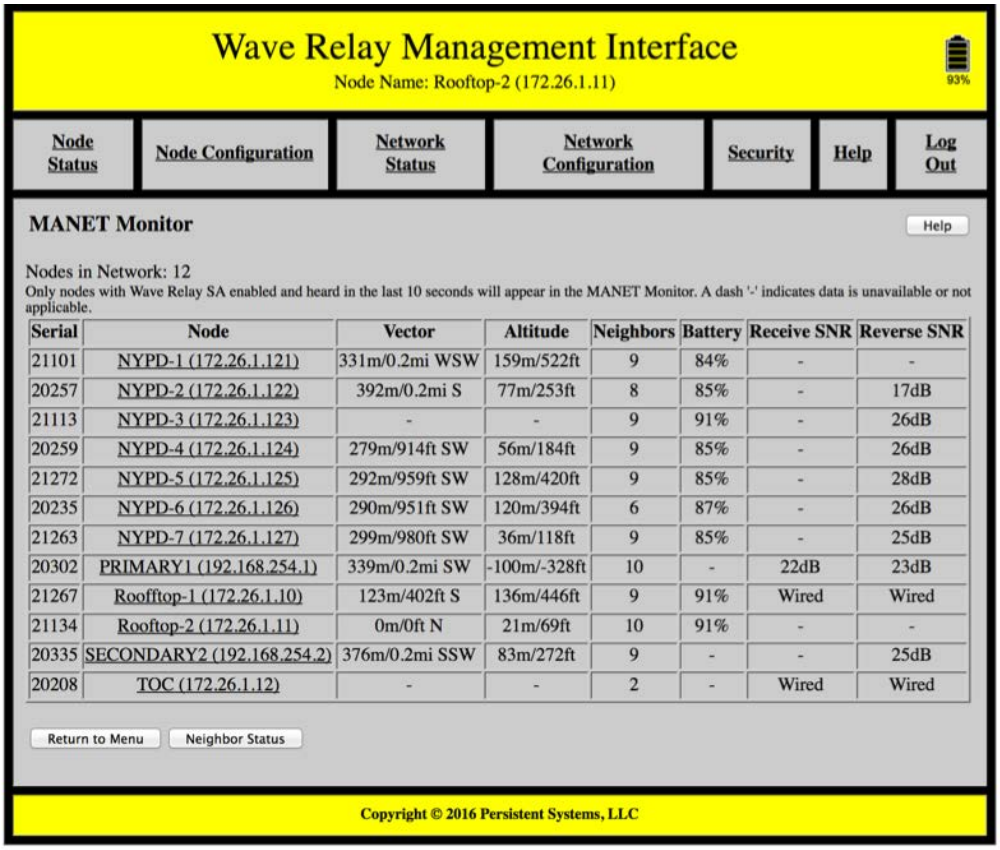
Figure 13: Rooftop-1 MANET Monitor View (Side Street Test - 0935)

Figure 13, depicts that during the side street test, Teams 1 and 2 were not directly connected to Rooftop-1 in both directions, connections were in the receive mode only. This demonstrated that the Rooftop-1 with a 12 dBi MIMO sector antenna on top of the TOC was able to connect to Team 1 and 2 directly, but that Team 1 and 2 with their 3x2.15 dBi antennas were unable to transmit successfully to Rooftop-1. In order to provide a more robust connection, from Teams 1 and 2 with the TOC, Teams 3, 4, 5, 6, 7, and the CTU MPU5's were required to serve as relay nodes.



Wave Relay Management Interface

Node Name: Rooftop-2 (172.26.1.11)

93%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	331m/0.2mi WSW	159m/522ft	9	84%	-	-
20257	NYPD-2 (172.26.1.122)	392m/0.2mi S	77m/253ft	8	85%	-	17dB
21113	NYPD-3 (172.26.1.123)	-	-	9	91%	-	26dB
20259	NYPD-4 (172.26.1.124)	279m/914ft SW	56m/184ft	9	85%	-	26dB
21272	NYPD-5 (172.26.1.125)	292m/959ft SW	128m/420ft	9	85%	-	28dB
20235	NYPD-6 (172.26.1.126)	290m/951ft SW	120m/394ft	6	87%	-	26dB
21263	NYPD-7 (172.26.1.127)	299m/980ft SW	36m/118ft	9	85%	-	25dB
20302	PRIMARY1 (192.168.254.1)	339m/0.2mi SW	-100m/-328ft	10	-	22dB	23dB
21267	Roofftop-1 (172.26.1.10)	123m/402ft S	136m/446ft	9	91%	Wired	Wired
21134	Rooftop-2 (172.26.1.11)	0m/0ft N	21m/69ft	10	91%	-	-
20335	SECONDARY2 (192.168.254.2)	376m/0.2mi SSW	83m/272ft	9	-	-	25dB
20208	TOC (172.26.1.12)	-	-	2	-	Wired	Wired

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Figure 14: Rooftop-2 MANET Monitor View (Side Street Test - 0935)

According to Figure 14, Rooftop-2 was able to connect to the CTU MPU5s with three dBi omnidirectional antennas and transmit to Teams 2-7, but could not receive from them or Team-1. Thus, it can be concluded that Rooftop-1's link to the relays (Teams 3-7 and the CTU MPU5s) was critical for communications with to the TOC.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	0m/0ft N	163m/535ft	9	84%	-	-
20257	NYPD-2 (172.26.1.122)	381m/0.2mi SE	78m/256ft	8	85%	30dB	35dB
21113	NYPD-3 (172.26.1.123)	-	-	9	91%	35dB	38dB
20259	NYPD-4 (172.26.1.124)	157m/514ft SE	57m/187ft	9	85%	32dB	35dB
21272	NYPD-5 (172.26.1.125)	112m/368ft ESE	129m/423ft	9	85%	32dB	38dB
20235	NYPD-6 (172.26.1.126)	122m/402ft ESE	118m/387ft	6	87%	-	42dB
21263	NYPD-7 (172.26.1.127)	171m/561ft SE	37m/121ft	9	85%	34dB	38dB
20302	PRIMARY1 (192.168.254.1)	270m/885ft SSE	-99m/-325ft	10	-	35dB	32dB
21267	Roofftop-1 (172.26.1.10)	274m/899ft ENE	137m/449ft	9	91%	-	26dB
21134	Rooftop-2 (172.26.1.11)	332m/0.2mi ENE	19m/62ft	10	91%	-	-
20335	SECONDARY2 (192.168.254.2)	211m/693ft SSE	84m/276ft	9	-	36dB	41dB
20208	TOC (172.26.1.12)	-	-	2	-	-	-

Figure 15: NYPD-1 MANET Monitor View (Side Street Test - 0935)

Figure 15 depicts that Team-1 had strong connections to all radios and the relays at 42nd and 7th were required to achieve connection with the TOC. During this test, distances of 885 ft. from Team-3 to Team-1 and 809 ft. from Team-3 to Team-2 were achieved, respectively. These distances were less than those from the TOC to CTU van, but performed well using only the low gain omni-directional antennas.

4.4 Marriott Marquis Hotel Test

The Marriot Marquis Hotel field test provided an operations-based demonstration of the MPU5's capability to provide voice and video connectivity along the vertical span of a typical NYC skyscraper. This test was conducted using the following Master Scenario Event List (MSEL), Table 3.

Table 3: Marriott Marquis Test MSEL

MSEL - Marriott Marquis					
Inject #	**Event Time**	**Event Type**	**Event Description**	**Recipient**	**Expected Outcome**
1	1000	Simulated	The President of the United States (POTUS) is scheduled for an event in the Marriott Marquis. The NYPD Emergency Services Unit (ESU), Truck 1, conducted radio capability tests to determine the placement of MANET radios in the event of an emergency response to the hotel. ESU is place on standby for the event	All Police Personnel	Pre-positioning of relay nodes is achieved and initial communication links are established in preparation for a National Special Security Event (NSSE)-type of event
2	1000	Simulated	NYPD receives 911 calls for service stating that a man wearing dark clothing carrying a large bag ran past hotel security and into an elevator	NYPD 911 Center	Dispatch of Police Personnel to the scene to include Emergency Services Unit and Command Bus
This is an Exercise - This is an Exercise - This is an Exercise					
3	1005	Command	ESU establishes command	ESU Command	ESU advises "central" that ESU is Marquis Command
4	1006	Team Response	MANET/Video communications check	ESU Teams	Command bus confirms that each MANET radio has established a connection to include the video feed
5	1010	Command	ESU conducts pre-deployment briefing and directs team to deploy to the lobby of the Marriott Marquis	ESU Teams	ESU Teams are informed that suspect is a male wearing dark clothing, possibly armed, that ran past hotel lobby security and into the express elevator (floors 20-49)
6	1015	Response	ESU deploys to the lobby of the Marriott Marquis	ESU Teams	ESU Teams deploys to the hotel lobby with Team 1 streaming video. Team 1 interviews hotel security

MSEL - Marriott Marquis					
Inject #	**Event Time**	**Event Type**	**Event Description**	**Recipient**	**Expected Outcome**
7	1020	Inject	Team 1 advises Command that the suspect is confirmed to have used the express elevators, floors 20-49. Teams ready to implement search	Command	Command authorizes the search beginning with the 49th floor
8	1022	Inject	Team 1 advises Command that Team 4 has been positioned in the hotel lobby to act as a relay	Command /Team 4	Command acknowledges, Team 4 to be stationary in the hotel lobby monitoring comms
9	1025	Inject	Team 1 advises Command that Team 5 has been positioned on the 5th floor as a relay	Command /Team 5	Command acknowledges, Team 5 to be stationary on the 5th floor monitoring comms
9	1030	Inject	Team 1 advises Command that Team 6 has been positioned on the 10th floor as a relay	Command /Team 6	Command acknowledges, Team 6 to be stationary on the 10th floor monitoring comms
This is an Exercise - This is an Exercise - This is an Exercise					
11	1035	Command	Command advises Team 1 that 911 calls place the suspect on the 47th floor	Team 1	Team 1 acknowledges
12	1040	Inject	Team 1 advises Command that Team 7 has been positioned on the 20th floor as a relay	Command /Team 7	Command acknowledges, Team 7 to be stationary on the 20th floor monitoring comms
13	1045	Inject	Team 1 advises Command that they are searching the 49th floor with Team 2 and Team 3	Command	Command acknowledges
This is an Exercise - This is an Exercise - This is an Exercise					
14	1050	Command	Command advises Team 1 that hotel security reports guests are evacuating the 45th floor	Team 1	Team 1 acknowledges. Advises Command that they are moving to the 48th floor
15	1055	Inject	Team 1 advises Command that they are beginning their search of the 48th floor	Command	Command acknowledges
This is an Exercise - This is an Exercise - This is an Exercise					

MSEL - Marriott Marquis					
Inject #	**Event Time**	**Event Type**	**Event Description**	**Recipient**	**Expected Outcome**
16	1100	Command	Command advises Team 1 that 911 calls for a bus (EMS) are received from the 45th floor. A large bag has been report and is unattended	Team 1	Team 1 acknowledges and advises that they are moving to the 47th floor
17	1105	Inject	Team 1 advises they are now searching the 46th floor	Command	Command acknowledges that Team 1 is searching the 46th floor
18	1110	Inject	Team 1 Advises that they are now searching the 45th floor	Command	Command acknowledges that Team 1 is searching the 45th floor
19	1115	Inject	Team 1 encounters the suspect on the 45th floor. Advises Command that suspect is located and apprehended without incident. Team 1 shows the contents of the bag via live video stream	Command	Command acknowledges

The Marriot Marquis is 49 floors high, therefore Rooftop-1 node's MIMO sector antenna was rotated 90 degrees then lowered and aimed toward the hotel to maximize the coverage radiated along the height of the hotel. In addition, relay nodes were deployed during the test while Team-1 was instructed to locate a non-functional inert bomb package on the 45th floor. The relay node locations are depicted in Figure 16.

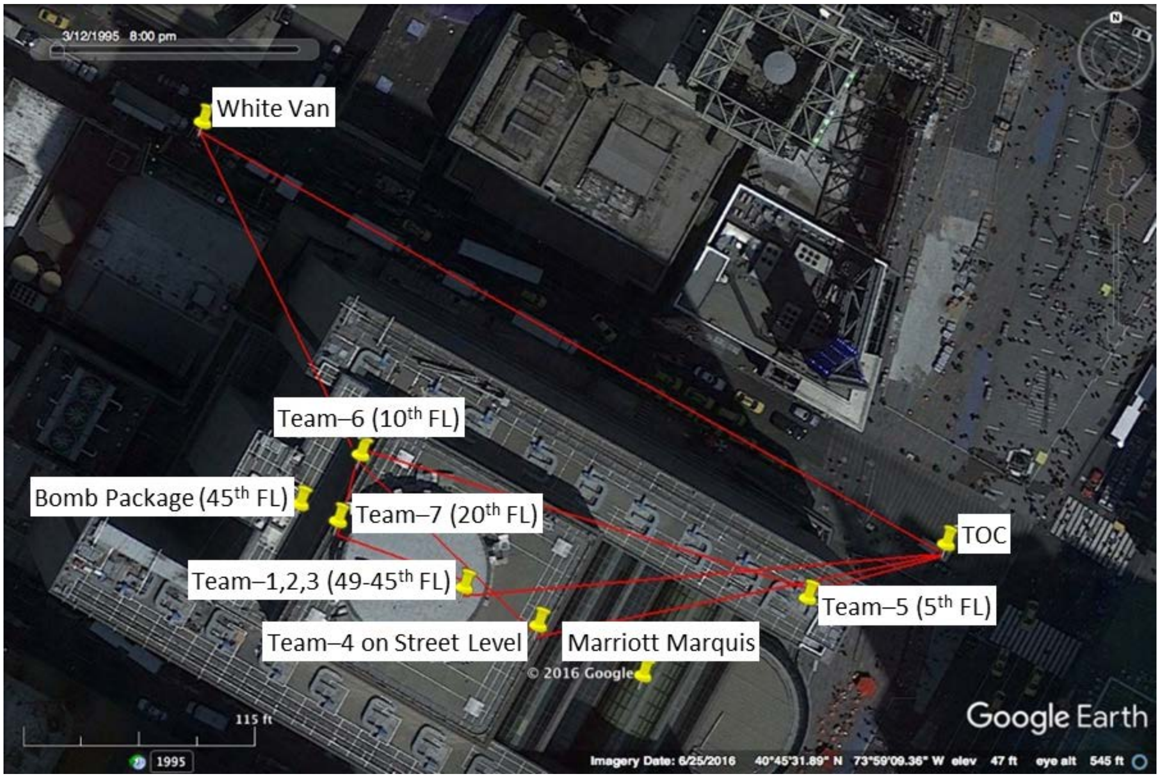
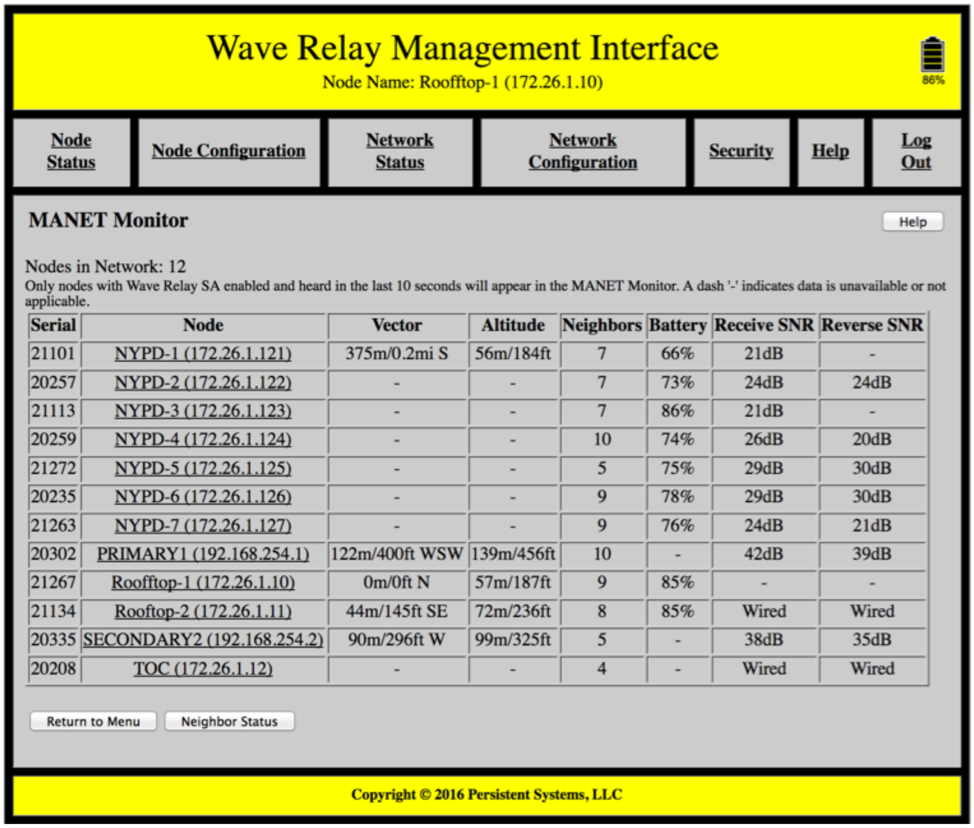


Figure 16: Marriott Marquis Test Node Locations



Wave Relay Management Interface

Node Name: Roofftop-1 (172.26.1.10)

86%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	375m/0.2mi S	56m/184ft	7	66%	21dB	-
20257	NYPD-2 (172.26.1.122)	-	-	7	73%	24dB	24dB
21113	NYPD-3 (172.26.1.123)	-	-	7	86%	21dB	-
20259	NYPD-4 (172.26.1.124)	-	-	10	74%	26dB	20dB
21272	NYPD-5 (172.26.1.125)	-	-	5	75%	29dB	30dB
20235	NYPD-6 (172.26.1.126)	-	-	9	78%	29dB	30dB
21263	NYPD-7 (172.26.1.127)	-	-	9	76%	24dB	21dB
20302	PRIMARY1 (192.168.254.1)	122m/400ft WSW	139m/456ft	10	-	42dB	39dB
21267	Roofftop-1 (172.26.1.10)	0m/0ft N	57m/187ft	9	85%	-	-
21134	Rooftop-2 (172.26.1.11)	44m/145ft SE	72m/236ft	8	85%	Wired	Wired
20335	SECONDARY2 (192.168.254.2)	90m/296ft W	99m/325ft	5	-	38dB	35dB
20208	TOC (172.26.1.12)	-	-	4	-	Wired	Wired

Return to Menu | Neighbor Status

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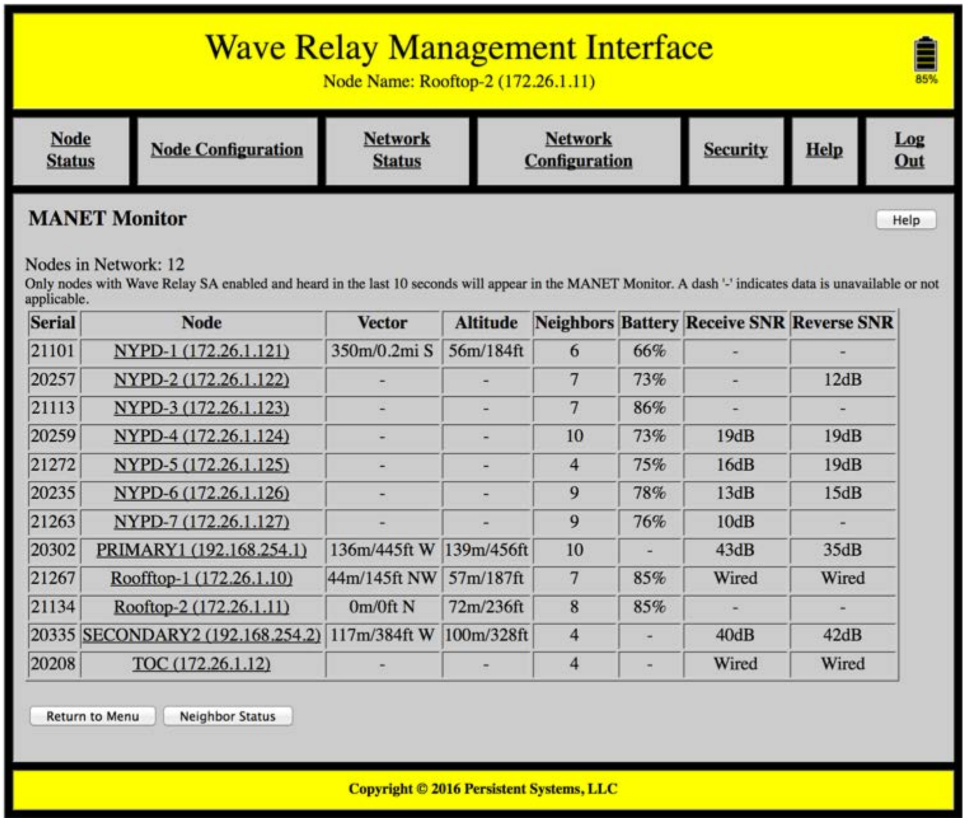
Figure 17: Rooftop-1 MANET Monitor View (End of Hotel Test – 1030)

According to Figure 17, Rooftop-1 had connection to all of the teams except could not sustain a connection at the end of the test in the transmit direction to Team-1 and 3. Rooftop-1's sector antenna was angled in such a manner to attempt to provide connectivity along the full height of the hotel, but there were some challenges with the antenna's ability to continuously sustain links with the nodes on the higher floors of the building.



Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	350m/0.2mi S	56m/184ft	6	66%	-	-
20257	NYPD-2 (172.26.1.122)	-	-	7	73%	-	12dB
21113	NYPD-3 (172.26.1.123)	-	-	7	86%	-	-
20259	NYPD-4 (172.26.1.124)	-	-	10	73%	19dB	19dB
21272	NYPD-5 (172.26.1.125)	-	-	4	75%	16dB	19dB
20235	NYPD-6 (172.26.1.126)	-	-	9	78%	13dB	15dB
21263	NYPD-7 (172.26.1.127)	-	-	9	76%	10dB	-
20302	PRIMARY1 (192.168.254.1)	136m/445ft W	139m/456ft	10	-	43dB	35dB
21267	Roofftop-1 (172.26.1.10)	44m/145ft NW	57m/187ft	7	85%	Wired	Wired
21134	Rooftop-2 (172.26.1.11)	0m/0ft N	72m/236ft	8	85%	-	-
20335	SECONDARY2 (192.168.254.2)	117m/384ft W	100m/328ft	4	-	40dB	42dB
20208	TOC (172.26.1.12)	-	-	4	-	Wired	Wired

Figure 18: Rooftop-2 MANET Monitor View (End of Hotel Test - 1030)

According to Figure 18, Rooftop-2 with its 3 x 3dBi omni antennas only connected to Team-4 (located at the hotel ground floor lobby), Team-5 (located at stairwell-D on 5th floor), and CTU van. These three nodes were the closest nodes to TOC. This indicates that the hotel operations relied on the high gain MIMO sector antenna (12 dBi) connected to Rooftop-1 to sustain sufficient connectivity to provide voice and real-time video streaming from Team-1 back to the TOC

Wave Relay Management Interface

Node Name: NYPD-1 (172.26.1.121)

67%

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

MANET Monitor

Help

Nodes in Network: 12

Only nodes with Wave Relay SA enabled and heard in the last 10 seconds will appear in the MANET Monitor. A dash '-' indicates data is unavailable or not applicable.

Serial	Node	Vector	Altitude	Neighbors	Battery	Receive SNR	Reverse SNR
21101	NYPD-1 (172.26.1.121)	0m/0ft N	56m/184ft	6	66%	-	-
20257	NYPD-2 (172.26.1.122)	-	-	7	73%	69dB	64dB
21113	NYPD-3 (172.26.1.123)	-	-	7	86%	65dB	72dB
20259	NYPD-4 (172.26.1.124)	-	-	9	73%	14dB	13dB
21272	NYPD-5 (172.26.1.125)	-	-	4	75%	-	-
20235	NYPD-6 (172.26.1.126)	-	-	9	78%	23dB	24dB
21263	NYPD-7 (172.26.1.127)	-	-	9	76%	25dB	27dB
20302	PRIMARY1 (192.168.254.1)	366m/0.2mi NNW	140m/459ft	10	-	-	-
21267	Roofftop-1 (172.26.1.10)	375m/0.2mi N	56m/184ft	9	85%	-	20dB
21134	Rooftop-2 (172.26.1.11)	349m/0.2mi N	73m/240ft	9	85%	-	-
20335	SECONDARY2 (192.168.254.2)	377m/0.2mi NNW	100m/328ft	4	-	-	-
20208	TOC (172.26.1.12)	-	-	4	-	-	-

Return to Menu | Neighbor Status

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Figure 19: NYPD-1 MANET Monitor View (End of Hotel Test- 1030)

According to Figure 19, Team-1 had good connections to Team-2, 3, 6, and 7 (the nodes located closest to Team-1) but poor connections to Team-4, 5, and CTU van. This suggests that Team-1 was connected via a single relay to the TOC (at Rooftop-1) through either Team-2 (45/49th floor), Team-6 (10th floor) and Team-7 (20th floor). Also, it is noteworthy that Team-1 was not connected to the MPU5s in the CTU van which was located at the farther end of the hotel on 46th St. and 8th Avenue.

At the conclusion of the test, Team-1 found the simulated bomb package on the 45th floor near the vending machines and the TOC was able to see the operation via live video stream (Figure 20).

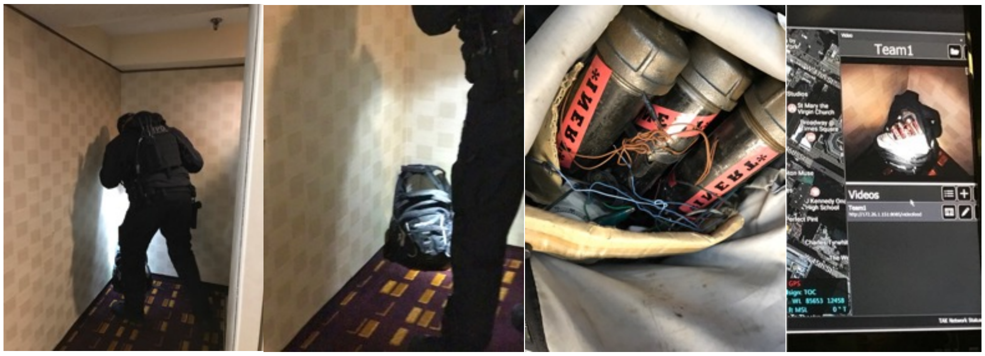


Figure 20: Locating the Simulated Bomb Package

5 Overall Key Findings

5.1 General

1. The overall test was viewed a success as the test objectives were achieved and valuable insight was gained regarding the deployment and utility of the MANET system within a local law enforcement operational environment. In addition, the NYPD ESU participants reported the test proved valuable for their purposes of better understanding their communications-based needs and options for solutions.

5.2 Operational

1. The capability to view a video stream at the TOC minimized voice traffic; the TOC did not have to constantly request location updates, hence improving the TOC's situational awareness.

2. The capability to view a video stream enhanced voice communications and provided clarity of the situation.

3. The Radio Over Internet Protocol (RoIP) capability on the MPU5 radios provided interoperability with the existing LMRs.

4. Overall MPU5 radios performed well in all three locations: 1) 42nd St. Subway Station, 2) Side-street on 42nd St., and 3) Marriott Marquis Hotel.

5. The MPU5 radios performed well inside the subway station and the Marriott Marquis Hotel where the LMR signals can be sparse or unavailable.

6. The geolocation capability inside subway stations and buildings was viewed to be valuable as it helped to prevent any friendly (blue-on-blue) incidents.

5.3 Technical

1. By better positioning and configuring the MIMO sector antenna, the communication distance performance was improved from what was experienced during the dry-run.

2. A communications link of 1100 feet (4 blocks from TOC to 42nd St. Subway Station entrance) was achieved using with a 12 dBi gain MIMO sector antenna on the roof of the mobile TOC bus **(Figure 3).**

3. For the side-street test on 42nd St., Team-1 and Team-2 could reach 8th Ave. and 6th Ave., respectively with the CTU van with 3.15dBi gain omni-directional antennas as a relay node (**Figure 12).**

4. The use of the Internet Protocol (IP) WebCam application on Team-1's EUD as a source for live video streaming was convenient and helpful for personnel who did not have a camera, however, it did not provide the multicasting capability that uses less bandwidth. See Appendix B: System Configurations for IP WebCam configuration.

5. At times, specifically during the subway test, the video quality viewed at the Mobile TOC was variable. However, Team-2 reported good video quality for the duration of the subway and side street tests.

6. For the Marriot Marquis test, the number of unicast video streams on the MANET network was reduced from eight to one by closing the ATAK video player on each team's EUD. This resulted in good quality video at the Mobile TOC with no choppiness.

7. With the new MPU5 firmware, high interferences at the TOC's rooftop-1 MPU5 and Team-1's MPU5 were observed. This observation contradicts the spectrum scan plot taken before the test began (Figure 21) in which no interference signal was detected near the operational frequency, 2227MHz. Further investigation may be necessary.

8. For elevated buildings, such as Marriott Marquis, the MIMO sector antenna had to be rotated 90 degrees to increase the coverage to 120 degree wide.

9. Additionally, two metrics related to stress-testing the network deserves further study. One of the metric is identifying how many simultaneous video streams could be carried by the mesh network before congestion and signal degradation begins to affect video quality. A second metric was finding out how many intermediary nodes between TOC node and NYPD-1 node can the mesh network support - we observed anecdotally that this number was between three and four – before video quality began to degrade. These two metrics were not conclusively tested and deserve further investigation.

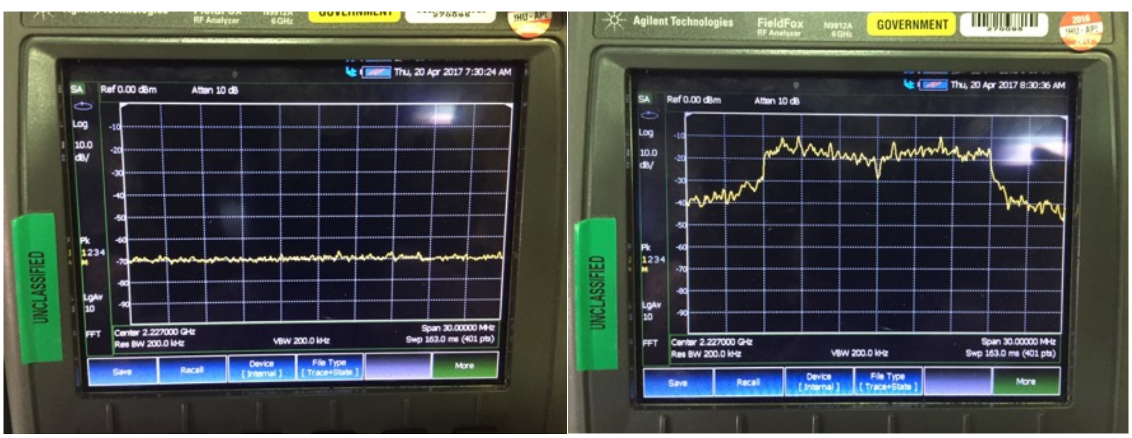


Figure 21: Spectrum Scan before and after MPU5 radios were turned on

6 End User Feedback

The JHU/APL test team had the opportunity to interact with the NYPD ESU participants during the pre-event training and orientation, the field test, and during the hot wash at the Marriott Marquis Hotel. The JHU/APL team documented end-users' feedback and developed additional end-user requirements to include a set of lessons learned, which are summarized below.

- **Officers didn't want to look down at the ATAK system** – During a tactical search, police officers are required to maintain complete situational awareness. While having access to the video stream provided by Team 1 was determined to be valuable, the use of the live video during the search proved to be non-compatible with officer safety protocols (i.e., positioning of the EUD and the camera on their personnel was not optimal for officer safety purposes as the officers wearing the units had to look down to view the monitor).

- **Builds situational awareness, "big time"** – NYPD ESU officers explained that having access to live video streams from the team lead and having blue force tracking "when outdoors" was extremely beneficial and reduced the concern for "blue on blue" incidents.

- **Video kept the incident commander informed "Leadership wasn't in need of continuous updates"**– The legacy LMR system is voice only. In a tactical search, the ESU Commander is required to know the locations of the deployed ESU teams. The live video stream provided by Team 1 during their search provided the TOC with visual cues of their location throughout the search. When GPS was lost in the building, the video image of the floor signs kept the incident commander informed.

- **The use of streaming live video kept the radio (voice) traffic to a minimum** – The EDU/ATAK system provided the same video feed view from team 1 that was provided to the TOC. Radio (voice) traffic was reduced. The video data was also integral in the decision making of the TOC. Without the video data from Team 1, the TOC Commander would have been required to be on-scene to make a decision regarding the de-activation and subsequent disposal of the suspicious device.

- **Video quality improved when all ATAKS were shut down except for Team 1** – The use of multiple video monitoring systems on the ATAK device degraded overall video quality.

- **Video of the suspicious bag's content was visually clear –** Video stream from Team 1 was well-defined allowing the Commander to make decisions without being near the device.

- **Placement of ATAK was in the way of ammunition magazines** – Current position of the ATAK placement is on the front of the tactical vest where the ammunition magazines would normally be attached. This would be problematic during a real-world situation as it reduced the spaces available for rapid access to spare

ammunition. Further testing, to include human systems integration, would be helpful to determine an optimal location for performance and safety.

- **Operators need to be able to attach the ATAK carrier on the vest and leave it** – ESU personnel do not have the time to attach the Samsung Note3 when needed. Further investigation may help to determine if it could be pre-wired similar to a Tazor pre-wire set.

- **Weight of the radio was not an issue**.

- **Current carrier for the Samsung Note3 can be used for the NYPD direct-attached storage (DAS) phone**.

- **System needs a tone that alerts you not to "step" on a person already talking.**

- **Current wiring of the radio system is a problem**. Personnel determined that there were "too many snag points" and suggested that the system should be "pre-wired" into the harness without the radio.

- **Positioning of the radio on the back of the operator does not allow for viewing of the status light** – The ESU personnel need to know when the MPU-5 radio was at the edge of its coverage. A color-coded light is mounted on the top of the radio for this purpose. However, because the radio was mounted on the back of the officer, it precluded them from seeing the light and therefore knowing their coverage limits.

- **End-users reported difficulty in powering the radios on and off and icons were too small.** End-users asked if the controls could be reconfigured and housed in the ATAK software. Further consultation is required with technical and human systems integration experts.

- **ATAK, as currently configured, has more capabilities (i.e. icons and apps) than what is currently needed.** The ATAK was originally developed for military use, therefore the software capabilities were more than the NYPD needed.

- **If ESU would lose their LMR system, this system could be very helpful** – However, current ATAK does not support critical tactical requirement of what is known - "what's around the corner."

- **Consider attaching the "Scout" robot video camera to the ATAK system and the MPU5** – The Scout Robot is a tactical unit that can be placed in front of search teams. The video system on the Scout, when connected to the ATAK system and shared by the MPU-5 radio, could provide the "look around the corner" capability.

- **It is not realistic, nor an option, to use police resources to carry the MPU5** - The MANET system requires several radios to make up the "mesh." To reach the higher floors in the Marriott Marquis, the ESU team was required to establish several "relay points." In doing so, personnel resources were lost. ESU leadership suggested that drop boxes (i.e., pelican cases with the radios) could be secured as relay points thus avoiding the use of additional human resources.

- **Command view needs "logical view" to compliment the GPS view** – When GPS is lost upon entering a building, supplemental positioning information can be supplied by using a logical view of positioning data. GPS needs to be encrypted and non-invasive.

7 Summary

The NYPD ESU MANET System field test conducted on April 20, 2017, used operationally-relevant scenarios and took place at two venues in New York's Times Square: the Marriott Marquis Times Square and the Times Square subway station. During test execution, JHU/APL with support from Persistent Systems, monitored MANET system performance from both an operational and technical perspective using qualitative and quantitative means.

Extensive on-campus testing (at JHU/APL) was conducted prior to field test to determine technical thresholds, which were then used as guidance to determine when links between inter-communicating MPU5s would terminate. This pre-event testing was critical to determine the deployment of relay nodes prior to test implementation. The metric used as the technical threshold was each link's SNR. In addition, a dry run (pre-event engineering test) was conducted in March 2017, during which time relay locations for the MPU5 radios were determined to ensure that the TOC could receive uninterrupted voice and real-time streaming video.

Collaborative planning with the NYPD ESU for this event was critical to its success. The scenario provided sufficient realistic opportunities to assess the system's utility and integration with their existing LMRs. The field test also provided opportunities for the participants to identify gaps and needed enhancements. The field test was viewed as an overall success as it achieved the following objectives:

- Basic *requirements* were elicited as it relates to the ability to maintain SA via a scalable peer-to-peer wireless network that integrates data, voice, and video in real-time operational settings
- The *deployment* and utility of the MANET system within the NYPD ESU operational environment was tested and evaluated
- An *operational evaluation and recommendations* report was completed
- A scenario relevant to the NYPD ESU mission was used for the field test.

In summary, feedback from the first responders was largely positive with stated appreciation of the software tool's ability to provide live video streaming and live location updates for personnel. The tool augmented voice communications since the team could see response team locations on a map, as well as a live video stream from the team lead. Participants also readily provided input regarding needed improvements and modifications to allow the equipment to meet their specific mission-based needs.

"Having the ability at the mobile command vehicle to view a live video feed improves our situational awareness because the video can augment our voice communications." said Detective John McKenna of NYPD ESU. These types of field tests also allow responders to provide input into improvements and modifications to allow the equipment to meet specific mission-based needs. For example, since the MANET system requires several radios to comprise a "mesh" network with multiple radios serving as relay nodes, and it is not feasible for NYPD personnel to carry radios

for the sole purpose of serving as relay nodes, participants suggested a possibility of using drop boxes (i.e., pelican cases with radios pre-loaded) as the relay points. It was also noted that the current version of the MPU5 smart radio worked well with the use of a high gain MIMO sector antenna (12 dBi) connected to the top of the TOC – this enhanced their ability to sustain sufficient connectivity for voice and real-time video streaming.

8 Reference

1. DHS MANET Fact Sheet. https://www.dhs.gov/publication/manet-fact-sheet

2. Persistent Systems MPU5: the world's first smart radio. http://www.persistentsystems.com/mpu5/

3. Communications Deployment Experiment for the Mobile Ad Hoc Networking (MANET) System Operational Field Test Plan, 4 April 2017.

Appendix A: Summary of the Test and Evaluation Plan

For the complete Test and Evaluation plan, please contact Ruth Vogel at JHU/APL.

Primary Objective

The primary objective of the test is to determine the MPU5's communication range capabilities for supporting voice, video, geographic location, and chat capabilities in a complex urban environment. These capabilities will be affected by environmental and operational constraints e.g., indoor/outdoor communications involving signal penetration through various building construction materials. For these deployments, the effectiveness is measured by the ability to perform the following communications given a certain range, number of participants, and connectivity rate:

1. The ability for an operator to achieve team wide voice communications by using the push to talk microphone.
2. The ability for the MPU5 to encode a composite video signal into one or more multicast video streams.
3. The ability for an operator to observe the geographic locations of peers on the end user device.

NYPD's interest in the MANET system focuses on the system's ability to support voice, video, and data traffic along with its integration with ATAK to provide situational awareness. Furthermore, NYPD requires communications and information sharing capabilities for penetrating buildings, underground areas, and other mission-relevant indoor-outdoor communications link permutations. Figure 22 depicts MANET based communications where each officer with an MPU5 radio serves as a relay node and provides voice and data/video stream via ATAK. Depending on the number of radios used, the MANET system should support communications (voice/data/video) inside a building and underground subway station.

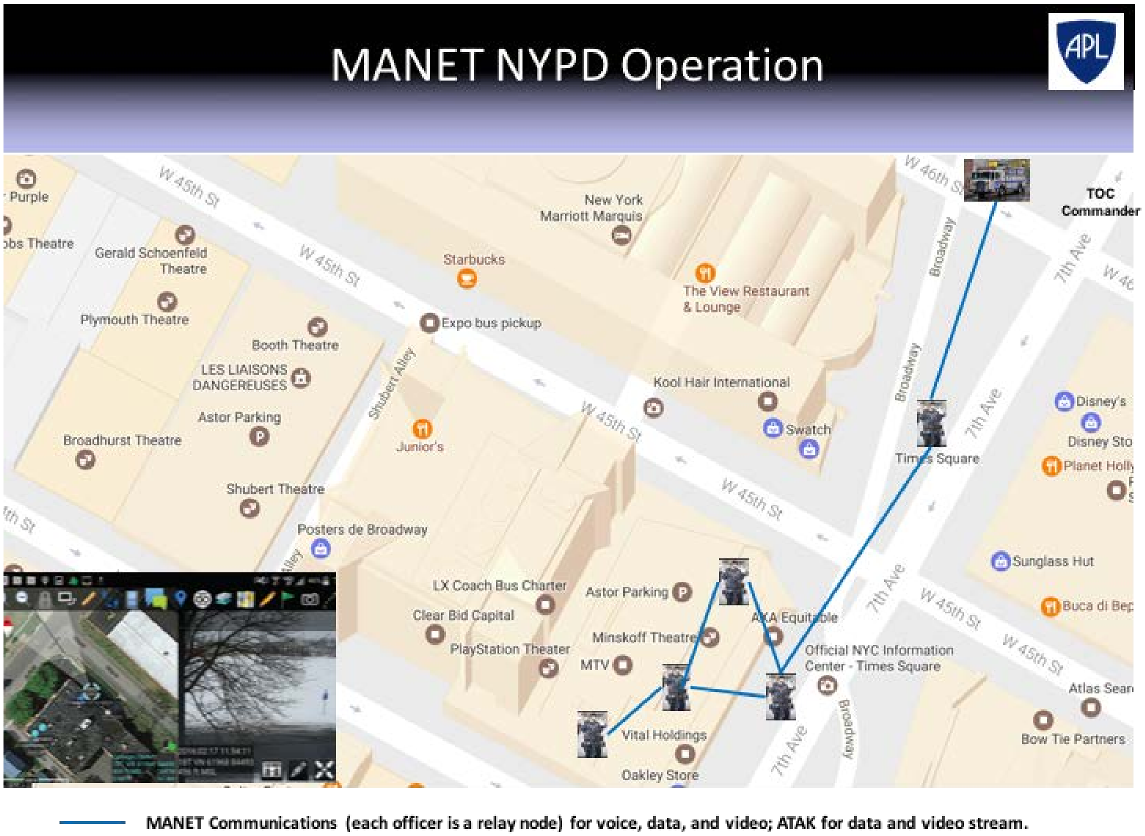


Figure 22: MANET Operational View - Example

For the detailed test procedures, refer to the Communications Deployment Experiment for the Mobile Ad Hoc Networking (MANET) System Operational Field Test Plan, 4 April 2017 [3] in the reference section.

Reporting of Results

JHU/APL will provide a preliminary operational field test report within 45 days after the completion of each deployment event. Additionally, a comprehensive final report summarizing the deployments, data analysis, and lessons learned/findings from all events will be provided within 90 days after the completion of the final deployment event.

Appendix B: System Configurations

ATAK Configuration

Version: ATAK-civ-3.4.27804

Setting name	Value	Notes
My Preferences-> My Callsign	WaveRelay Name	Callsigns can be changed at any time during the exercise
My Preferences-> Use Wave Relay Callsign	False	Has no effect
My Preferences-> Use GPS Time	True	Required for time synchronization
My Preferences-> Send Location Over Network	True	This is ATAK's Cursor on Target message
My Preferences-> Report Location before Obtaining location fix	False	
Control Preferences-> Remove all marker type from map when they stale out	True	
Control Preferences-> Stale item cleanup time	1 minute	

The following two video streams are available in the ATAK Video Player

1. NYPD-1 (http://172.26.1.151:8085/videofeed)
2. Camera 2 (udp://239.23.212.200:9722)

IP Webcam Configuration

Version: IP Webcam v1.12.5r

Setting name	Value	Notes
Video Preferences-> Video Resolution	640x480	The default resolution of 1920x1080 exceeds the processing capabilities on the EUD
Video Preferences-> Quality	50	This is the default value for video quality
Video Preferences-> FPS Limit	30	This is the default value for frames per second
Local Broadcasting-> Login/password	Leave blank	In a security controls sense, access controls are inherited from the MPU5
Local Broadcasting-> Port	8085	The default port number 8080 collides with an active ATAK port
Stream on device boot	On	Begin streaming video on boot

MPU5 Configuration

- Center frequency (MHz): 2227
- Bandwidth (MHz): 20
- Max. Distance (Mile): 1
- Channel Density: High (9+ nodes)
- Firmware version: upgrade-MPU5-19.1.0-dev.23
- TEAM-1 provides video streams using the IP WebCam app on his EUD (Samsung Note3).
- All teams equipped with an ATAK attached to their MPU5
- The TOC with a MIMO sector antenna (12 dBi gain)

MPU5 Serial Number	Node Name	IP Address	ATAK Call sign
21101	NYPD-1	172.26.1.121	TEAM-1
20257	NYPD-2	172.26.1.122	TEAM-2
21113	NYPD-3	172.26.1.123	TEAM-3
20259	NYPD-4	172.26.1.124	TEAM-4
21272	NYPD-5	172.26.1.125	TEAM-5
20235	NYPD-6	172.26.1.126	TEAM-6
21263	NYPD-7	172.26.1.127	TEAM-7
20314	NYPD-8 (backup)	172.26.1.128	TEAM-8 (backup)
20244	NYPD-9 (K-9)	172.26.1.129	TEAM-9 (K-9)
21267	Rooftop-1	172.26.1.10	N/A
21134	Rooftop-2	172.26.1.11	N/A (for RoIP)
20208	TOC	172.26.1.12	TOC

All MPU5 radios except for the TOC will be equipped with three omni directional antennas (three spring loaded antenna with 2.1 dBi gain). The TOC will have one MPU5 with a MIMO sector antenna (12 dBi) connected. The sector antenna will be mounted on the roof of the TOC vehicle using a special stand. Another MPU5 on the rooftop will be tethered to a Motorola APX7000 LMR radio for interoperability testing. The third MPU5 will be located inside the TOC vehicle. All three TOC MPU5 radios will be connected to an Ethernet switch in addition to two laptop computers (Figure 3)

Table 4 provides the configurations of the MPU5 radios during the April 20th Test. Note that the TOC radio (located inside the vehicle) was set to 45 mW per chain, the lowest transmit power setting, to ensure communications between the TOC and the rest of the MPU5 network would take place via Rooftop-1 or Rooftop-2 (the two outdoor TOC MPU5 nodes). The TOC radio's only connection to the MPU5 network would be via Ethernet (switch) to Rooftop-1 and Rooftop-2

Table 4: NYPD Test MPU5 Configurations

Radio Name/ Team Name	Transmit Power per Chain	Antenna Gain per Antenna	Antenna Model #	Antenna Type
TOC	45mW per ch.	2.15 dBi	ANT-2005	Omnidirectional
Rooftop-1	2W per ch.	12 dBi	ANT-2014	MIMO Sector
Rooftop-2	2W per ch.	3 dBi	ANT-2006	Omnidirectional
NYPD-1/Team-1	2W per ch.	2.15 dBi	ANT-2003	Omnidirectional
NYPD-2/Team-2	2W per ch.	2.15 dBi	ANT-2003	Omnidirectional
NYPD-3/Team-3	2W per ch.	2.15 dBi	ANT-2003	Omnidirectional
NYPD-4/Team-4	2W per ch.	2.15 dBi	ANT-2003	Omnidirectional
NYPD-5/Team-5	2W per ch.	2.15 dBi	ANT-2003	Omnidirectional
NYPD-6/Team-6	2W per ch.	2.15 dBi	ANT-2003	Omnidirectional
NYPD-7/Team-7	2W per ch.	2.15 dBi	ANT-2003	Omnidirectional
PRIMARY1 (CTU Van)	2W per ch.	3.5 dBi	ANT-2007	Omnidirectional
SECONDARY2 (CTU Van)	2W per ch.	3.5 dBi	ANT-2007	Omnidirectional

Communications Check Discussion and Observation

The pre-test communications check consisted of several steps that were required to properly set up and configure the MANET system. One of the steps involved performing a Throughput (or Bandwidth) test from the Rooftop-1 node (TOC node on top of the vehicle connected to the MIMO sector antenna) to NYPD-1, the team that would be providing the streaming video back to the TOC from the EUD and would be the node traveling the farthest extent during each test. The Throughput Test was executed to establish a performance baseline prior to test execution while all the nodes were located at the TOC. It should be noted that during the pre-test communications check, Rooftop-1's MIMO sector antenna was pointed down (south) 7th Avenue toward the 42nd St. Subway Station and the NYPD-1 MPU5 with its three 2.15 dBi omnidirectional antennas was located on the sidewalk near the TOC.

During the pre-test Throughput Test step, the JHU/APL team observed that the Upload and Download throughputs were approximately in the 2Mbps range. This was much lower than was observed in past laboratory testing (often in the 75-80 Mbps range when nodes were in the same room and 5-10m apart from each other), so the JHU/APL team requested the assistance of the Persistent Systems technical team for further examination of this unexpected result. The Persistent Systems team examined some additional views on the Web Management Interface and noticed that on the Neighbor Status view, Rooftop-1 was reporting "High" Interference on its RF Status table.

This "High" Interference report was unexpected to the test team as DHS S&T was able to obtain a Frequency Special Temporary Authority (STA) for MANET system operation at 2.227 GHz for the March 2017 Dry Run and the April 2017 Test Exercise. Furthermore, in order to obtain a sense of the state of the frequency band during Test Day on 20 April, the JHU/APL team captured Spectrum Analyzer scans at 2.227 GHz at the TOC location during the pre-test communications check. Scans were captured prior to the systems being turned on at 0730 (Figure 23) and then at 0830 (Figure 24), when the systems were turned on to confirm that the systems were operating as expected. The Max Hold setting was applied for these scans to ensure the spectrum analyzer would capture any significant RF activity (even if momentary) at 2.227 GHz.

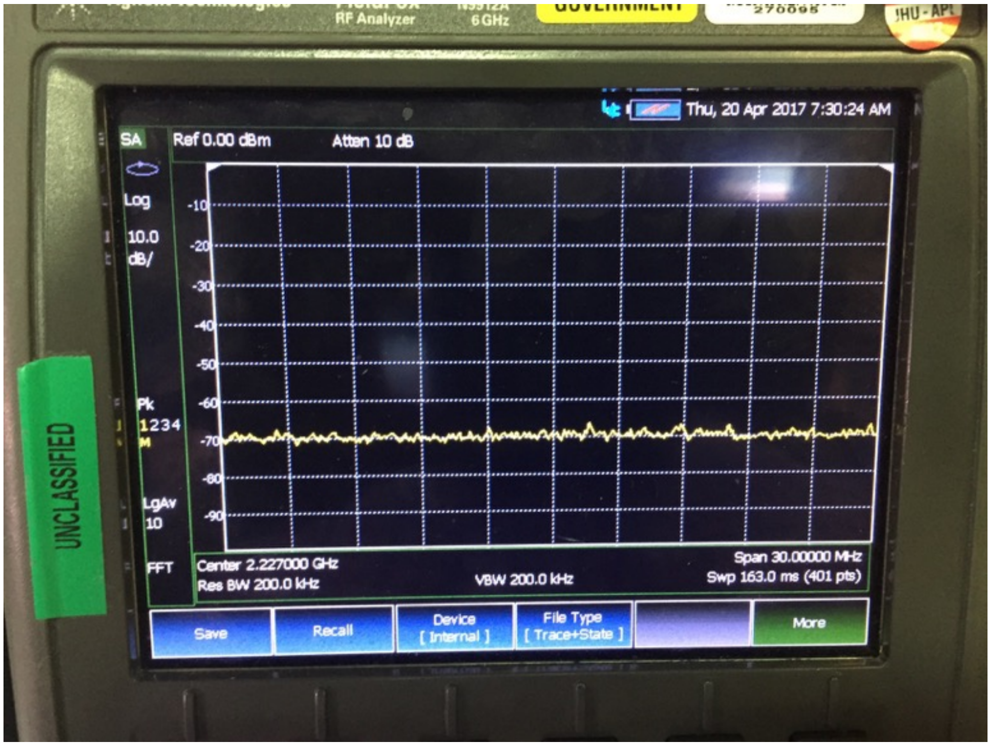


Figure 23: Spectrum Analyzer Scan prior to MANET systems being turned on during Pre-Test Communications Check

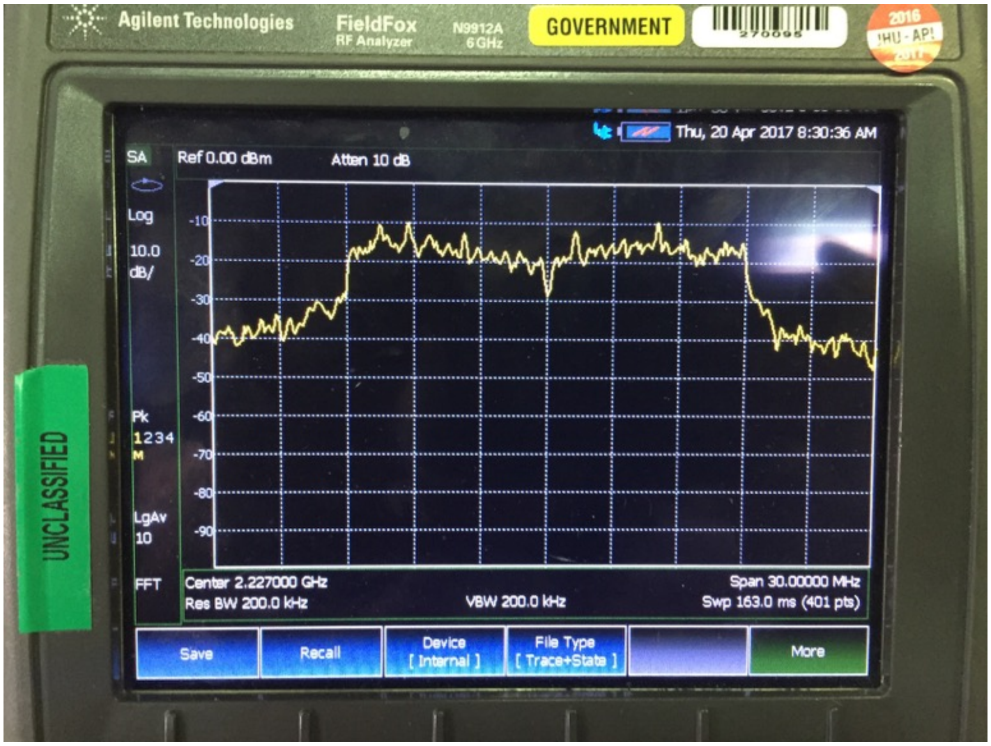


Figure 24: Spectrum Analyzer Scan once MANET systems Powered On during Pre-Test Communications Check

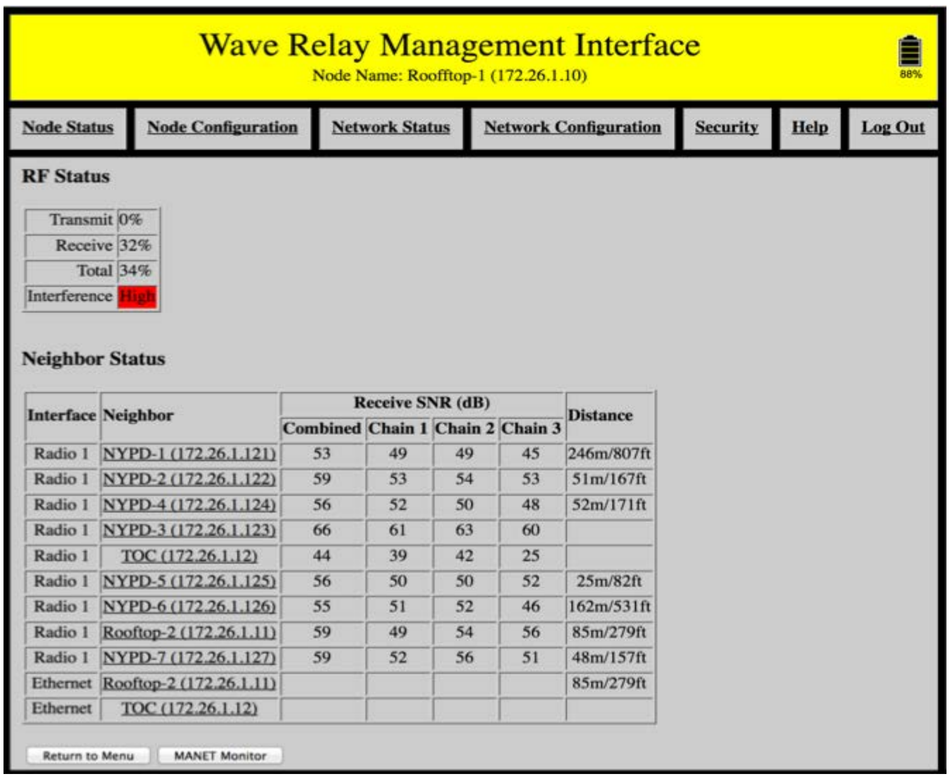
As can been seen in Figure 23, there was no significant observable RF activity at 2.227 GHz prior to the MANET systems being turned on during the Pre-Test Communications Check. Once the systems were turned on, the RF activity level significantly changed at 2.227 GHz as can be seen in Figure 24.

This unexpected "High" Interference report from the MPU5s at Pre-Test Communications Check was noted. At this time, the real-time streaming video from NYPD-1 was reaching the TOC and WinTAK laptops, so the test team decided to proceed with the first test, the Subway Test, to adhere to the test schedule.

Once the Subway Test was complete and all seven teams were back at the TOC, the JHU/APL team was able to capture screenshots of the Neighbor Status view of the most relevant nodes to collect their Interference reports: Rooftop-1, Rooftop-2, and NYPD-1. Table 5 presents the location, antenna characteristics, and interference level reports of these three nodes. These are important features of the test setup for the nodes that would influence what type of RF activity they would sense at their antennas. Figures 25-Figure 27 present the RF Status reports for the three nodes in between tests.

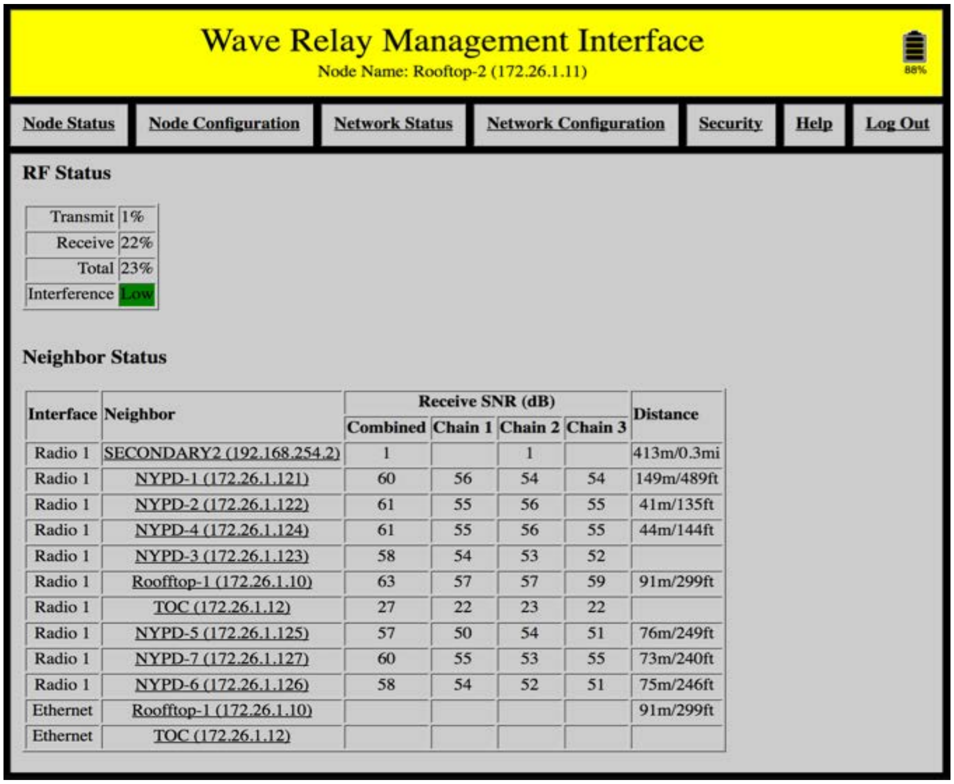
Table 5: Rooftop-1, Rooftop-2, NYPD-1 Setup and Configuration

MPU5	Location	Antenna Characteristics	Interference Level Reported
Rooftop-1	TOC Rooftop	12 dBi 3x3 MIMO sector antenna	High
Rooftop-2	TOC Rooftop	3 x 3 dBi omnidirectional Antennas	Low
NYPD-1	Sidewalk near TOC	3 x 2.15 dBi omnidirectional antennas	High



Interface	Neighbor	Receive SNR (dB)				Distance
		Combined	Chain 1	Chain 2	Chain 3	
Radio 1	NYPD-1 (172.26.1.121)	53	49	49	45	246m/807ft
Radio 1	NYPD-2 (172.26.1.122)	59	53	54	53	51m/167ft
Radio 1	NYPD-4 (172.26.1.124)	56	52	50	48	52m/171ft
Radio 1	NYPD-3 (172.26.1.123)	66	61	63	60	
Radio 1	TOC (172.26.1.12)	44	39	42	25	
Radio 1	NYPD-5 (172.26.1.125)	56	50	50	52	25m/82ft
Radio 1	NYPD-6 (172.26.1.126)	55	51	52	46	162m/531ft
Radio 1	Rooftop-2 (172.26.1.11)	59	49	54	56	85m/279ft
Radio 1	NYPD-7 (172.26.1.127)	59	52	56	51	48m/157ft
Ethernet	Rooftop-2 (172.26.1.11)					85m/279ft
Ethernet	TOC (172.26.1.12)					

Figure 25: Rooftop-1 Neighbor Status between Subway/Side Street and Hotel Tests (1006)



Wave Relay Management Interface
Node Name: Rooftop-2 (172.26.1.11)

Node Status | Node Configuration | Network Status | Network Configuration | Security | Help | Log Out

RF Status

Transmit	1%
Receive	22%
Total	23%
Interference	Low

Neighbor Status

Interface	Neighbor	Receive SNR (dB)				Distance
		Combined	Chain 1	Chain 2	Chain 3	
Radio 1	SECONDARY2 (192.168.254.2)	1		1		413m/0.3mi
Radio 1	NYPD-1 (172.26.1.121)	60	56	54	54	149m/489ft
Radio 1	NYPD-2 (172.26.1.122)	61	55	56	55	41m/135ft
Radio 1	NYPD-4 (172.26.1.124)	61	55	56	55	44m/144ft
Radio 1	NYPD-3 (172.26.1.123)	58	54	53	52	
Radio 1	Roofftop-1 (172.26.1.10)	63	57	57	59	91m/299ft
Radio 1	TOC (172.26.1.12)	27	22	23	22	
Radio 1	NYPD-5 (172.26.1.125)	57	50	54	51	76m/249ft
Radio 1	NYPD-7 (172.26.1.127)	60	55	53	55	73m/240ft
Radio 1	NYPD-6 (172.26.1.126)	58	54	52	51	75m/246ft
Ethernet	Roofftop-1 (172.26.1.10)					91m/299ft
Ethernet	TOC (172.26.1.12)					

Figure 26: Rooftop-2 Neighbor Status View in between Subway/Side Street and Hotel (1007)

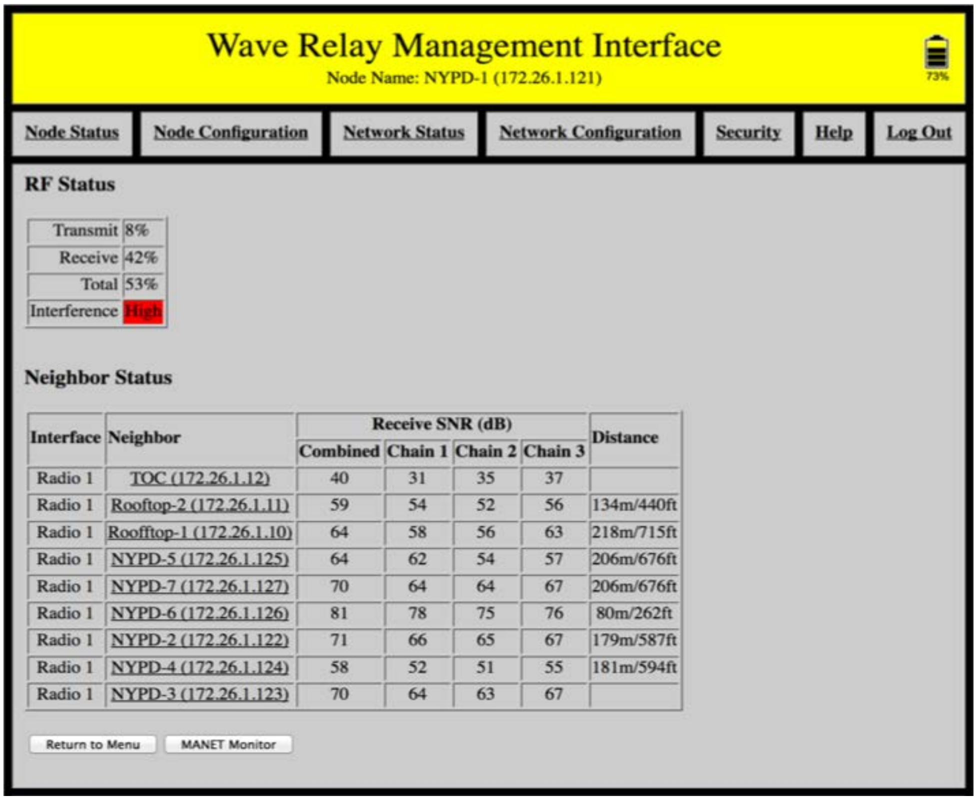


Figure 27: NYPD-1 Neighbor Status View between Subway/Side Street and Hotel tests (1007)

According to these RF Status/Interference reports, between the two tests, Rooftop-1 and NYPD-1 were experiencing "High" Interference, while Rooftop-2 was experiencing "Low" Interference. The differences in these reports (between Rooftop-1/NYPD-1 and Rooftop-2) were noteworthy. Rooftop-1 and Rooftop-2 were located right next to each other on the TOC rooftop, but had different types of antennas from each other as noted in Table 5 and experienced different levels of Interference as reported by the Neighbor Status view. Rooftop-2 and NYPD 1, while deployed at different heights (on TOC rooftop vs. on the ground respectively) had similar antennas (omnidirectional), but reported different levels of Interference as reported by the Neighbor Status view.

After the test day, JHU/APL had an opportunity to follow up with Persistent Systems on some further technical details related to the RF Status table on the Neighbor Status view. Specifically, JHU/APL inquired about how "Low" and "High" Interference values are established by the system and what do the "Transmit," "Receive", and "Total" percentages mean. Persistent Systems provided the following information regarding the RF Status Table:

The way we detect interference and deal with it is through a number of detection methods. The two most influential detection and avoidance methods we use are (1) detection of RF energy, and (2) detection of RF that's coded/carrier sense transmitted packets. When I say RF energy, I mean a system that's transmitting and we cannot establish a data link layer relationship with. That will be categorized as energy/interference. Within the Wave Relay algorithm and radio's hardware we set a threshold for the detection of this energy. Basically, if the energy is above this level, it will trigger a level of interference that you can read in the GUI. The higher the level of energy the more severely we will be impacted. If the packets are coded as in we can establish a layer 2 connection with the wireless device, i.e. WIFI, then we can use a proprietary method to detect, avoid and or work in conjunction with these systems. There is also a separate detection level for coded packets. You will see this cause the RX duty cycle to increase because the Wave Relay radio has established in a layer 2 protocol with the interfering or possibly interfering device. This will also impact the interference level as well. The more carrier sensing devices "WIFI" that we receive above this threshold we set the higher the duty cycle.

The Receive percentages for Rooftop-1, Rooftop-2, and NYPD-1, according to the test screenshots, were 32 percent, 22 percent, and 42 percent respectively. Based on the information provided by Persistent Systems regarding how interference is handled, this indicates that RF energy was being detected in this band and was resulting in the systems establishing a Layer 2 (Data Link Layer) relationship with the potentially interfering devices.

The key observations and notes regarding the Interference reports are:

- Rooftop-1 to NYPD-1 Throughput Test measured bandwidth was much lower than expected (~2Mbps) during Pre-Test Communications Check. This prompted the Persistent Systems technical team to check Neighbor Status of nodes.
- Spectrum Analyzer scans prior to the test resulted in no significant observable RF energy at 2.227 GHz and distinct observable energy once the MPU5s were turned on during the Pre-Test phase
- DHS S&T obtained a Special Temporary Authority (STA) from the FCC to operate at 2.227 GHz for the test.
- Between tests, the Interference level reports of Rooftop-1 ("High"), Rooftop-2 ("Low"), and NYPD-1 ("High") were captured.
    - Rooftop-1 was similar to Rooftop-2 in its location (TOC Rooftop), but dissimilar in antennas used (sector antenna for Rooftop-1 vs. omnidirectional antenna for Rooftop-2)
    - NYPD-1 was similar to Rooftop-2 in its antenna types (3 x omnidirectional antennas), but dissimilar in their placement (sidewalk on back of ESU office for NYPD-1 vs. TOC Rooftop for Rooftop-2)
- According to technical information provided by Persistent Systems, Rooftop-1 and NYPD-1 were detecting high levels of unexpected RF energy, while Rooftop-2 was detecting low levels of unexpected RF energy.

JHU/APL's overall conclusion is that there remained a degree of uncertainty of the cause of the low throughput measured between Rooftop-1 and NYPD-1 during the pre-test communications check as well as the interference reported by the MPU5 systems (especially Rooftop-1 and NYPD-1). This would merit further technical investigation to reach a more conclusive set of answers should additional resources be available.

Appendix C: NYPD Test and Evaluation Agenda

MANET Field Operations Test – NYPD 17 – 20 April 2017

Monday – 17th ½ Day (APL Tech Team and NYPD Radio Engineers if Available)

0800: Depart BWI by Amtrak

1200: Arrive NYPD training center at 20th St. and 2nd Ave.

1300: Lunch

1400: Equipment set-up and Comms testing with Persistent Systems and NYPD Radio Technicians

1700: Wrap up

1730: Depart for hotel

Tuesday – 18th Full Day (APL Tech Team, NYPD Participants and Radio Engineers)

0800: Meet NYPD at training center at 20th St. and 2nd Ave.

0830: Set up Equipment for NYPD, Comms check, scan spectrum and quick overview of test procedures

1000: Equipment training for new NYPD participants (persons from Dry Run not available)

1300: Lunch

1400: Table Top/walk-thru scenarios and testing sequence with NYPD participants

1700: Depart for hotel

Wednesday – 19th Full Day (APL Tech Team, NYPD Participants and DHS Leadership)

0800: APL arrives NYPD training center at 20th St. and 2nd Ave. and begin final set-up and testing

0900: Comms check, scan spectrum and overview of test procedures, set up equipment with NPYD gear

1200: Lunch

1300: DHS Leadership arrives, Introductions, Lunch

1400: DHS and NYPD Briefings and Discussion

1600: Wrap up

1700: Depart for Hotel

Thursday – 20th Full Day (APL Tech Team, NYPD Participants and DHS Leadership)

0700: Tech Team and NYPD Set-up

0900: Leadership Arrives

1000: Field Test - Minskoff

1130: Tech Demo - Subway

1230: Lunch

1330: Field Test – Marriott Conduct hot-wash

1600: Hot Wash

1800: Depart NYC

Appendix D: Summary of goTenna Field Test with NYPD

BACKGROUND

The Johns Hopkins University Applied Physics Laboratory (JHU/APL) was asked by the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Next Generation First Responder Program (NGFR) to assess the "goTenna," a commercial product for text messaging where a cellular network is not available, to determine if a text messaging system (without cellular connectivity) has value in law enforcement environments.

The overarching objectives for assessing the goTenna were to:

- Evaluate the *deployment and utility* for local and state law enforcement environments
- Provide an *operational evaluation and recommendations* report

JHU/APL utilized two different types of operational environments as test beds: 1) State Law Enforcement — New York State Police (NYSP); and 2) Local Law Enforcement — New York City Police Department (NYPD). Operational testing criteria was based on the equipment's ability to establish, provide and maintain communication capabilities in operational mission-specific scenarios within the end-users' environment. Due to the varying environments for the NYSP and the NYPD, the operational scenarios for each agency differ as they are mission-specific and guided by the end-users' needs and requirements. Therefore, the definitions and parameters for each goal/metric will also vary by agency and operational need. NYSP (state) testing was completed in September 2016 and the final report was submitted.

SUMMARY OF goTenna FIELD TEST PREPARATIONS

In preparation for operational testing, two goTenna radios were tested in a residential neighborhood and on Sugarloaf Mountain in Maryland in early September, 2016. In both tests, the goTenna radios achieved a maximum of 0.2 miles in distance for sending chat messages.

APL continued testing the goTenna's ability to send 1-to-1 messages at APL prior to the NYPD dry run. The goTennas were observed to work well in a lab environment and other parts of the APL campus (*Figure 28*). Two devices were used in the test; the receiving device was stationary and located near the center of the building and the transmitting device was mobile both inside and outside of the building. Green dots indicate a successful 1-to-1 message delivery to the stationary device inside of the building and red dots indicate a 1-to-1 message that could not be delivered after 5 consecutive attempts. The goTenna devices' firmware was verified to be v0.25.05.

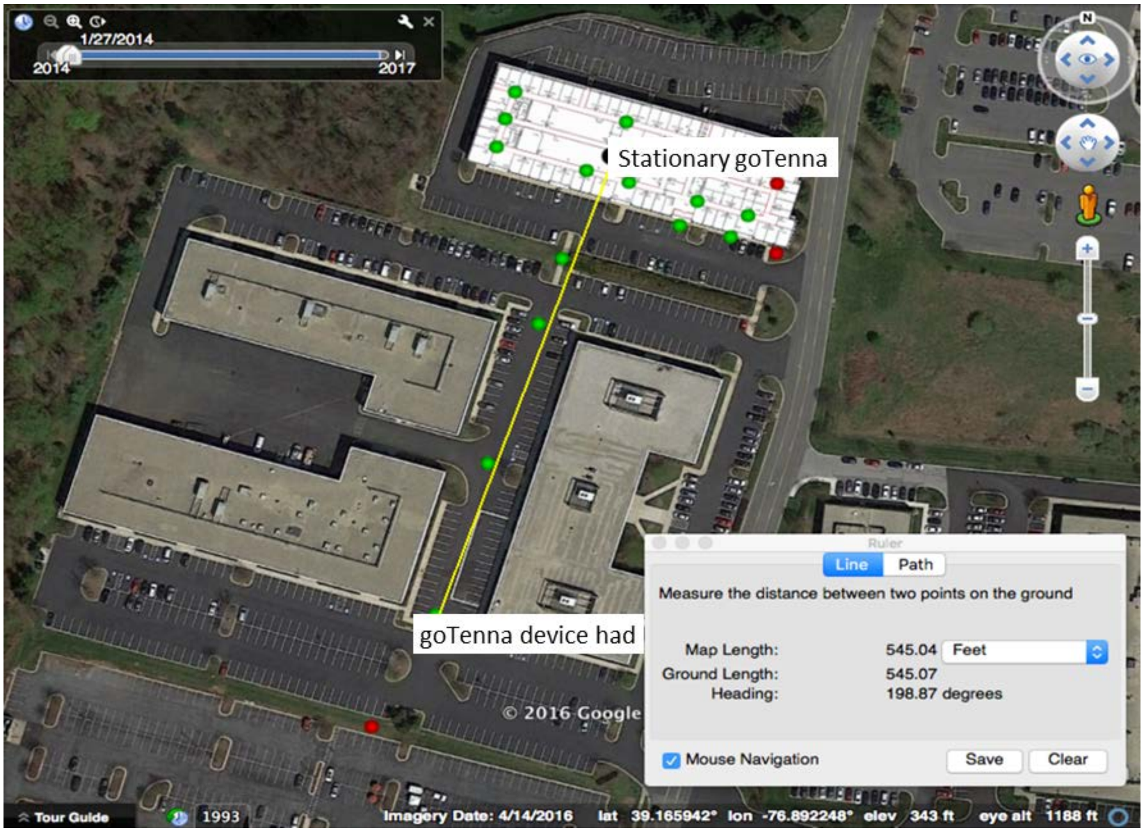


Figure 28: goTenna testing at APL

The first operational field test of the goTennas was conducted with the New York State Police (NYSP) in September 2016. During the preparation for operational testing it was learned that the goTenna system would not pair with the State-owned smartphones after multiple attempts. As a result, field testing was not conducted. APL reported the problem to goTenna's technical support representative, who instructed us to download the new firmware (released after the NYSP test) and replace the old firmware (v0.23.02). After upgrading the firmware, APL conducted a test in APL's lab and observed that the Bluetooth connection was inconsistent and unreliable.

NYPD FIELD TEST DRY RUN

The goTenna was part of the communications test dry run with the NYPD in Times Square, NYC on March 23, 2017 (Figure 29). The APL technical team established appropriate goTenna device pairing with their respective EUD as part of the comms check. However, after the initial pairing was verified, the team observed Bluetooth pairing problems between the ATAK/Samsung Note3 based EUDs. To continue with the operational testing, APL personnel used their personal smartphones and were able to download the goTenna app and connect to four (4) goTennas. The four smartphones with the goTenna connections were able to send and receive "chat" messages while standing near the NYPD Command Bus. This satisfied the initial condition to proceed with the test.

Figure 29: Location of goTenna device

The goTenna operational test observations are summarized below:

- In a densely populated, urban environment, the goTenna device did not connect/pair-up within three feet from the smartphone
- One goTenna connected when the smartphone was placed directly on top of the goTenna
- After one goTenna finally paired, it did not sustain its connection.
- APL smartphone-2 tried to send four “shout” messages to other teams but those messages were not delivered in real-time. Team-10 received three of four messages when they returned to the NYPD Command Bus. Team-1 did not receive any messages from Team-2.
- The JHU/APL smartphone-10 attempted to send twelve consecutive shout messages. APL smartphone-1 received seven of the twelve messages as shown in Figure 30 below. (It was impossible to correlate the times the shout messages were received as some messages did not display until the team returned to the NYPD Command Bus).

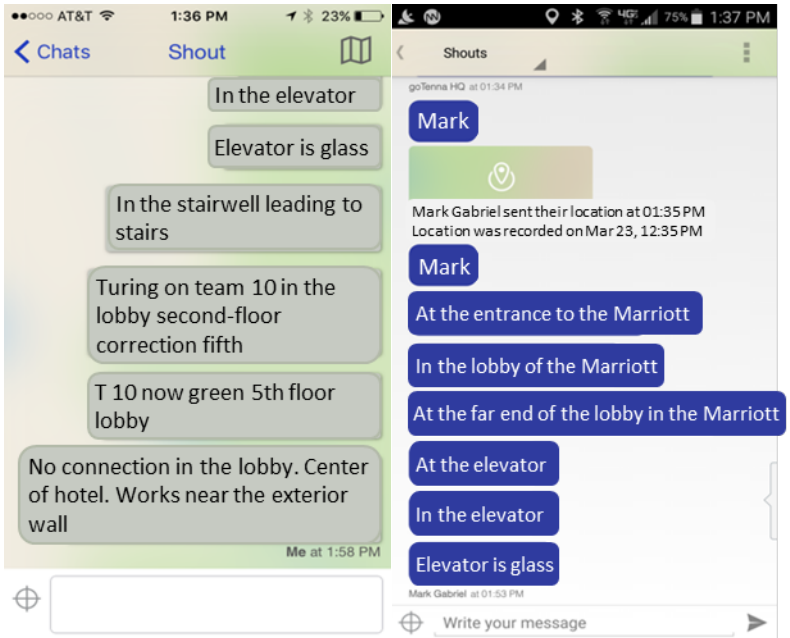


Figure 30: Chat messages between Phone10 and Phone 1

FOLLOW-UP

On March 24, 2017, the JHU/APL technical team contacted the CEO of goTenna to discuss: (1) the possible demonstration of their new product, goTenna Pro, with the MANET capability during the April 2017 NYPD test and (2) the connection problem APL encountered in NYC. He acknowledged that the goTenna has challenges with Bluetooth pairing in densely-populated environments and was originally designed for use in a rural or remote location for recreational purposes. He also mentioned that goTenna is considering use of a tethering (wired) connection option with the new goTenna Pro, which is under development for a target audience of first responders. APL inquired if he would like to participate and demonstrate the use of the new goTenna Pro version in the NYPD field test planned for April. The offer was declined as the CEO stated that the goTenna Pro is not ready for formal demonstrations but was open to discussing further after the technology reached a more appropriate technical readiness level.

RECOMMENDATIONS

Based on the findings regarding the goTenna's usability in a highly populated, dense urban environment, JHU/APL recommends the following:

> **Option 1:** Defer the goTenna testing in a densely populated urban environment until the goTenna Pro is available.
> **Option 2:** Conduct a standalone goTenna test within the urban NYC environment. Results are expected to be identical to those acquired in the dry run, but DHS S&T leadership can directly observe the problems this version has

pairing and sustaining connectively in this environment. Results will be documented in the final report.

Option 3: Conduct the goTenna testing as per the current test plan, which is a repeat of the dry run, and expect to get the identical results as what was learned from the dry run. Results will be documented in the final report.

Option 4: DHS S&T leadership contact the CEO of goTenna and invite them to NYC for the April field test an opportunity to demonstrate his Pro version.

Of note, goTenna is developing two additional versions: 1) goTenna Mesh, which has a 3mi/4.8 km range but relay through others is expected to get 2 – 3X, and 2) goTenna Professional which is currently marketed as a line of high-performance products for mission-critical applications in public safety, military and industry (gotenna.com). goTenna Mesh is available only for pre-order. No additional information is yet available regarding the release time of the goTenna Professional.

Appendix E: Dry-run Test in NYC

Background

On March 23, 2017, the Johns Hopkins University Applied Physics Laboratory (JHU/APL), with support from Persistent Systems, conducted a dry run assessment of the MANET system (MPU5 Radio, Android Team Awareness Kit –ATAK, software, and related supporting components such as antennas, cables, etc.). Outcomes from this dry run were used to plan for and implement the operational field test to be conducted on April 20, 2017.

Objectives

- Determine the number of MANET radios necessary to maintain voice, data and video connectivity in a densely populated urban environment
- Determine interoperability with NYPD's legacy land mobile radio (LMR) system
- Develop NYPD operational familiarity with the MPU-5 radio and the Android Team Awareness Kit (ATAK)
- Validate the scenarios and applicable CONOPS

Agenda

Wednesday – 22nd

1130: Meet NYPD at old NYPD training center at 20th St. and 2nd Ave.
1200: Lunch
1300: Review/Edit test procedures with NYPD
1500: Configure radios, check voice and video, check goTenna
1600: Quick training on MPU5, ATAK, and goTenna
1700: Wrap up

Thursday – 23rd

0830: Check in at Command Bus - TOC (7th Ave. and 46th St.)
0900: Comms check, scan spectrum at 2227 MHz and review test procedures
1000: Conduct test at Minskoff Theater
1100: Conduct test at 42nd St. /7th Ave. Subway Station
1200: Lunch
1300: Conduct test at Marriott Marquis Hotel
1400: Meet at TOC (7th Ave. and 46th St.)
1500: Hot-wash

<u>Test Overview</u>

1. Brief mission and test sequence to teams at the TOC
2. Proceed to Minskoff Theater on 45th St. and conduct test

3. Proceed to 42^{nd} St. Subway Station and conduct side-street test on 44^{th} St. and inside the station
4. Proceed to Marriott Marquis Hotel and conduct vertical test sequence
5. Hot Wash

<u>**Minskoff Theater Test**</u>

Objective: Determine whether the MANET system will maintain connectivity and provide quality video and voice data during tactical search in a large venue while supporting NYPD CONOPS.

To maintain connectivity with the TOC:

- Required a relay node outside the entrance to the theatre as well as in the 1^{st} and 2^{nd} floor lobbies

- Provided connectivity for voice and video for three tactical officers – one located on the main floor orchestra area and the other two were located on the left and right side of the mezzanine

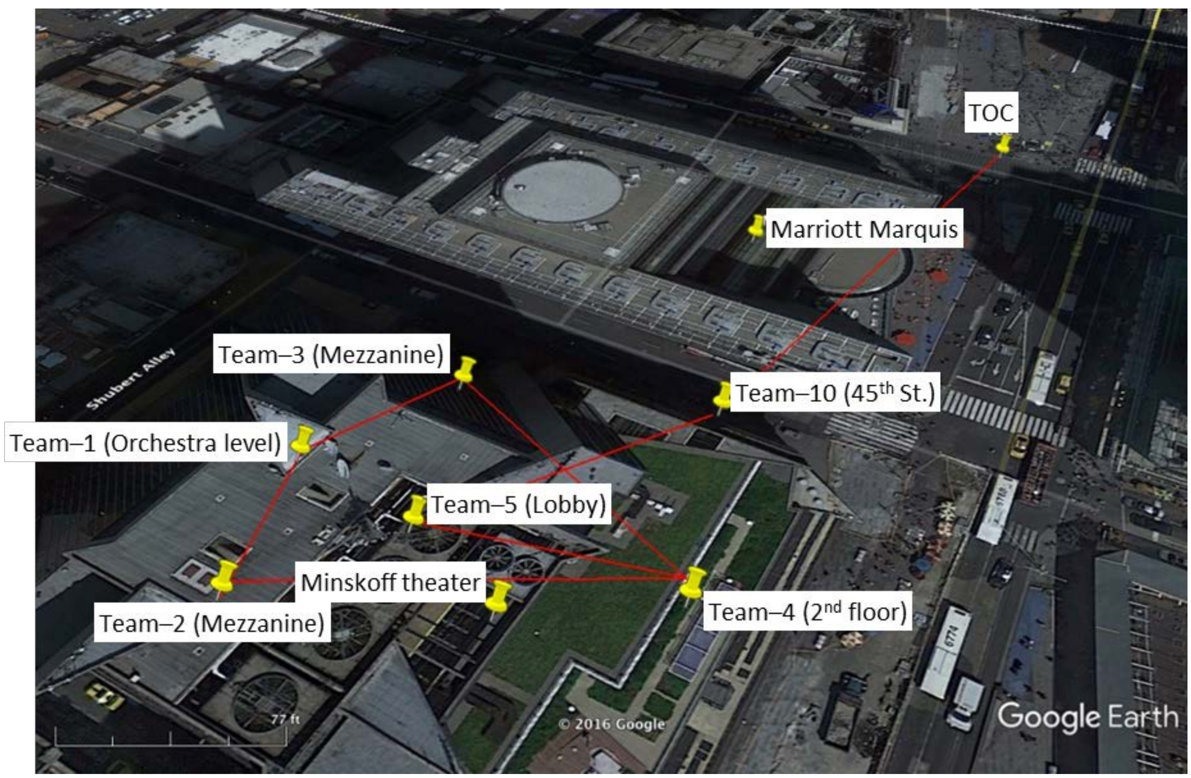


Figure 31: Minskoff Theater Test

Side-street Test on 44th St.

Objective: Determine whether the MANET system will maintain connectivity and provide quality video and voice data around large buildings in an urban setting.

To maintain connectivity with the TOC:

- Required a relay node at the corner of 7th and 44th
- Teams 1 and 2 proceeded in opposite directions for a total range of ~700 feet horizontally

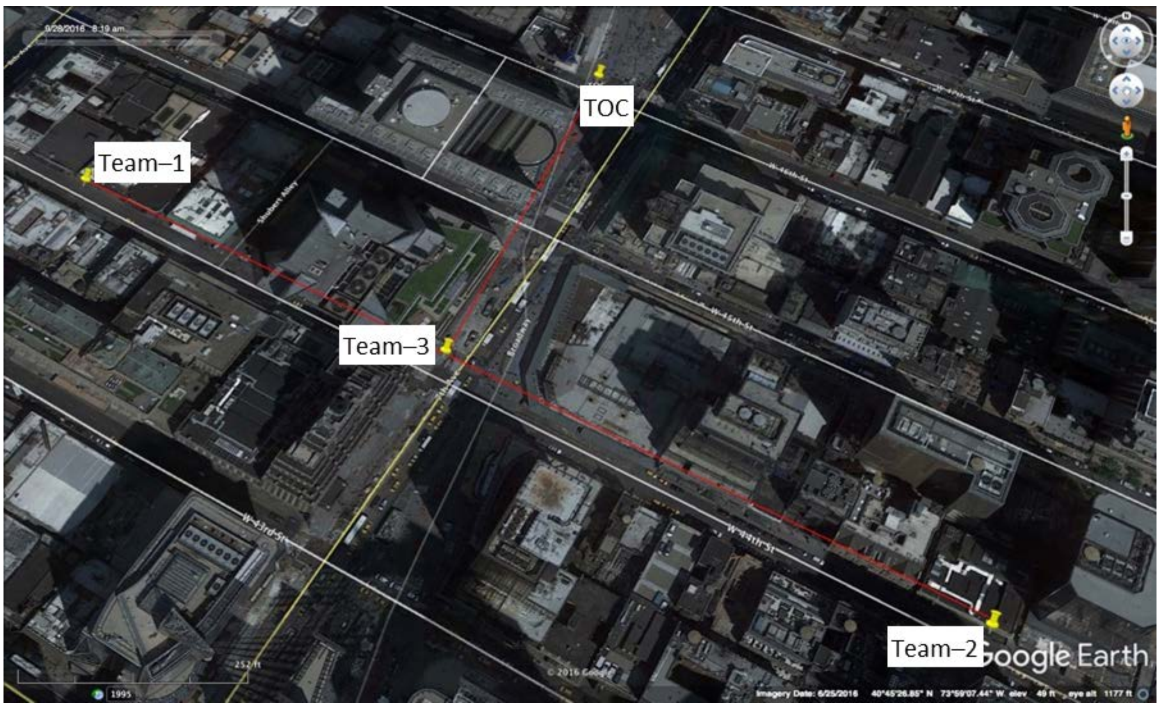


Figure 32: Side-street Test on 44th St.

42nd St. Subway Station Test

Objective: Determine whether the MANET system will maintain connectivity and provide quality video and voice data in the NYC Subway.

To maintain connectivity with the TOC:

- A total of three relay nodes were required to communicate to the team in the subway (underground)

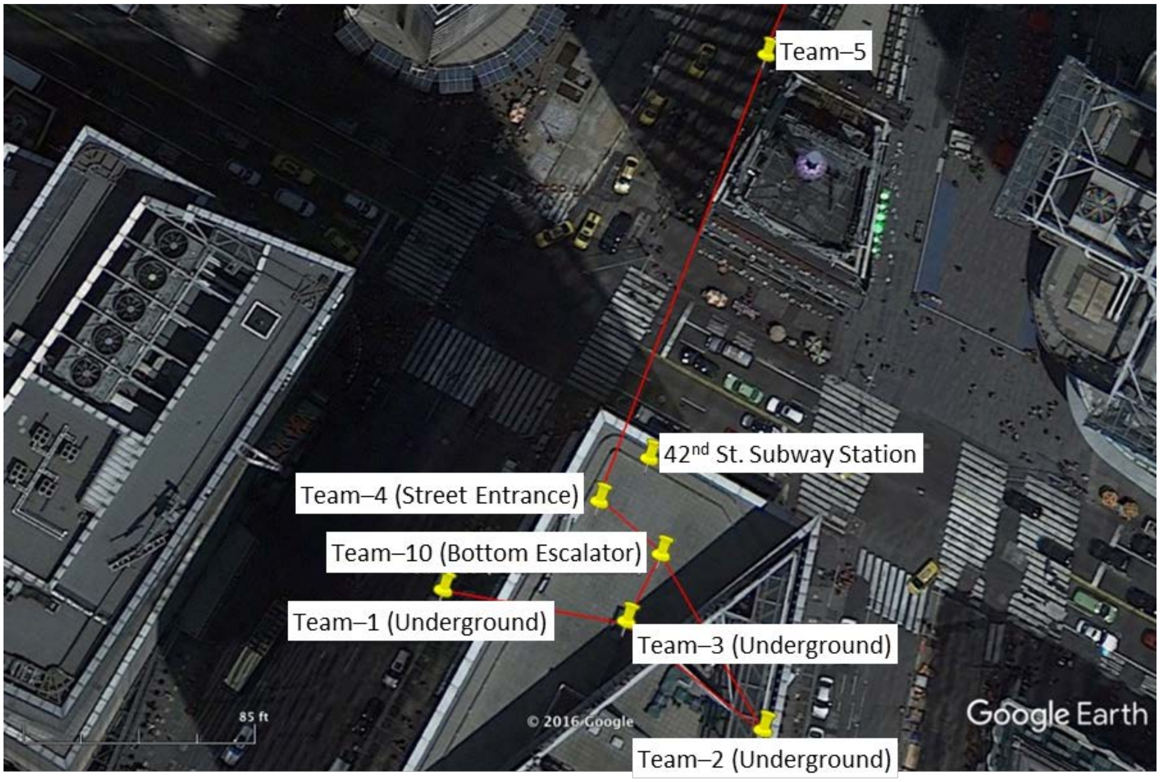


Figure 33: Subway Station Test

<u>**Marriott Marquis Test**</u>

Objective: Determine whether the MANET system will maintain connectivity and provide quality video and voice data during a tactical search in a vertical environment.

To maintain connectivity with the TOC:

- High gain antenna placed on top of the TOC (command bus) improved coverage
- Positioning of the TOC needs to be ideal to support optimal dispersion of the antenna signal
- Required relay nodes in the lobby, 5th, 10th, and 20th floors in order for Team 1 to send video from the 49th floor (far side of the building)

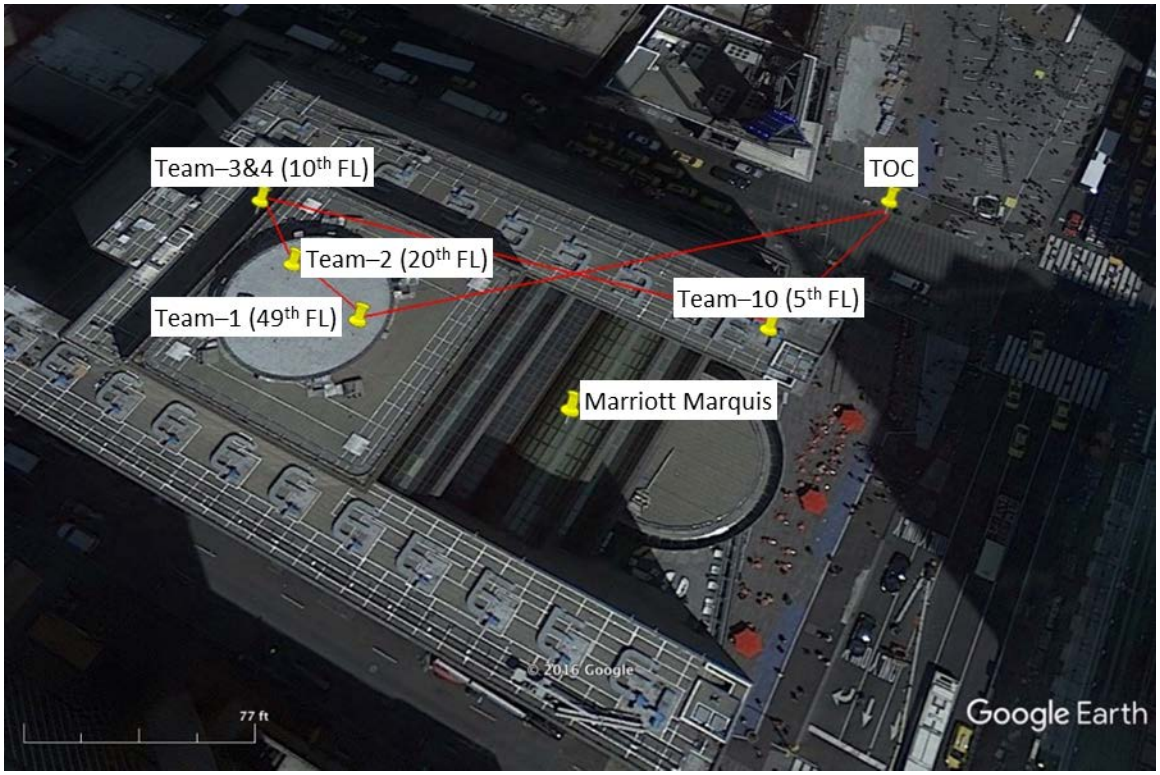


Figure 34: Marriott Marquis Test

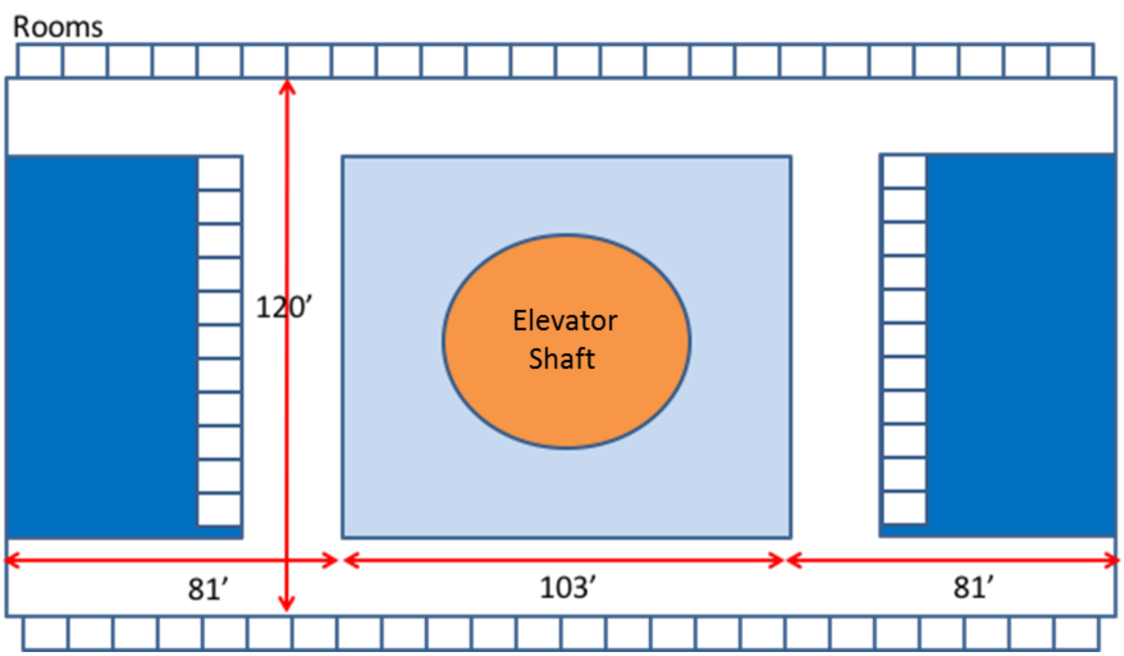


Figure 35: Marriot Marquis Floor (9th-45th) Dimension

Summary of Outcomes

- MPU5 Radios provided a completely self-contained network that was not dependent on any network infrastructure (demonstrated to be an ad-hoc network)
- Radios provided video and data in addition to voice for enhanced situational awareness
- Radio was interoperable with NYPD's existing communications system
- ATAK camera was sufficient for video communications - no need for camera on helmet
- Performance increased with use of a high gain antenna and prepositioning of nodes
- System is self-forming and self-healing – limitation is the radio needs to be worn on the front as the signal strength is noted by change in the color of the light on the radio, as well as it can be noted by the command software
- GPS is unreliable in an urban environment
- GPS is not readily available inside a structure (i.e., large concrete buildings both above and underground)
- Radios do not "self-identify" when transmitting
- NYPD would not use personnel as "relay nodes" to support urgent communications need

Appendix F: Baseline Requirements and Feedback

Requirements Gathering and Input Questions

1. *What are your current communications needs?*
    a. How do these needs change/differ for different operations (e.g., manhunt, search and rescue)?
    b. What are your "wish list" communications capabilities? (If technology limitations did not exist.)
    c. What qualities or features do you like about your current systems/capabilities? Any dislikes?

2. *When two prisoners escaped last year, what kinds of communications issues or limitations did you experience? Are there any other experiences in which you encountered these same limitations?*
    a. How good was the APX7000 LMR coverage (using towers and mobile relays)?
    b. Which frequency was used for LMRs during the event?

3. *What kind of capabilities are lacking with LMRs?*

4. *What are your current workarounds for these limitations?*

5. *What are your expectations for MPU5 MANET radios?*

Summary of Participants' Comments from Hotwash Discussion

- *We currently have one city-wide repeated frequency, two point to point frequencies and just acquired a third point to point encrypted frequency. All these frequencies are strictly for voice transmissions only.*

- *What we see in the MPU5 system is a secure system that can also transmit video.*

- *We are interested in using the ATAK system to assist with situational awareness.*

- *We are looking for a secure, dependable system that can work across the city and penetrate buildings and underground areas and provide a better situational awareness with the use of video and ATAK.*

- *Current radio system only has one citywide frequency that is not secure and can only transmit voice. No real current work-arounds at this time, other than using cell phones for distance, security and pictures/video.*

- *The MPU5 MANET system met some of our expectations, but they are not ready for real-world operational use in the NYPD setting. The system does provide a secure means of talking/video while using the ATAK system to assist with situational awareness.*

- *Participants appreciated the software tool's ability to provide live video streaming and live location updates for personnel.*

- *The software tool augmented voice communications with the live video stream feed – which was very helpful.*

- *The system required several radios to comprise the "mesh" network (i.e., multiple radios were required to serve as relay nodes). It's not realistic for NYPD personnel to carry radios for the sole purpose of serving as relay nodes.*

- *The current version of the MPU5 smart radio worked well with the use of a high gain multiple input, multiple output (MIMO) sector antenna (12 dBi) connected to the top of the TOC.*

Appendix G: Acronyms and Definitions

AAR	After Action Report
ATAK	Android Tactical Awareness Kit
CTU	Counter Terrorism Unit
DAS	Direct-Attached Storage
dB	Decibels
dBi	Decibels relative to isotropic
DHS	Department of Homeland Security
ESU	Emergency Service Unit
EUD	End User Device
FRG/OIC	First Responders Group/Office for Interoperability and Compatibility
GHz	Gigahertz
GPS	Global Positioning System
IP	Internet Protocol
JHU/APL	Johns Hopkins University Applied Physics Laboratory
LMR	Land Mobile Radio
MANET	Mobile Ad-hoc Networking
MHz	Megahertz
MIMO	Multiple Input, Multiple Output
MSEL	Master Scenario Event List
NGFR	Generation First Responder Program
NSSE	National Special Security Event
NYC	New York City
NYPD	New York City Police Department
NYSP	New York State Police
PLI	Position Location Information
PTT	Push-to-Talk
RoIP	Radio Over Internet Protocol
S&T	Science and Technology Directorate
SA	Situational Awareness
SNR	Signal-to-Noise Ratio
SORT	Special Operations Response Team
STA	Special Temporary Authority
SWAT	Special Weapons and Tactics
TOC	Tactical Operations Center
USB	Universal Serial Bus
WinTak	Windows-based Tactical Awareness Kit