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*Urban Operational Experimentation hosted by the
National Urban Security Technology Laboratory (NUSTL)*

Internet of Things Networks for First Responders Report

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**Homeland
Security**

Science and Technology

Executive Summary

On July 28, 2015, the Internet of Things Networks for First Responders (IoT) was assessed during the Department of Homeland Security (DHS) Science and Technology (S&T) Urban Operational Experimentation (OpEx) event, which the National Urban Security Technology Laboratory (NUSTL) hosted. This event brought together emergency responders and product developers to experiment with emerging technologies in operational conditions. Input from local emergency responder agencies helped select the technologies evaluated during this event, which also met capability gaps identified in Project Responder 4 (1).

The IoT is a low-power, handheld, prototype transmitter-receiver technology. It is capable of sending and receiving signals through challenging environments, such as reinforced concrete buildings, using a unique multipath technique. All data is routed through an aggregator and can be displayed with associated software.

Participants and observers first watched a presentation about the technology, and then split into two groups to test the transmission and receipt of sensor signals at points throughout a 12-story reinforced concrete building and adjacent subway platform. Test points were chosen based on prior radio frequency mapping with New York City Fire Department (FDNY) equipment. The locations ranged from easy to challenging. At each marked point, IoT transmitters and FDNY equipment were activated, and data collectors recorded whether the devices were able to communicate back to the aggregator point and to the IoT receiver. Data collectors also recorded responder comments during the operation and in subsequent group discussions.

The IoT successfully communicated in all but three of the 20 test points attempted, though in some cases with a notable time lag. During the experiment, both IoT transmitters, at different times, failed to reset, requiring removal and reinsertion of the batteries. Both groups ran out of time to cover all points, but each test point was covered by at least one group.

Evaluators were interested in the technology and noted signal transmission outperformed some of their existing equipment. They felt the best use case would be in integrating with equipment they already had. For example, firefighters felt it could be integrated into their Self-Contained Breathing Apparatus (SCBA) to transmit a distress signal. Some evaluators expressed interest in using the device for non-verbal communication to reduce voice traffic during an event. The technology could also be used to transmit equipment status, such as SCBA air level; real-time biometric data; in-building Global Positioning System tracking information; or warnings, such as an evacuation notice. Responders made suggestions for a new text feature, automated reset, a built-in transmission confirmation, improved software protocols, higher power and an improved antenna design. Overall, the participants were interested in seeing further evaluation at different locations and further development by the manufacturer.



Figure 1 – OpEx Participants

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1 Introduction

The Internet of Things Networks for First Responders (IoT) is a prototype technology being developed by BAE Systems, Link Labs and Cisco. It uses a new wireless technique to achieve high immunity to multipath interference and is capable of sending data in reinforced concrete structures or other radio frequency (RF) shielded areas. The system consists of small, low-cost, battery-powered sensors with two-way communication to a network aggregator and a situational awareness display. This technology has many possible applications, including large arrays of unattended sensors feeding information to larger data systems, or emergency responder position locators or distress signals in RF-shielded environments.

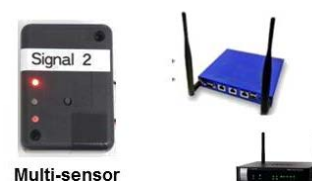


Figure 2 - IoT Sensor, Data Aggregator and Router

On July 28, 2015, during the Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Urban Operational Experimentation (OpEx) event, hosted by the National Urban Security Technology Laboratory (NUSTL), testers experimented with the IoT. The New York City Fire Department (FDNY), New York City Emergency Management, New York City Police Department (NYPD) and Port Authority of New York and New Jersey subject matter experts supported the OpEx, selected the technologies, and worked with NUSTL scientists to plan the experimentation scenarios and arrange test venues. Ten emergency responders from New York, New Jersey, California, Maryland, Massachusetts, Illinois, Virginia and the Washington, D.C. metropolitan area experimented with the technologies and provided feedback and observations. Table 1 lists all of the technologies included in this event, which were selected with input from local first responder agencies and met capability gaps identified in the Project Responder 4 National Technology Plan for Emergency Response to Catastrophic Incidents.

Table 1. Technologies Included in OpEx 2015

Product Name Manufacturer	Description
Situational Head Up Display Avon Protection Systems	Micro liquid crystal display (LCD) display with full color widescreen layout built into face shield
Tridion™-9 PerkinElmer	Portable Gas Chromatography/Mass Spectrometry (GC/MS) system that provides identification of volatile and semi-volatile organic hazards in the field in less than three minutes
BioFlash-E Biological Identifier PathSensors	Portable and rapid aerosol sample collection and identification of up to 16 biological threat agents
Fido B2 IBAC FLIR	Networked array of portable biosensors
Internet of Things Networks for First Responders BAE Systems	Networked sensors that use a long-range wireless protocol capable of concrete penetration to send signals through a network aggregator

Product Name Manufacturer	Description
Knight Robot/HAZPROBE WM Robots	All-terrain robot with a manipulator arm, cameras, and a boring and inspecting device that can drill through walls for bomb tech personnel to inspect suspect abandoned vehicles or objects
RepKnight ADI Technologies	Monitors and analyzes social media with geolocation feature
X-Ray Scanning Rover Smart Imaging Systems	X-ray scanner integrated into a custom-built robot that is designed to rapidly screen suspicious left-behind bags or parcels on the ground

1.1 Purpose

The purpose of the IoT operational experimentation was to evaluate the prototype technology for emergency responder use. By bringing together emergency responders and product developers during technology development, design changes can be effected early, responders can learn about emerging technologies to enhance their mission capabilities, and S&T can gain a better understanding of responder needs and gaps to guide future homeland security investments.

1.2 Objective

This experimentation is designed to allow responders to experience the use of the IoT sensors in operational settings, and to offer feedback and suggestions to the developers to enhance the product capabilities for responder operations.

1.3 Responder Capability Need

While in an early stage of development, IoT technologies would address key findings from Project Responder 4 (2) that “many of the potential technology advances will not be possible without the ability to transmit and integrate multiple sources of data” and “are dependent on sensor systems that provide real-time data about the location of responders, (and) victims.” Also needed is “a data communication infrastructure” and “a system to integrate the data.” Responder input into designs for the next generation of prototypes would be beneficial to meeting the capability needs documented in Project Responder 4.

1.4 Prototype Description

The IoT consists of small, battery-powered sensors that send signals to a network aggregator. It uses a long-range wireless protocol that functions without cellular or Wi-Fi networks. It operates in the unlicensed Industrial, Scientific, and Medical radio frequency band at 900 megahertz and milliwatt power levels. The system is capable of penetration in reinforced concrete buildings using a technique to obtain high immunity to multipath interference. The system transmits sensor-level data (i.e., not real-time voice or video). The data aggregator is long range, low power and can be located indoors or outdoors. Signals collected at the data aggregator are shown on a situational awareness display that can be optimized for a large number of IoT sensors. Figure 3 shows components of the IoT.

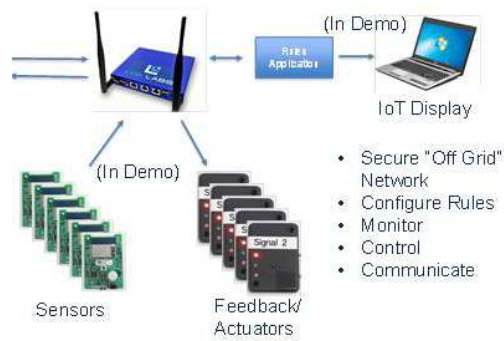


Figure 3 - IoT Networks for First Responders
Multi-sensor, data aggregator and display are hardware components of the IoT system.

One potential application for this technology is in large, low-cost, unattended sensor networks, allowing for data collection and aggregation to create actionable data for control, situational awareness and decision making. Another application is in wearable emergency responder gear, transmitting biometric or position information, equipment status, or a distress signal to a command and control position.

The prototypes used in this experimentation consist of paired sensors with a transmit button and a receive indicator light. When the transmit button is activated, it sends a signal through the data aggregator to the paired sensor; if the signal is received, the indicator light glows. An Internet-based situational awareness display shows the sensor activity.

2 Experimentation Design

A detailed description of the experimentation design can be found in the Experimentation Plan for the Internet of Things Networks for First Responders (2). The experimentation scenario was developed with input from responders and instrument designers to simulate an emergency responder communication scenario in a reinforced concrete building.

2.1 Event Design

This event convened a group of experienced emergency responders to experiment with sensor prototypes in an urban environment. Experimentation took place in NUSTL's office building, a 12-story reinforced concrete structure in Manhattan, New York. Completed in 1929, the building originally warehoused goods for the Customs Bureau and has unusually thick reinforced-concrete slab floors for heavy floor loading. In the western two thirds of the building, the concrete floor slabs are seven inches thick—about twice the thickness of the slabs in most buildings. In the eastern third of the building, the slabs are a 3½ inches thick, but are supported by a dense grid of thick reinforced-concrete beams. NUSTL's building is representative of a difficult RF environment that may be encountered within cities.

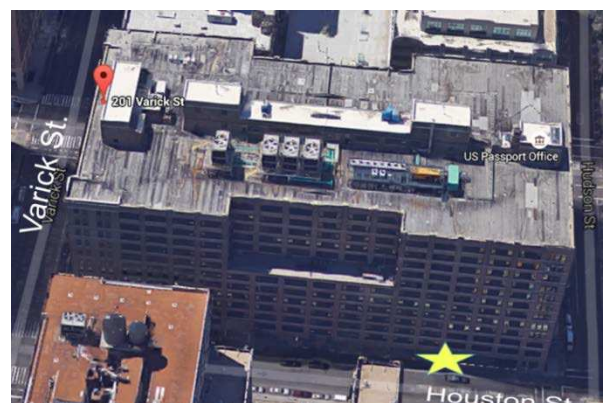


Figure 4 – The 12-story Reinforced Concrete Building
(View from Google Maps)

Test points in the building were marked to indicate locations for participants to test sensor signals. These locations, distributed among multiple walking paths (Figure 5), were selected based on previous mapping of RF transmission using New York City Fire Department (FDNY) communications and tracking equipment. With the data aggregator at street level outside the northwest corner of the building (denoted by yellow star in Figure 4), test points spanned the first floor near the aggregator to the farthest accessible point in the southeast corner. Points were also selected at different elevations: the basement; the ninth floor; and points on the sixth and second floor in the farthest stairwell. Building construction and distance both play a part in the expected difficulty of wireless transmission; points expected to be easy and challenging were included. Additional test points were mapped at the stairs, entry and platform of the subway station along the east side of the building (Figure 5).

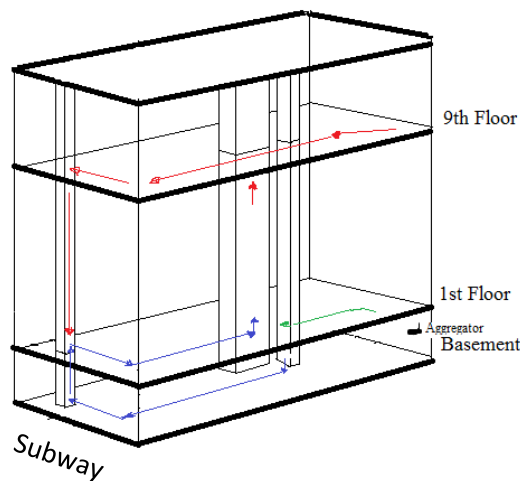


Figure 5 - Schematic of Test Paths

Colored arrows represent paths followed to reach test points. The green arrow signifies the initial common path containing four test points. Red arrows are the ninth floor loop with seven points. Blue arrows show the basement loop consisting of seven test points. There are also four test points in the subway. Table A-1 in the Appendix lists the points.

Emergency responders divided into two groups and traversed the test points in different order. At each marked point, IoT sensors and FDNY communications and tracking equipment were activated, and data collectors recorded whether the devices were able to communicate back to the aggregator point and receiver. FDNY communications and tracking equipment included their portable 2-way radios (2-watt and 5-watt capability) and a firefighter locator system, the Scott Safety Pak-Tracker. The Pak-Tracker consists of a transmitter and receiver, using a directional 2.4 gigahertz RF with milliwatt signal strength received from the transmitter, and is intended to direct a searcher to a trapped or downed firefighter. While the FDNY radios and Pak-tracker fulfill different roles than what is envisioned for the IoT, they provided points of reference for those familiar with their communication capabilities in challenging RF environments. Data collectors recorded responder comments during experimentation and in subsequent group discussions.

2.2 Summary of Experimentation

On July 29, 2015, participants from the FDNY, New York City Urban Search and Rescue NY Task Force 1, NYPD, Port Authority Police Department and First Responder Resource Group convened at the NUSTL facility located in Manhattan, New York, to participate in the IoT experimentation. Twelve evaluators

with a range of emergency response experience in urban environments provided feedback about the system.

The meeting started in a conference room; test activities were performed throughout the building and in an adjacent subway station. The NUSTL experimentation director provided participants with information on the OpEx program and the goals, purpose and overview of the IoT experiment. Product designers from BAE Systems and Link Labs gave a presentation on their current technology and product vision, and demonstrated the IoT transmitters and receivers. In addition, FDNY firefighters demonstrated their portable 2-way radios and Scott Safety Pak-Tracker.

Experimentation began with participants proceeding to where the data aggregator was stationed on an FDNY vehicle outside the first floor vehicle bay (Figure 6).

Evaluators were divided into groups A and B. Initially, the groups stayed together for the first four test points, then diverged to traverse the remaining test points in different orders. A NUSTL data collector went with each group, while other observers remained at the situational awareness display station located in a NUSTL conference room. In Group A, the IoT transmitter was carried through the building to the test points, while the receiver remained co-located outdoors with the data aggregator. This group communicated through 2-way building radios to confirm receipt of signal at the aggregator station.¹ In Group B, both the IoT transmitter and receiver were carried to the test points, such that the signal had to reach the data aggregator and return to the receiver. Group B communicated to personnel at the aggregator station using FDNY radios and also maintained the Pak-Tracker. At each test point, a participant would activate the IoT transmitter and check for receipt of the signal at the receiver. Group B would additionally note the performance of the Pak-tracker and FDNY 2-way radios.



Figure 6 - IoT Data Aggregator on Roof of Vehicle

During the experiment, both groups had some difficulty communicating back to the data aggregator station using 2-way radios at certain points. Both groups ran out of time to cover all points. Both groups initially covered the common path of four test points from the aggregator station to the closest stairwell on the first floor. At that point, Group A took the nearby elevators to the ninth floor, while Group B continued into the basement. Group A traversed the ninth floor from the point closest to the aggregator in the northwest corner to the farthest stairwell in the southeast corner. They continued down the stairwell taking readings at a number of landings, and went back to the first floor. This covered seven test points. Then, in the interest of saving time, Group A skipped the basement loop and proceeded to the four subway station points. They completed two; the final two were omitted after IoT and radio communications failed at the entrance to the subway platform.

Group B traversed the basement from the stairwell nearest the aggregator in the northwest building corner to the farthest stairwell in the southeast corner, then back up to the first floor for additional readings heading toward the center of the building on the first floor. They completed the seven test points in this loop. Due to time constraints, Group B only finished four test points of the ninth floor loop

¹ The NUSTL 2-way building radios, unlike the FDNY radios, are set up with additional repeaters to work throughout the building. Therefore, Group A did not take data on the success of communicating through building radios from the test points to the aggregator station.

and was unable to complete any subway points. After the groups reconvened in the conference room, the experimentation director led the participants in a discussion to glean feedback about the IoT.



Figure 7 - Groups A and B During the Experiment

3 Results

A summary of the experiment results can be found in Table A-1 in the Appendix. The IoT successfully transmitted in all but three of the 20 locations attempted. In some instances, there was a notable time delay in receiving the signal. The time lag was not quantified during this event; future tests could address this. No significant differences were found in bringing one unit versus the pair (i.e., 1-way and “round-trip” communication with the aggregator); however, not all points were tested by both groups. In the building, the milliwatt Pak-tracker worked at only four locations that were nearest to its receiver at the data aggregator station. The success of the milliwatt IoT transmission more closely tracked with the FDNY’s 2-watt radio than the Pak-tracker. The subway station proved to be a more difficult environment; IoT sensor communications worked at the landing halfway downstairs to the station, but not farther in. Table A-2 in the Appendix captures participant commentary and feedback during the event, which is also summarized in the next section.

3.1 User Feedback

The participants recognized the IoT is a prototype, and their comments mostly focused on potential use cases, development plans and recommendations. This group of responders focused on the technology’s possible use in the communication of data among responders or between an individual responder and a command post, as opposed to other proposed applications (e.g., unattended sensor network). Evaluators found value in the technology and noted its signal transmission outperformed some of their existing equipment. They felt the best use case would be in integrating with equipment that they already had. They stated they would not want a new standalone device with the associated overhead of acquisition, battery replacement and maintenance. For example, firefighters felt it could be integrated into their self-contained breathing apparatus (SCBA) system to transmit a distress signal if needed. Responders suggested the technology not be licensed exclusively to one manufacturer, as it could be a solution for different equipment for emergency responders throughout the nation.

During the experiment, there were instances in which the prototype IoT devices failed to reset. To reset them, the battery had to be removed and then reattached. The evaluators indicated this would be impractical in the environments and situations in which they work. They suggested adding a reset button to the device or an automatic reset feature that does not require manual intervention.

Responders also would like the system to have a built-in data transmission confirmation or some method of acknowledging that the message was received. One suggestion was to combine the

transmitter and receivers into a single unit. Currently, the prototype sensor will automatically try to send a message three times. Responders noted the software protocol should be specifically geared for the purpose: for a critical message such as a distress signal, the transmission should be constantly repeated until acknowledged.

Multiple evaluators stated they would like to see a text feature that would allow preset messages such as “Acknowledge” or “Help Needed” to be sent. Other evaluators expressed interest in using the device for non-verbal communication to reduce voice traffic during an event. Participants and the vendor mentioned multiple applications for the technology, including transmitting equipment status such as SCBA air level, real-time biometric data, in-building Global Positioning System (GPS) tracking information, or warnings such as an evacuation notice. Some responders cautioned that if the technology were used for transmission of real-time biometrics (e.g., responder heart rate or temperature), that there must be a way to validate data so that personnel would not be pulled out over false readings or poorly transmitted data.

Responders expressed interest in transmitting video feeds; however, the vendor stated that the low data rate of IoT would not accommodate video. The technology is only suitable for text, voice snippets or low resolution pictures. For this type of information, the vendor believes transmitting at lower frequency will further improve performance. The participants also suggested the unit could use higher power and an improved antenna design to increase signal strength.

Overall, the participants were interested in the technology and many stated they would like to see formal testing. Firefighter participants would like to see testing of the IoT technology versus 2-watt radios, in multiple buildings and at points that are challenging for 2-watt transmitters. Police participants suggested involvement of their Emergency Service Unit (ESU) for technology evaluation as they are the group that would be most likely to use this type of product.

4 References

1. Project Responder 4: 2014 National Technology Plan for Emergency Response to Catastrophic Incidents (July 2014). Prepared for Department of Homeland Security by the Homeland Security Studies and Analysis Institute. Falls Church, Virginia. (<http://www.homelandsecurity.org>) Publication Number RP13-17-02.
2. Urban Operational Experimentation. *Experimentation Plan Internet of Things Networks for First Responders*, OpEx-T-PL-2. 2015.

5 Acronym List

DHS	-	Department of Homeland Security
ESU	-	Emergency Service Unit
FDNY	-	New York City Fire Department
IoT	-	Internet of Things
NUSTL	-	National Urban Security Technology Laboratory
OpEx	-	Operational Experimentation
RF	-	Radio Frequency
S&T	-	Science and Technology Directorate
SCBA	-	Self-Contained Breathing Apparatus

Appendix

Group A carried the transmitter to the test points, while leaving the receiver next to the data aggregator (essentially 1-way communication). Group B carried both the transmitter and receiver such that the signal would make a 2-way trip through the data aggregator. Group A used the NUSTL radio system set up to work throughout the building; Group B used FDNY radios and the Pak-Tracker. In Table A-1, 2W refers to the FDNY radio at a 2-watt power setting; 5W refers to the FDNY radio set at 5-watt power setting; yes means the signal was received; and no means that it was not received.

Table A-1. Compilation of Data from Groups A & B

Test Point	Location Description	Group A	Group B		
		IoT (1-way)	IoT (2-way)	Pak-Tracker	FDNY Radio
1	1 st floor NW inside double doors	yes	yes	yes	yes (2W)
2	1 st floor outside double doors	yes	yes	yes	yes (2W)
3	1 st floor outside central stairwell	yes	yes	no	yes (2W)
4	1 st floor inside central stairwell	yes	yes	no	yes (2W)
9 th Floor Loop					
5	9 th Floor NW corner	yes	yes	yes	yes (2W)
6	9 th floor NW	yes	yes	no	yes (2W)
7	9 th floor outside central Stairwell	yes	yes	no	yes (2W)
8	9 th floor East	yes	yes	no	yes (5W)
9	9 th floor inside SE stairwell	yes	No time		
10	6 th floor in SE stairwell	yes	No time		
11	2 nd floor in SE stairwell	yes†	No time		
Basement Loop					
12	basement inside central stairwell	No time	yes	no	yes
13	basement corridor west	No time	yes	yes	yes
14	basement corridor central	No time	yes/no†	no	Partial (2W)
15	basement east	No time	yes	no	Partial (2W)
16	basement outside SE stairwell	No time	no	no	Partial (5W)
17	1 st floor inside SE stairwell	No time	no	no	no (5W)
18	1 st floor east of main lobby	No time	yes	no	yes (5W)
Subway					
1	1 st landing on subway stairs	yes	No time		
2	outside subway turnstiles	no	No time		
3,4	No further subway points done after failure at subway point 2				

† Test repeated; battery removed to reset the IoT device.

Table A-2. Consolidated Data Collection Notes - responder comments grouped by topic.

Topic	Responder Comments
Value	The responders found value in the IoT technology and noted it had potential to enhance their existing equipment. They stated the signal transmission of the IoT performed better than the Pak-tracker in the experimentation.
	Responders agreed the IoT technology should not be a stand-alone device, with associated equipment management (i.e., another device to carry, charge and maintain). They were interested in incorporating it into their existing devices.
	The responders suggested the vendor should partner with or license to SCBA manufacturers to incorporate IoT into SCBA to transmit a distress signal. They suggested not working exclusively with one manufacturer, so the technology could benefit different equipment for emergency responders throughout the nation.
Hardware	During the experiment, the devices failed to reset and batteries had to be removed and reinserted to reset the unit. Responders indicated this would be impractical in the environments and situations in which they work. A responder suggested adding a reset button to the device that would kill the power instead of needing to remove the battery packs. Another suggested default resetting that would not require manual intervention.
	A responder suggested using higher wattage (more power) to improve signal strength.
	A responder suggested redesigning the antenna on the prototype to potentially improve signal performance.
Software	A responder suggested the device protocol should require a confirmation or acknowledgement that the receiver system got the message. It was also noted the message being received is just as critical as the message being sent. An evaluator suggested consolidating the two handheld devices (transmitter and receiver) into one.
	A responder suggested that device protocol should correlate with its purpose, i.e., the more critical the message, the more aggressive the notification should be. The current prototype makes three attempts to send a message; responders suggested that for a distress signal, the message should be constantly repeated until acknowledged.
Features	Multiple responders stated they would like the device to have additional sensors and notification capabilities. For example, IoT could send a distress signal, evacuation notice, air quality, air status, internal and external temperatures, biometric information or GPS information.
	Evaluators indicated that location tracking within buildings would be very useful during emergency situations – the vendor noted that this is something that they are working towards with the support of commercial communication companies.
	A responder mentioned current efforts to reduce reliance on voice traffic, and suggested IoT could be used for non-verbal communication in sending equipment information like air level or biometric data. Another responder cautioned if the technology were used for transmission of real-time biometrics (e.g., responder heart rate or temperature), that there must be a way to validate data so personnel would not be pulled out for false readings or poorly transmitted data.
	A responder suggested adding a text feature that could activate preset phrases or words, i.e., press button 1 for “Acknowledge,” press button 2 for “Help Needed.”

Topic	Responder Comments
	<p>Responders would like to see video feeds be a part of this technology. However, the vendor stated that the data rate of IoT is suitable for voice snippets, low resolution pictures, but not video. They plan to move IoT to lower frequencies for better expected performance.</p>
Future Testing	<p>The responders indicated they would like to see formal testing of the IoT technology versus 2-watt radios, to include multiple buildings throughout the city and test points that are challenging for 2-watt radio transmissions.</p>
	<p>Police participants suggested involving ESU in assessments as they are a group that may use this type of technology.</p>