Michigan Department of Transportation

Multipath SPAT Broadcast Project

Job Number 108002

Project Final Report

UMTRI-2013-9

March, 2013

Technical Report Documentation Page

1. Report No. UMTRI-2013-9	2. Government Accession No.	3. MDOT Project Manager Steven J. Cook, P.E.
4. Title and Subtitle Multipath Signal Phase and Timing Broadcast Project		5. Report Date March, 2013
		6. Performing Organization Code
7. Author(s) Ralph Robinson, Francois Dion, PHD		8. Performing Organization Report No.
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, MI 48109		10. Work Unit No. (TRAIS)
		11. Contract No. 2009-0747
12. Sponsoring Agency Name and Address Michigan Department of Transportation ITS Program Office 8885 Risk Road Lansing, MI 48909		13. Period Covered October 20, 2009 to May 31, 2013
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The Multipath Signal Phase and Timing (SPAT) Broadcast Project demonstrates a Safe Green Passage traffic signal application that provides speed guidance to an approaching driver so that a vehicle may safely pass through the green phase of an upcoming traffic signal. This is accomplished by the signal system's ability to send SPAT information to approaching vehicles even when they are several miles or multiple signals away. This project was developed in partnership with the Institute for Information Industry, a Taiwan ITS consortium, the Michigan Department of Transportation (MDOT), and the University of Michigan Transportation Research Institute (UMTRI). The Institute for Information Industry provided system components, software and a related Traffic Signal Violation Warning application. UMTRI provided a Paramics system simulation of the multipath SPAT application, functional requirements, and overall coordination of the project. The implementation at two signalized intersections was supported by the Road Commission of Oakland County. The system was developed and demonstrated on August 8, 2011. While the functional demonstration was successful, the traffic simulation of 25,000+ vehicles did not show the expected statistical increase in flow-through efficiency. Further, the Dedicated Short Range Communications (DSRC) technology requires line-of-sight placement, which significantly limits the ability to maximize the distance from the signal to the vehicle, and therefore limits the effectiveness of the application.

17. Key Word SPAT, DSRC, Signal, Cellular, Phase, RSE, simulation		18. Distribution Statement No restrictions. This document is available to the public through the Michigan Department of Transportation		
19. Security Classification (of this report) Unclassified		20. Security Classification (of this page) Unclassified	21. No. of Pages 12	22. Price

Table of Contents

Table of Figures

Project Description

The Multipath SPAT Broadcast Project demonstrates a Green Passage traffic signal application that provides speed guidance to an approaching driver so that a vehicle can safely pass through the green phase of an upcoming traffic signal. This is accomplished by the signal system's ability to send Signal, Phase and Timing (SPAT) information to approaching vehicles even when they are several miles or multiple signals away.
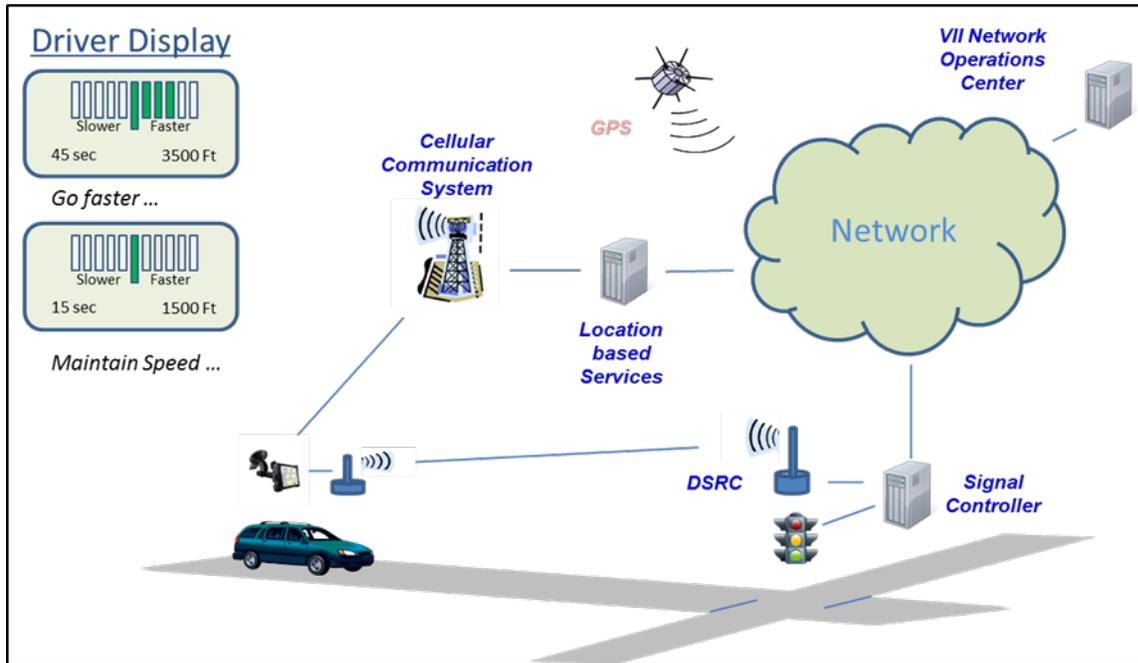

Figure 1 - Multipath SPAT Broadcast System Architecture

This multipath SPAT project was a joint development between MDOT, UMTRI, and the Institute for Information Industry, a Taiwanese consortium. An agreement was made between MDOT and the Institute for Information Industry to join forces and provide a demonstration of an application of interest to the connected vehicle community. MDOT provided funding for the Road Side Equipment (RSE); the Institute for Information Industry provided the vehicle-based physical hardware and software; and UMTRI led the functional requirements development and performed a Paramics simulation analysis of the performance metrics. This work was done on one demonstration vehicle and two instrumented intersections. The Institute for Information Industry team came to Detroit for a demonstration and project group meeting in 2011.

In this demonstration, SPAT information was sent from the signal controller by cellular and Dedicated Short Range Communications (DSRC) radios and was received by the vehicle's on-board device. The desired speed is calculated based on current location, vehicle speed, and scheduled signal phase changes. If needed, a recommended change in speed is made to the driver by the device's display. The

display also shows a down counter with the number of seconds to signal change from green to amber/red.

Figure 2 - Test site map

The intersections used in this demonstration include the northbound Telegraph route at Long Lake Road and the following intersection of Telegraph and Hickory Grove (42°35'19.96"N, 83°16'52.63"W). Spacing between these intersections is one mile, with few intersecting streets and driveways. Telegraph is a boulevard with three lanes going north and south and five cross-over locations along the route. There is a signal on Telegraph Road at a parking lot about 600 feet south of Long Lake Road. The next signal is about 0.9 mile south at Lone Pine road.

The demonstration showed that if the driver is able to follow the instructions shown on the device's display while traveling north on Telegraph at Lone Pine Road, the vehicle will have a very good chance of encountering a green light at Long Lake Road and a green light at the next signal in 600 feet. Any actions of other vehicles that would prevent the driver from speeding up or slowing down as recommended would inhibit the driver from passing through safely on green. The speed recommendation by the device can only range between the speed limit at the high end and 60 percent of the speed limit at the low end. When a recommendation is needed outside of this range, the device does not display any recommendation to the driver. The display, however, does continue to show the number of seconds to the next signal phase change (green to amber). Once past the Long Lake Road intersection, new SPAT data is used to calculate the recommended speed to approach the Hickory Grove
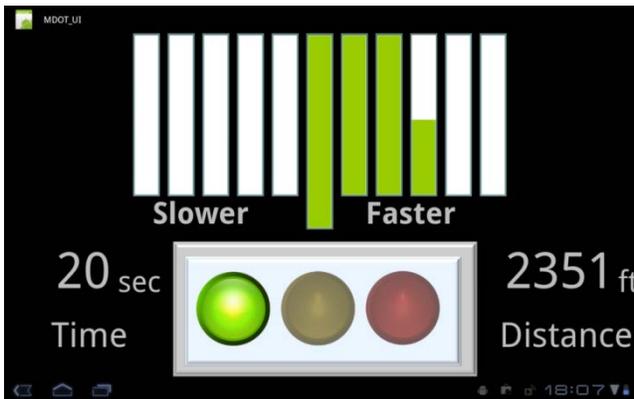

Figure 3 - In-vehicle display

signal while the light is green. Once through the intersection at Hickory Grove, the display will go blank since no further information is available in this limited demonstration. Prior to entering the demonstration area at Telegraph and Long Lake Road, the display is blank. When useful SPAT data is received by the device, the display is activated and begins to provide the speed recommendation to the driver.

At long distances, cellular service provides the SPAT information with a 3-5 second delay to the vehicle. Once in range of <1,000 feet, data transmission is handed-off to DSRC, which reduces the latency to near real time.   Since only one demonstration vehicle and two DSRC-equipped signals are used, the complexity of the Location Based Server (LBS) is minimized since it does not have to coordinate signal timing among hundreds of other units in the area. In fact, in this limited demonstration, direct cellular communications may be all that is required to pass SPAT from the intersections to the vehicle.

A separate but related application to be demonstrated is the Traffic Signal Violation Warning function. When a vehicle is approaching a signalized intersection too fast to stop safely, a warning is sounded to the driver by the on-board equipment. It may start as a gentle reminder to slow down but as the situation worsens, the alarm becomes more urgent. This is a planned feature of the connected vehicle systems in development by Crash Avoidance Metric Partnership (CAMP) consortium. However, in this demonstration, the feature is closely tied to the "green light pass-through" application and will be integrated into the on-board device using the dilemma zone algorithm developed by the Institute for Information Industry.

The multipath SPAT demonstration system consists of the following:

- A vehicle-mounted personal device containing a cellular transceiver, DSRC radio, display and GPS receiver.
- Two intersections equipped with Siemens signal controllers (M52) and a Road Side Unit (RSU) that broadcasts SPAT information to approaching vehicles and an LBS server.
- A LBS managing data filters to sort shared information among appropriate users (vehicles and RSUs) based on vehicle direction, speed and location.

Paramics Simulation of the Safe Green Passage application

A simulation was done by UMTRI to evaluate the potential performance of the Safe Green Passage application. Three intersections were chosen along Grand River in Novi, Michigan, starting with Drake Road, then Halstead Road, and ending at an M-5 exit ramp. These intersections were chosen because they were representative of a typical environment; in addition, they were already modeled in the Vehicle Infrastructure Integration (VII) Test Bed simulation, and the Southeast Michigan Council of Governments (SEMCOG) had signal timing information available for the signals being modeled. Signal timing was taken from the Road Commission of Oakland County (RCOC) Sydney Coordinated Adaptive Traffic System (SCATS) database. A full description of the Paramics simulation and modeling effort is given in the appendix of this report. This simulation analysis was done at UMTRI by Francois Dion, P.E., PHD, now at University of California – Berkeley. The following is a summary of the detailed simulation results.

The model-constrained system recommended speeds between the speed limit at the high end and 60 percent of the speed at the low end. The 60 percent value limit is subjective and based on the logical thought that a vehicle driven at less than that speed would draw undesirable attention from other drivers who do not know the reason for the slow speed. Ten simulation runs were averaged for each result. The four metrics measured include Travel Time, Total Delay, stopped delay, and number of stops. The following observations were made:

1. As travel demand increases, travel time increases along with stop delays
2. As travel demand increases, travel time changes from +2 percent (better) to -2 percent (worse)
3. As travel demand increases, 40 percent stop delays decrease to 10 percent (worse)

4. As travel demand increases, number of stops decreased from -55 percent to -25 percent (worse)
5. Increase in market penetration rate, decreases effectiveness
6. With SPAT there is a 15–25 percent increase in travel time
7. As distance to intersection increases, overall performance improves
8. Distance between intersections sets maximum distance for improved performance
9. Increase in market penetration rate; biggest change occurs between 5 and 30 percent
10. With SPAT; 50 percent reduction in the number of stops and stop delays
11. Reductions can be significant when close to intersection (up to previous intersection)
12. Small impact on large network if only a few intersections are equipped
13. Overall effect is to slow down traffic, thus increasing travel time
14. Benefits decrease with increased traffic demand; slower vehicles ahead reduce desired speeds
15. Uncertainty of left and right turns affected by unknown queue lengths, oncoming gaps, cross-traffic gaps, etc.
16. No benefits are observed when distances greater than the previous intersection are used
17. All simulations done with fixed signal timing; dynamic signal timing is problematic
18. Vehicle needs trip origin, destination, and route to determine which intersection SPAT lane to use
19. Must be able to load SPAT data from all required intersections in path
20. Uncertainty of path results in confusing driver information generation

Overall, the benefits of this application decline the farther a vehicle is from the next intersection in its path, at least up to the previous intersection. There are no measureable benefits found when trying to modulate the speed for a vehicle that is more than one intersection away from its current location. Further, there are many reasons why the necessary speed for even the next intersection cannot be predicted. A sample list follows:

- High travel demand; too many vehicles on the road; unable to control recommended speed well
- Queues in lane at intersection unknown to application algorithm
- Other drivers' turning movements unknown to application algorithm
- Other drivers turning into lane in front minimize desired speed options
- Dynamic signal timing is non-predictable by application algorithm

A summary of the simulation results indicates that the major impacts to traffic efficiency are negative when using a long-range, dual-mode SPAT application.

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Project Timeline

The following activity descriptions are drawn directly from project quarterly reports.

4Q 2010 –

The project team discussed and selected two intersections on Telegraph Road for the location of test sites. HRC has taken the task to identify correct controller part numbers with the Road Commission of Oakland County (RCOC). UMTRI has begun the CONOPS requirements and simulation of performance. Early results indicate limited potential success to achieve the full performance expected. More studies will confirm. MDOT project manager specified additional requirements for the vehicle equipment display to enhance usefulness to the driver.

Requirements development has been started; initial draft completed by the end of October. The requirements included definition and type of display and functionality.

Two Signal Controllers and two DSRC units were purchased in the next month and shipped to Institute for Information Industry for modifications. Material transfer forms have been submitted.

Project kick-off meeting among the key stakeholders occurred September 16, 2011. Attendees included UMTRI, MDOT Project Manager, Telcordia rep, Institute for Information Industry Project manager, Hubbell, Roth and Clark and Telcordia.

1Q 2011 -

An agreement among the team members settled on a system configuration consisting of a modified Siemens controller, a Taiwan partner's I-VSCG-RSU V1.0, and Taiwan Partner's On-board Equipment (OBE) DSRC module. UMTRI initiated the purchase of the I-VSCG-RSU equipment per contract agreement. Siemens is in process of making software changes to the MK52 controller to accommodate

broadcasting of SPAT information for left turn phases. Release was expected by the end of January. UMTRI initiated procurement immediately. Required interface specifications will not be completed until after the release of the modified unit.

Simulation results have been analyzed to determine the communication requirements for the SPAT application. Due to limited benefits of a vehicle having SPAT information beyond the distance between any two SPAT-equipped intersections (typically ranges beyond one mile), long-range communications are not required. To achieve greater benefits beyond one section, control of the signal timing would be useful but would also require coordination of the entire road network, full penetration of equipped vehicles, and require navigation services and origin-destination information for each vehicle. For these reasons, the demonstration was constrained to a limited implementation that required minimal information to be exchanged and provided to approaching vehicles.

A meeting was scheduled with the RCOC RSU installer (Glen Davies, RCOC installation and technical field support) to discuss the equipment installation requirements and resolve any issues with mounting locations. A limited mounting survey was required to establish line-of-sight communication path for the DSRC radios. DSRC, at 5.9 GH, operates line-of-sight, meaning any obstructions can diminish signal strength dramatically. Even tree leaves can absorb sufficient energy from the transmitted signal to jeopardize reliability. In this demonstration, fully suitable intersections could not be found and signal strength was compromised. Trees in the median of Telegraph Road could not be removed and compromised the signal strength along an approach to one of the intersections used for the demonstration.

2Q 2011 –

Per UMTI's contract, two Siemens controllers (M52), two Taiwan partner's I-VSCG-RSU V1.0 RSEs, and Taiwan Partner's OBE DSRC modules were procured for the integration and testing of the system.   One set was sent to the Institute for Information Industry for bench testing, and one set was sent to Oakland County for evaluation and confirmation of the physical installation requirements. The Siemens controllers are the same versions being used by the Telegraph SPAT corridor project. Institute for Information Industry is integrating the components to provide the system demonstration. The interface documentation for the Siemens controller was provided to the Institute for Information Industry to start that process. Institute for Information Industry visited the demonstration site on March 17, 2011, and met with the team. They brought a cellular card and their OBE module to confirm their module would work in the United States. It did. A site visit was made by the project team to understand the physical layout of the test site including placement of nearby boulevard cross-over and cross-over signals.

Institute for Information Industry will complete the integration and testing needed for the demonstration targeted for June or July. The vehicle module will require some modifications to the Human Machine Interface (HMI) to accommodate a novice driver as well as more technical information to accommodate the engineering evaluation of the system's performance. For example, part of the display may contain a dimensionless bar graph indicating whether the driver should speed up or slow

down to make the next green light. Other displayed information may contain the current state of the signal being approached and the count-down timing when the state will change.

A meeting was held with an RCOC installer (Glen Davies), and HRC, to discuss the equipment installation requirements and resolve any issues with mounting locations. The equipment needs to be installed in two Oakland County intersections along Telegraph road. MDOT has released a Request for Proposal (RFP) for a contractor to provide those installation services. RCOC and MDOT met to discuss installation, resources, and funding needed to complete the work.

The Siemens controllers were purchased from Carrier & Gable, who were responsible for shipping, handling and insurance. One controller unit was shipped to Taiwan for system testing and one unit was shipped to Glen Davies at RCOC.

One RSU purchased from Institute for Information Industry was sent to RCOC, and one was retained by Institute for Information Industry for testing then shipped later for installation by RCOC.

Project conference calls among the key stakeholders (UMTRI, MDOT, Institute for Information Industry, Telcordia, HRC) occurred January 3, 2011 and February 9, 2011, to coordinate and review status and findings. Minutes have been distributed to the attendees. A face-to-face meeting was held March 17, 2011, with our Taiwanese partners (Frank C. D. Tsai, Institute for Information Industry, Cheng-Hsuan Cho, Institute for Information Industry and T.H. Yang -- ICP DAS) and our local Team members (Dick Beaubien, Colleen Hill, Danielle Deneau, and Glen Davies). The meeting was held at an HRC conference room in Bloomfield Hills and included a site visit to the demonstration site location.

3Q 2011 –

A draft requirements document was distributed to the Institute for Information Industry team in April and continually updated later. The Institute for Information Industry team has received all of the required equipment to develop and test the working Safe Green Passage application. The software has been completed and underwent testing in Taiwan. To assist in bench testing the system, RCOC provided signal timing data for the two demonstration intersections.   The team targeted August 1, 2011, for a demonstration/presentation.

This is the timing of the events working up to the August 8, 2011, demonstration:

1. RSU(2) and Siemens Controller(1) shipped from Taiwan   7/15/11
2. RSUs and Controller received by RCOC   7/20/11
3. RSU and controllers installed by RCOC   7/21/11 – 7/22/11
4. Taiwan Team arrives in Michigan   7/25/11
5. System and application Setup and testing   7/26/11 – 7/28/11
6. Functional confirmation completed   7/28/11
7. Demonstration rehearsal – finalize program   7/29/11
8. Present and demonstrate application to MDOT   8/1/11

Software implementation was completed and underwent bench testing. Equipment was shipped to the United States and installed at the Telegraph Road intersections of Hickory Grove and Long Lake by July 22, 2011.

4Q 2011 –

The August 1, 2011, demonstration was moved to August 8, 2011, to accommodate attendee's schedule. The Institute for Information Industry team arrived from Taipei August 1, 2011, and met with RCOC, HRC and UMTRI on August 2, 2011, to test the equipment sent to RCOC. Several problems were found and fixed, requiring a reconfiguration, a different cellular card, and software changes to the signal controller protocol due to a misinterpretation of the specs. Once the equipment was functional, vehicle testing found additional issues with the equipment at the test site. The T-Mobile cellular service was weak along the Telegraph corridor at that location, resulting in signal drop-outs. A change in service is recommended for future use. Further, the DSRC RSE located on the signal poles in the median requires line-of-sight transmission to oncoming vehicles. The placement of the poles was partially blocked, preventing signal reception past approximately 800 feet where the curvature of the road limited the line-of-sight. While this was deemed adequate for this demonstration, the pole mounting location is being adjusted for future use. Prior to the demonstration, a few refinements were made to the HMI display to improve novice driver utilization and de-emphasize engineering evaluation features.

The demonstration to MDOT management successfully occurred on August 8, 2011, as planned. After a one-hour presentation and explanation at HRC, the Institute for Information Industry Team took the MDOT attendees around the test course with successful demonstration of the dual-mode SPAT functionality. After the project demonstration on August 8, 2011, the MDOT Team requested Institute for Information Industry to leave the demonstration hardware (OBE) with RCOC for six months to support any potential additional demonstrations by MDOT. An agreement was made to return the vehicle equipment to Institute for Information Industry at the end of that period. A press release titled "MDOT and Taiwan to collaborate on Intelligent Transportation Systems project" was given October 7, 2011, to Bill Shrek, MDOT Director of Communications, for publication.

The two RSE controllers and transmitters will be left in place for the foreseeable future. These are located at Telegraph Road and Hickory Grove and at Telegraph and Long Lake roads. It should be noted that the equipment is developmental level hardware and not designed for long-term outside use. It was subsequently decided to return the equipment to the Institute for Information Industry.

The MDOT management demonstration meeting described above included MDOT attendees Steve Cook, Collin Castle, and Matt Smith.

Project Completion

At MDOT's request, the original project completion date of June, 2012, was extended one year to June 1, 2013. This was intended to support additional demonstrations of this technology if the opportunity presented itself. This would be supported by funds left over from equipment purchases that were less

costly than original estimates. An effort was made to set up the SPAT equipment for a demonstration for the MDOT Director's delegation during the Detroit AASHTO Conference in October 2011. However, when the equipment was installed, the team had connection and communication issues that prevented equipment from working. An effort was made to send the equipment back to Taiwan for repairs, configuring, and testing. Upon return and reinstallation, the equipment still did not work. This reinforced the conclusion that this type of deployment without local support of the hardware is very difficult. The effort was subsequently stopped. MDOT asked Glen Davies of the RCOC to ship the hardware back to the Institute for Information Industry owners per the original agreement. This was completed on December 1, 2012.

Lessons Learned

Overall Effectiveness of Safe Green Passage application

- Simulation of the Safe Green Passage application using several thousand virtual vehicles indicates that some benefits can be obtained from the application under ideal conditions, i.e., light traffic and close proximity to the approaching traffic signal. As travel demand increases, the number of stops made decreases, but the overall travel time increases for the subject vehicle as well as the traffic overall.
- No benefit can be found if the vehicle is farther away than the previous signal.
- This application can only work if all of the controlled signals are fixed timing. Dynamic signal timing, as it is currently implemented, cannot reliably work with Safe Green Passage.
- The DSRC RSE technology loses signal strength with tree obstructions. The intersections used in this demonstration coupled with the available poles on which to mount the equipment resulted in limited line-of-site reception. While adequate for the demonstration, the reception should be significantly improved for a real deployment. Perhaps some trees should be removed or new pole locations added.
- Similarly, the Institute for Information Industry selected T-Mobile cellular data service and Air Card for use before coming to install the equipment. Unfortunately, the T-Mobile service has a weak signal location halfway between the selected demonstration signals. The resulting signal drop-outs led the project team to change the service to Verizon, but only after the project demonstration meeting was held.

Conclusions

This multipath SPAT communication system was demonstrated to provide signal phase information to the driver using both cellular and DSRC. At distances outside the capabilities of DSRC, cellular communication provided signal phase information to the driver's in-vehicle display in 3-5 seconds using 3G service. Once in range (approximately 1,000 feet) of the signal, DSRC provided signal phase information near real-time to the driver's in-vehicle display.

While on the surface, the Safe Green Passage application seems to have potential to assist the driver, in-depth analysis of the details required to implement the application reveal many weaknesses that inhibit its usefulness. Among the weaknesses are a limited speed-range window in which to maneuver coupled with other vehicles on the road interfering with a driver's freedom to adjust his or her speed as needed, thus keeping the Safe Green Passage application from being beneficial. This is true when the vehicle is approaching the next signal equipped with SPAT. When the vehicle is more than one signal away, no benefits can be distinguished. Also, dynamic signal systems prohibit the use of Safe Green Passage due to the potential of providing wrong signal timing information to the driver. For these reasons, further development of the Safe Green Passage application will not be pursued at this time.

APPENDIX

Reports available on request:

1. *Paramics SPAT Broadcast Application – PDF*
2. *SPAT Simulation Result Summary Slides - PDF*
3. *Institute for Information Industry System Overview Slides- PDF*