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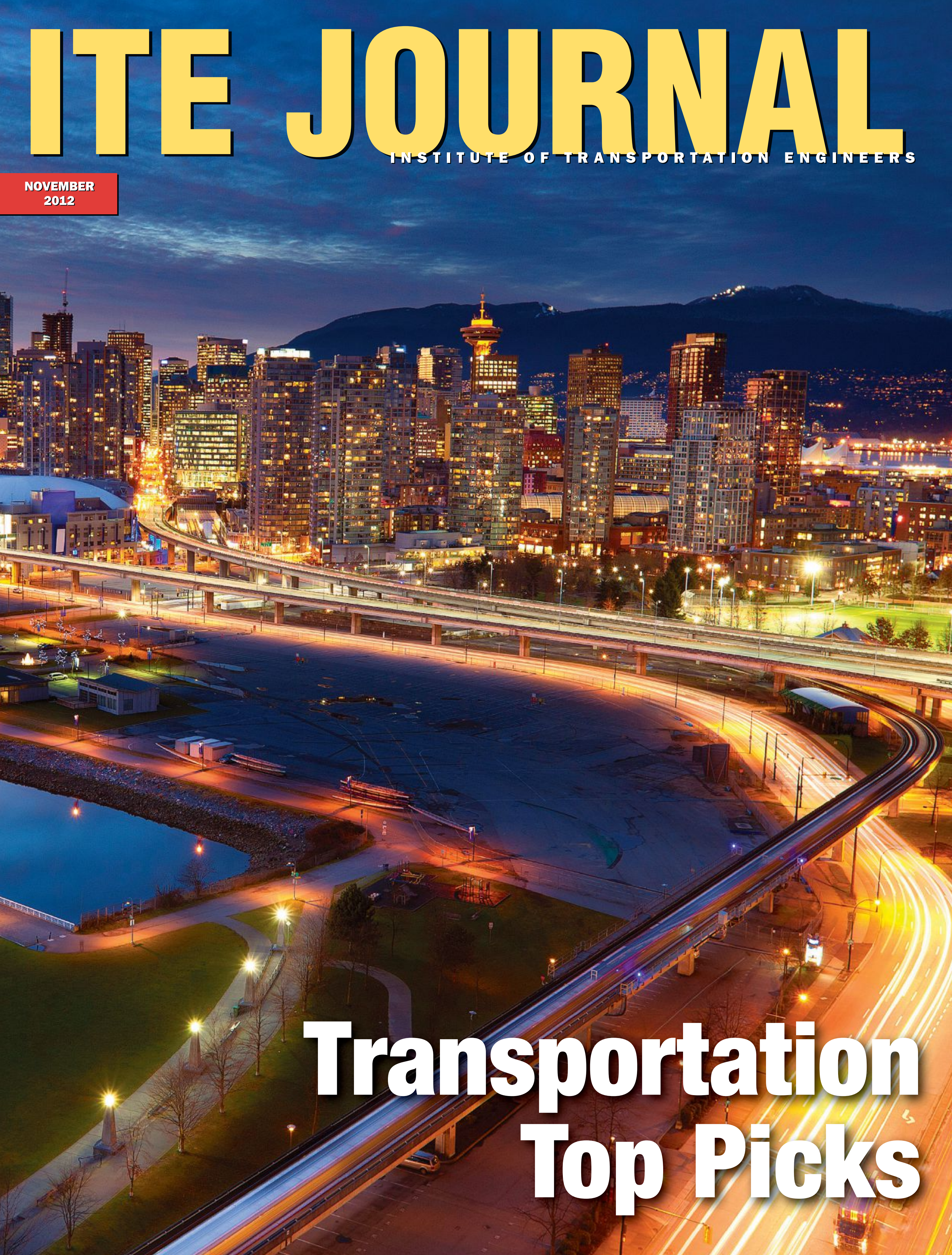

Transportation Top Picks

Upgrading Citywide Traffic Signal Systems Over Broadband Wireless Mesh Networks

Wireless mesh networks have become a more frequently used method of communication for traffic applications. The City of Chattanooga, TN, USA, is upgrading its traffic signal system, which will eventually connect approximately 400 signals in the region. This paper shares the experience gained and insights learned through this upgrading process.

BY JIDONG YANG, PH.D., P.E., JOHN W. VAN WINKLE, P.E., AND STEPHEN E. MEYER, P.E.

Introduction

The Chattanooga, TN, USA, metropolitan area has experienced dramatic growth in recent years. With the incipient arrival of Volkswagen Group of America and Amazon.com, tremendous growth is anticipated in the next two decades. This unprecedented growth has brought employment opportunities to the region, but also has burdened the aged transportation infrastructure with heavily increased traffic demand that has already caused significant congestion and delays. The City of Chattanooga, as the leading agency, is coordinating with other stakeholders in the region, including the Tennessee Department of Transportation (TDOT), the regional planning agency, transit agencies, counties, and cities to design and implement a regional intelligent transportation system (ITS). The system will encompass approximately 400 signals with traffic-responsive and adaptive control features. Surveillance cameras and dynamic message signs are to be deployed at strategic locations for real-time traffic monitoring and roadside information dissemination. The system also features center-to-center communications from the city's new traffic operations center (TOC) to other centers in the region, including the Tennessee Department of Transportation Region II Traffic Management Center (TMC), the Hamilton County 911 Center, and the Chattanooga Area Regional Transportation Authority (CARTA) Operations Center. These center-to-center communications aim to facilitate a concerted effort toward proactive traffic management in the region. A traveler information system covering the local street network is also considered to provide real-time travel information via Web sites and/or smart phone applications to registered users. As the first step of this regional effort, the City of Chattanooga has recently upgraded its central business district (CBD) traffic signal system with a brand new TOC. Continuous bidirectional communication has been established between the TOC and field traffic control devices in the CBD area via a broadband wireless mesh network (WMN), currently being installed by the city's Information Services Division. In light of the magnitude and the WMN-based communication feature, the project represents one of few pioneering ITS endeavors of its kind in the United States having 100 percent of the ITS communications on a wireless network.

WMNs have many advantages over the wired and traditional wireless options. Without cabling needs, the WMN can be installed quickly with low cost and exceptional flexibility. Compared with traditional wireless technologies, the cellular service is relatively inexpensive and offers low data rates. The wireless local area networks (WLANs) have limited coverage. The wireless metropolitan area networks (WMANs) lack mobility support and impose the line of sight (LOS) requirement.[1] In contrast, WMNs provide low-cost, wide-coverage wireless broadband Internet access for both fixed and mobile users. They have been deployed for U.S. metropolitan areas of various sizes to assist with public services and safety personnel. For example, Tucson, AZ, deployed a WMN for its traffic signal management system, which saves approximately $200,000 per year in telecommunication fees and also allows for video transmission, which was not possible using phone lines.[2] The City of Midland, TX, implemented a WMN to manage traffic and create a foundation for citywide service delivery.[3]

Given the recent increase in WMNs, it should also be recognized that many municipalities and transportation agencies have invested in optical fiber infrastructure, which typically is limited by specific routes and splice locations. WMNs enable municipalities and government agencies to leverage these fiber deployments to effectively extend coverage and address both fixed and mobile communication needs. According to a cost comparison example by TROPOS,[4] a combination of fiber and wireless mesh to cover a 6-square-mile area (25 intersections) can result in a greater than 50 percent cost reduction compared with fiber alone. Further, with low or no incremental cost, WMNs can be designed to simultaneously support multiple municipal applications, such as ITS, mobile public safety, mobile city workforce, street lighting, automated utility meter reading, and Smart Grid.

The City of Chattanooga is deploying a WMN based on the IEEE 801.11b/g/n standard utilizing the 2.4 gigahertz (GHz) band. One of the key applications that the WMN aims to support is the regional ITS currently being deployed, which includes features of traffic responsive and adaptive traffic control. Lan and others pointed out that the suitability of WMNs for mission-critical infrastructure applications, such as real-time traffic control, remains by and large unknown, as protocols typically employed in WMNs generally are not designed for real-time communications because of stringent requirements for the reliability and latency of the data exchanges.[5] However, the recent advancement in WMN technologies has greatly mitigated these issues. The main purpose of this paper is to share the experience and insights learned so far through this system deployment process and help facilitate similar efforts in the future.

WMNs represent an emerging trend in communication systems for various applications. They are dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves, effectively creating an ad hoc network.

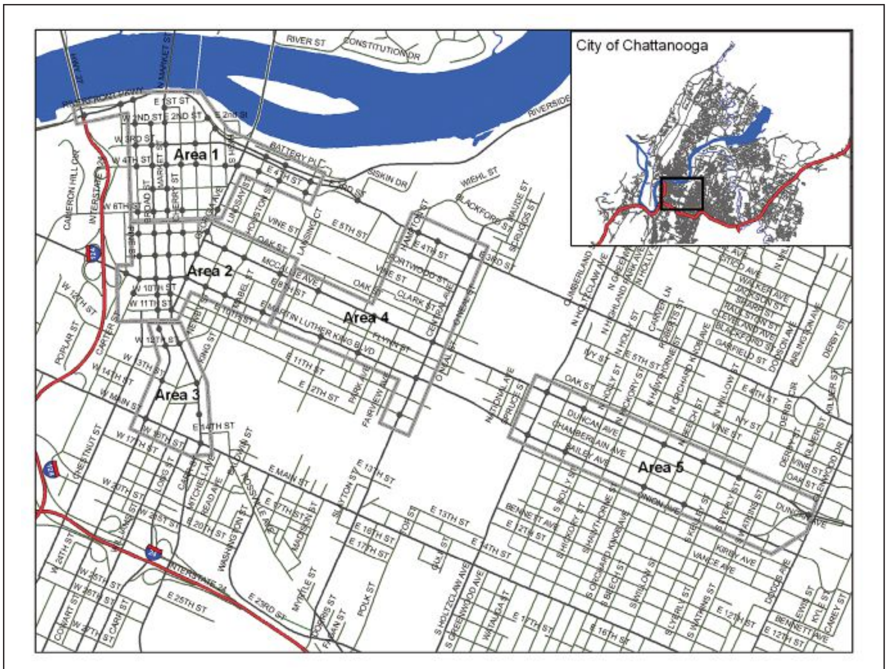

Figure 1. Chattanooga CBD traffic signal systems by control area.

Legacy System

Since the 1980s, the City of Chattanooga had used a Traconex system to manage the traffic signals within the CBD. The system consisted of a central computer interconnected with master control units through dedicated phone lines. Each master was connected with a number of individually addressable intersection controllers through twisted pair wires. Figure 1 depicts the five masters used for five control areas in the CBD. NEMA TS-1 cabinets, Traconex controllers, and traditional conflict monitor units (CMUs) are part of this legacy system. After years of usage, this system was having frequent hardware failures and was approaching the end of its useful life, and the city recently updated its network servers and software. The old traffic signal system control software was no longer compatible with the new servers and software.

CBD Signal System Upgrade

The CBD signal system upgrade includes three major components: (1) deployment of a WMN for system communication, (2) installation of a new TOC, and (3) upgrade of the field signal control equipment for 86 intersections within the CBD.

WMNs represent an emerging trend in communication systems for various applications. They are dynamically self-organized and self-configured, with the nodes in the network automatically establishing and maintaining mesh connectivity among themselves, effectively creating an ad hoc network. This feature brings many advantages to WMNs, such as a low upfront cost, easy network maintenance, robustness, and reliable service coverage.[6] For traffic control systems, wired connections, such as copper and fiber, are the traditional communication schemes. The new technological advancement in wireless communication made broadband WMNs an attractive communication alternative for traffic control systems. In September 2010, the Chattanooga Electric Power Board announced the first gigabit broadband service in the United States. Using the Electric Power Board's gigabit fiber infrastructure as a backbone, the City of Chattanooga is installing a WMN for citywide public services. The WMN is based on the IEEE 802.11b/g/n standard and uses the unlicensed 2.4 GHz band. Figure 2 presents the concept of WMN communication.

The illustration shows the two types of WMN nodes: mesh nodes and root nodes. Mesh nodes do not connect to the wired network and instead forward local and relay remote user traffic from other mesh nodes to the root nodes assigned. Root nodes, by contrast, physically connect to the underlying wired network and are responsible for passing traffic between a collection of mesh nodes and the backhaul network. Because of the redundancy in mesh network design, user traffic can be routed around network faults to self-heal when service is interrupted.

The new TOC was installed in office space adjoining the traffic engineering offices for ease of access and control. The traffic server was placed at the city's network operations center (NOC) and maintained by the city's Information Services Division. The TOC hosts the main workstation connecting to the traffic server at the NOC through a fiber optic cable. Another workstation was installed at the traffic operations building and connected to the NOC via a WMN access point. A fiber link will eventually be installed to connect the traffic operations building with the NOC. The traffic operations staff was also provided with a laptop computer, which is used as a mobile workstation for troubleshooting and maintenance. The server and each workstation run a central traffic management software program (TACTICS) developed by Siemens, which is able to monitor and control the local traffic controllers wirelessly through the WMN.

The CBD field traffic equipment was upgraded by area during off-peak periods to minimize traffic disruption. The CBD signal system consists of five control areas (Figure 1). Because there was no prior experience with this type of system conversion, to accommodate the learning process and minimize disruption to traffic, the upgrade started at Area 5, the most remote CBD area, and proceeded in a backward order to Area 1. The upgrade includes replacing cabinets, traffic controllers, and malfunction monitor units (MMUs), and installing Ethernet switches, radios, and antennas to allow bidirectional communication between the TOC and the field equipment through the WMN. Specifically, all Traconex controllers were replaced with eight-phase Eagle EPAC M52 controllers. The CMUs were replaced by MMUs. All NEMA TS-1 cabinets were replaced by NEMA TS-2 Type 2 cabinets, of which 80 percent were supplemented with additional load switches. Each cabinet was equipped with an Ethernet switch, an IEEE 802.11b/g/n compatible radio device, and an omnidirectional antenna mounted on the top of each cabinet.

To facilitate the deployment process, a detailed work plan was developed (Figure 3) with the leading party identified for each task. In particular, the city's Traffic Engineering Division oversees the entire process. The Traffic Operations shops, the signs and signals maintenance, and construction subdivision of Traffic Engineering Division conduct standard equipment testing before and after equipment installation. The city's Information Services Division leads the effort on WMN deployment.

Figure 3 shows the traffic database conversion conducted by Traffic Engineering before the TOC was installed. An Internet protocol (IP) scheme was developed to systematically allocate IP addresses for all the IP-addressable devices in each cabinet. Eight consecutive IP addresses were allocated for each cabinet. (Note that this scheme was developed according to the mesh grid areas, which are different

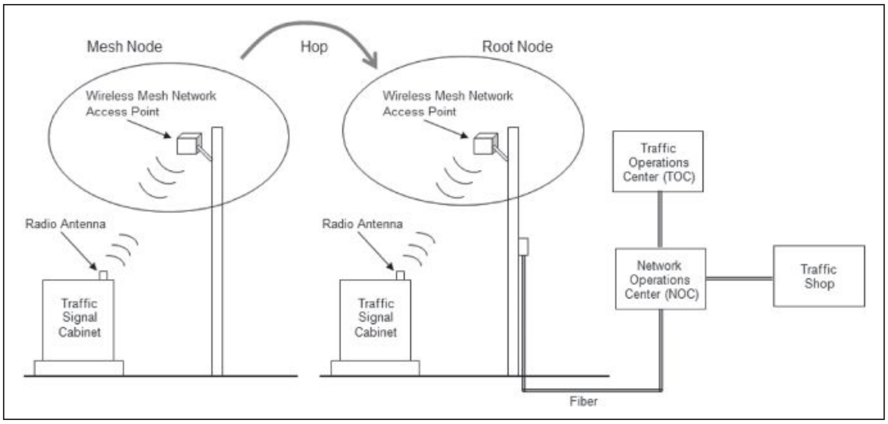

Figure 2. e-communication scheme via WMN.

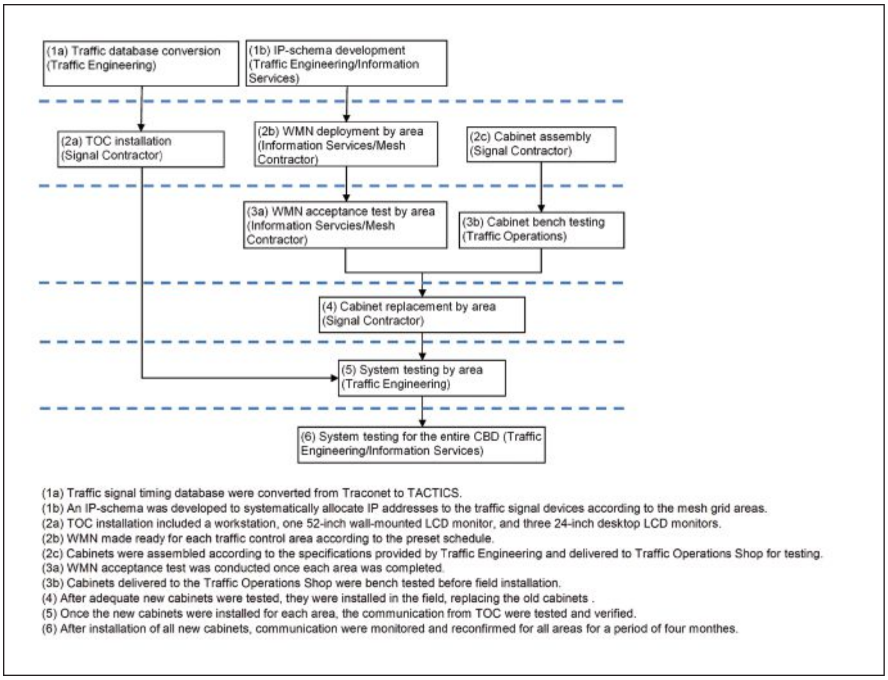

Figure 3. Work plan of CBD signal system upgrade.

than the traffic signal control areas.) IP communication offers the advantage of increasing the number of types of devices that can be implemented, which allows different manufacturers to integrate their equipment into the system. Three tasks—TOC installation, WMN deployment, and cabinet assembly—were undertaken simultaneously to ensure timely delivery of the project. As the WMN rolled out, acceptance tests were conducted by area. Bench testing was conducted for all new cabinets before they were installed in the field. The cabinet replacement was initiated after adequate backlogs of tested cabinets were accumulated. After each cabinet was installed, radios and antennas were configured and tested by the contractor on site, and the communication was verified from the TOC through TACTICS. Subsequent system testing was conducted for each completed area, and finally for the entire CBD.

Without prior experience and with multiple parties involved in the process, effective planning and coordination throughout the deployment process is the key to project success.

Summary

Without prior experience and with multiple parties involved in the process, effective planning and coordination throughout the deployment process is the key to project success. For better coordination, a concrete work plan and backup plans for equipment installation should be developed and agreed upon by all parties to address apparent and envisioned situations. With numerous technologies emerging in the ITS field, extra caution should be exercised to ensure that the various technologies and products are compatible. This requires thorough research and evaluation of alternative products. Additionally, it is critical for all parties, including contractors and various departmental staff, to understand the similarities and differences between the old system and the new system to ensure a seamless transition. Through the process, we have gained significant experience and would like to share some insights and lessons learned.

1. Since WMNs are relatively new to ITS applications, ITS engineers may not have specialized WMN knowledge. As such, a specialized WMN contractor is normally used. In this context, it is important to clearly specify the scope of work for the signal contractor and the WMN contractor, which are typically not under the same contract. For the Chattanooga CBD signal system upgrade project, the WMN contractor installed the WMN and the signal contractor installed the client radios for all traffic cabinets. Later, it was discovered that radios and antennas would be better handled by the WMN contractor for convenient configuration and troubleshooting during and after installation. Nonetheless, close collaboration between the WMN contractor and the signal contractor is required to identify and solve any communication problems at the system level. The downside of having the WMN contractor install radios and antennas is that the WMN contractor must also be involved with the signal contractor. For example, the cabinet assembling and radio installation has to be carefully coordinated to facilitate the fieldwork plan.
2. When it comes to system operations and maintenance, decisions need to be made clearly on who does what. Most ITS operations and maintenance activities are conducted by a traffic engineering department. Knowing that servers are normally integral parts of modern ITS systems, it seems to be well justified for an IT department to maintain the servers for safety and security reasons. In such cases, a standard operating procedure is recommended to clarify the responsibilities of each party under various circumstances.
3. For the Chattanooga CBD signal system upgrade, it would have been ideal if the WMN had been made ready before replacing the new cabinets. However, this was not practical for two reasons. First, successful installation and testing did not guarantee good radio coverage for all the cabinets to be installed afterward. We learned this while deploying the first control area (Area 5). Second, some unexpected delays in WMN deployment would have significantly affected the project schedule. For example, some delays were encountered when installing fiber root nodes for the WMN. With these considerations, the cabinets were installed before the WMN was ready for the rest of the control areas to maintain the original schedule. It turned out that this practice was a better choice because of the lack of experience in this type of emerging application and the constraint of the project schedule. However, the drawback was that the traffic control for these areas had to temporarily rely on the time-of-day plans stored at the local controllers before the WMN was made ready. Because there was a change in the manufacturer brand of controllers and operation, it was important to verify the before-and-after operation of the signal timing to maintain consistent coordination during the construction.
4. Provided that the WMN uses the unlicensed 2.4 GHz band, it is subject to interference from other Wi-Fi users in the vicinity. As part of the testing process, adjustments were made to minimize interference, including changing Wi-Fi channels, adding access points, adjusting radio power, and converting mesh nodes to root nodes. Because a thorough field survey was conducted before the WMN was designed and installed, root node conversion occurred only

in rare cases due to location-specific features, and these changes did not significantly increase the overall cost. The system communication status has been tracked on a daily basis to identify temporal and spatial changes. Continual adjustment has been made to improve the stability of the system.

5. For troubleshooting purposes, a dummy intersection (i.e., a stand-alone controller) was set up in TACTICS with direct Ethernet connection to the city's local area network (LAN). This setting was used for troubleshooting network communication issues to identify whether a communication failure is due to the LAN or wireless LAN (WLAN).
6. Depending on their age, many of the old signal systems do not have the feature of automatic clock adjustment for Daylight Savings Time. This needs to be considered during construction, when part of the old system and part of the new system will coexist and be consistent in operation. To synchronize the two systems, the construction needs to be scheduled by area or sub-area to not straddle the time changes. Otherwise, manual time adjustment in the field may be needed.
7. Close attention should be paid to the differences on how the legacy system and the new system implement traffic signal timing plans. Operations need to be checked and verified in the field for consistency.

Overall, the new system provides many advantages over the old system, including the following:

1. Continuous real-time communication via the WMN. With the new system, the city traffic operations and maintenance staff is able to monitor and diagnose the field conditions in real time and alerted to system and equipment malfunction or failure so that timely responses can be dispatched. The Traffic Operations staff has been receiving service requests from the public on a daily basis regarding the signal timing. With this new system, any signal timing adjustments can be handled instantaneously and remotely.
2. Sixteen megabits per second for data uploading and downloading per IP device. This bandwidth can be expanded up to 150 megabits per second if future needs arise. This allows for real-time transmission of closed-circuit television images to be installed in later phases.
3. Improved security with exclusive traffic server and Wi-Fi Protected Access (WPA-2) Enterprise.
4. This communication system can be used by all city departments in the future that require data transmission and monitoring between city facilities. Currently, the police and traffic engineering departments are using the system. Plans are to include the water/waste water department, the storm water department, the water quality department, the street maintenance department, the building inspection department, the recreation department, the Chattanooga Area Regional Transit Authority, and other government agencies. Communications system reliability is much higher today than with the previous twisted pair copper system because numerous city departments depend on the system for continuous operation 24 hours a day, 7 days a week. Police operations specifically require extremely high security with virtually 100 percent reliability, and Traffic Engineering receives the benefit of both being on the same system.

The regional ITS is still under development. The CBD upgrade is the first step. The next phase, which has recently started, is to upgrade 14 major arterials, including 115 signalized intersections in the region. As part of this upgrade, traffic responsive and adaptive traffic control features will be implemented. ■

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JIDONG YANG, *Ph.D., P.E., is the traffic signal systems engineer for the City of Chattanooga, TN, USA, and serves as intelligent transportation system (ITS) program manager overseeing the planning, design, construction, operations, and maintenance of the regional ITS in the Chattanooga metropolitan area. He holds a Ph.D. in transportation engineering from the University of South Florida and is a registered professional engineer in Tennessee and Florida. He is a member of ITE.*

JOHN W. VAN WINKLE, *P.E., is the city traffic engineer for the City of Chattanooga. He has more than 36 years of experience in the traffic engineering profession and has worked for the City of Chattanooga for the past 26 years, serving as the city traffic engineer since 1991. He received a B.S. in civil engineering and an M.S. in traffic engineering from the University of Tennessee. He is a Past President of both the ITE Southern District and the ITE Tennessee Section and has been active with the ITE International Traffic Engineering Technical Council. He is currently a member of the Public Agency Council and the Roundabout Committee. He is a fellow of ITE.*

STEPHEN E. MEYER, *P.E., is vice president of engineering and development for Excalibur Integrated Systems, Inc., in Chattanooga. Excalibur designed and is building the wireless mesh network for the City of Chattanooga. He has served in various positions for the ITE Tennessee Section and is a registered Professional Engineer in 16 states. He is a member of ITE.*