Chapter XVII
A Wireless Mesh Network Platform for Vehicle Positioning and Location Tracking

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ABSTRACT

Large urban areas in North America as well as many other parts of the world are experiencing unprecedented and soaring congestion problems. It is imperative that modern societies upgrade their transportation systems in order to remain competitive, and maintain the high quality of life and social wellbeing. Current practices in Intelligent Transportation Systems (ITS) data gathering are dominated by the use of point detectors for surveillance, and wire-line communication networks for data transmission. Reliance on point detectors is losing appeal due to detector reliability issues, the cost of building and maintaining detector networks, and potential traffic disruption during construction and maintenance of these networks. This chapter describes a novel wireless mesh network platform for traffic monitoring. The platform uses traveling cars as data collection probes and uses wireless municipal mesh networks to transport sensed data. The platform assumes that cars or drivers' mobile devices are equipped with the *widely adopted low-cost Bluetooth wireless technology. Field trials of the proposed platform demonstrated its capability to track cars traveling at speeds of 0 to 70 km/hour. The platform was able to track cars as they travel and turn on a typical road network. In addition, the platform was used to approximate car speeds through determining the change in position in a time period. The preliminary results indicated an accuracy of ± 10%- 15%. The chapter describes the architecture, implementation, and field-testing of the proposed platform. It also discusses aspects of large-scale deployment of the proposed platform to cover large geographic areas.*

INTRODUCTION

Large urban areas in North America as well as many other parts of the world are experiencing unprecedented and soaring congestion problems. It is imperative that modern societies upgrade their transportation systems in order to remain competitive and to maintain the high quality of life and social well being that we rightly prize so highly. Transportation management agencies are under increasing pressure to adopt more innovative approaches to enhance the efficiency of existing transportation networks. Solutions in the form of building more roads are neither desirable nor feasible in many cases. A more feasible approach would be to maximize the use of the capacity already afforded by existing networks before expansions can be justified.

Over the past two decades, numerous technologies and methods have been developed and deployed to support real-time monitoring of transportation systems (Zheng, Winstanley, Yan, & Fotheringham, 2008). However, the installation and maintenance costs as well as the inherent limitations (e.g., power consumption, telemetry) of existing technologies constitute a major impediment towards implementing continuous real-time monitoring in a cost-effective manner. The efficiency and economic viability of current monitoring practices not only have limited the deployment of such technologies, but many transportation agencies still do not have an effective or systematic strategy for traffic monitoring.

The "heart" of traffic monitoring lies in gathering and using real-time system information to enable proactive management and control of the network. Current practices in monitoring traffic systems are dominated by the use of point detectors for surveillance, and wire-line communication networks for data transmission. In most large metropolitan areas, major freeways and arteries are covered by pavement-embedded induction loop detector stations to measure traffic volumes and speeds. Gathered information are typically aggregated over 20-30 seconds then transmitted over copper or fiber optic wire lines to the nearest operations centre. This approach is losing appeal due to detector reliability issues, the cost of building and maintaining detector networks, and potential traffic disruption during construction and maintenance operations. Modern off-road detector technologies have improved significantly over the past decade, resulting in new and more mature detector types based on radar, ultrasound, infrared, and acoustic technologies. With the inherent limitations of existing technologies, a new technology that allows for cost-effective real-time and continuous monitoring of traffic systems is urgently needed.

In this chapter, we propose a novel wireless and cost-effective platform for ITS monitoring. The novelty of the platform lies in using traveling cars equipped with Bluetooth devices as probes for collecting raw traffic data. The platform employs municipal wireless mesh network (WMN) infrastructure to gather and transport real-time traffic data to a centralized ITS server. The platform does not require installation of infrastructures which results in further cost-effectiveness by exploiting any existing WMN infrastructure and the wide spread use of Bluetooth devices. It is estimated that 80% of the cars by 2009 will be Bluetooth enabled (Bluetooth SIG, 2006). In case a car is not Bluetooth-enabled, mobile Bluetooth devices in the car such as a driver's cell phone can be used. The cost-effectiveness of the platform is achieved by using unlicensed wireless technologies in addition to common hardware and open source software for building the platform.

The use of location-based sensing technologies and wireless communication devices has been steadily gaining grounds in the industry because of their obvious advantages relative to point detector surveillance technologies. An emerging category of solutions that promises cheaper and broader network coverage involves the use of traveling vehicles as probes transmitting information about the surrounding traffic environment as they progress through the road network. As vehicles travel through major and minor roads, they can serve to collect and transmit valuable traffic information.

Wireless technologies used to collect traffic data can be classified into satellite-based (e.g., Global Positioning System (GPS)) and terrestrial-based technologies (e.g., cellular networks, IEEE 802.11). Selecting a feasible technology for a particular application would involve evaluating trade-offs between the cost of building data collection system, accuracy of collected data, bandwidth available for transmission, system capacity, and ubiquity of the technology. An overview of the most commonly used technologies is provided in the next section.

This chapter describes the architecture, implementation, and field-testing of a novel wireless platform for traffic network monitoring. Performance results of two small-scale field deployments are presented. In addition, considerations for large-scale deployment of the platform and the main technological, economical, and operational factors that affect such deployments are also discussed.

RELATED WORK

This section summarizes the relevant literature on using wireless technologies for vehicle tracking, and provides a brief overview of the WMN technology as it pertains to the proposed platform.

Wireless Vehicle Tracking

In most large metropolitan areas, in order to measure traffic volumes and speeds, major freeways and arterials are covered by induction loop sensors that are embedded into pavements. Gathered information are typically aggregated over 20-30 seconds and transmitted over copper or fiber optic wire lines to the nearest operations centre. At a typically centralized operations centre, ITS software processes the gathered information and produces recommendation on how to, for example, divert traffic to avoid congestions. These systems face many problems. Using induction loop sensors is losing appeal due to sensor reliability issues, cost of building and maintaining detector networks, and potential traffic disruption during construction and maintenance operations. Modern off-road detector technologies have improved significantly over the past decade, resulting in new and more mature detector types based on radar, ultrasound, infrared, and acoustic technologies.

In general, the wireless technologies used to collect traffic data can be classified as satellite-base such as GPS or terrestrial-based such as cellular networks and IEEE 802.11 (i.e., Wi-Fi) technologies. There is typically a trade-off between cost of building a data collection system, accuracy of collected data, bandwidth available for transmission, system capacity and ubiquity of the technology among all these wireless technologies. The trade-offs indicate that no one technology is suitable for all applications.

Recently, there has been an increasing trend towards the use of terrestrial wireless systems for vehicle tracking applications. Satellite-based systems, while providing high positional accuracy, require relatively expensive equipment to locate and communicate vehicle positions (e.g. using GPS and cellular communication). Terrestrial wireless technologies have the advantage of providing more bandwidth and two-way communication, which potentially enables richer applications and information exchange.

GPS position information is very accurate with an error in the range of meters. Changes of the position within an interval of time give velocity information. However, GPS communication requires line-of-sight and consequently it cannot be used inside tunnels and urban areas with tall buildings (the urban canyon effect).

In order to provide tracking information, GPS is typically integrated with wireless communication systems. GPS can be coupled with Short Message Service (SMS) wireless technology to provide vehicle monitoring information to a monitoring server (Al-Rousan, Al-Ali, & Darwish, 2004; Young & Skobla, 2003). The system periodically sends location information each 5 or 10 seconds. However, the time taken to send an SMS message is dependent on the status of the cellular network (e.g. congestions). The expected massive amount of exchanged data makes the use of SMS-based systems both expensive and unreliable in most cases.

GPS may also be integrated with General Packet Radio Service (GPS) or Global System for Mobile communications (GSM) location services to support vehicle monitoring systems. In Zhang et al. (2005), the authors provide a comparison of using the Transmission Control Protocol and User Datagram Protocol to send the position information of the vehicle's on-board GPS module to the monitoring server via vehicle on-board General Packet Radio Service (GPRS) module. The GPRS-based systems can provide accurate position of the vehicle and real time monitoring, and are generally cheaper than the SMS-based systems. The disadvantages of this system include the requirement for installation of GPS modules in the vehicles, and the high operating costs for GPRS subscription and data transmission.

GSM-based location services were introduced in 1995 (Spirito, 2001; Broida, 2003). In general, two standard positioning methods can be used: (1) time of arrival and (2) enhanced observed time difference (E-OTD). The time of arrival method calculates the propagation period of a known signal sent by the mobile station (MS). This requires installation of location measurement units at each base transceiver station (BTS). However, this method does not require modifications to cellular handsets. The readings of three base transceiver stations are used to determine the location by triangulation algorithms. This method is known to be time-sensitive because one microsecond of timing error may result in approximately 300 meters of location error. To reduce such errors, the time difference of arrival (TDOA) method was proposed to enhance the accuracy of the TOA method.

The E-OTD method has three measurement parameters: observed time difference (OTD), real time difference (RTD), and geographical time difference (GTD). The OTD relies on the measurement of the TDOA between two BTS, the RTD is the synchronization error between two BTS (i.e. synchronization difference between two stations), and the GTD is the difference between the OTD and the RTD. This method was found to achieve errors in the range of 100 to 300 meters but it requires modifications to the MS to enable the OTD measurement.

Amongst the rapidly emerging communication technologies is Dedicated Short Range Communication (DSRC) described in IEEE P1609.3/D18 (2005). DSRC systems are being designed to provide short-range, wireless links to transfer information between vehicles and roadside units, other vehicles, or portable roadside units. DSRC is anticipated to be essential to many ITS applications that improve traveler safety, and decrease traffic congestion. Examples of such information transfer include: traffic light control, traffic monitoring, traveler alerts, automatic toll collection, traffic congestion detection, emergency vehicle traffic signal pre-emption and electronic inspection of moving trucks through data transmissions with roadside inspection facilities.

In addition, Bluetooth has been used for indoor object tracking. Two methods that use the Received Signal Strength Indicator (RSSI) to track objects are described in Huang et al. (2006). Bluetooth is a wireless cable replacement technology. It operates in the unlicensed Industrial Scientific Medical (ISM) Frequency range of 2.4 GHZ. Bluetooth is designed to be a low power and low cost wireless technology. Bluetooth is found in many electronic devices such as cellular phones, laptops, headphone, keyboard, and printers. Bluetooth devices can be implemented internally in these devices or can be added as a separate USB dongle. There are three classes of Bluetooth devices classified based on power level which is directly associated with the device communication range. Class 1 has a range of 100 meters where class 3 only has 10 meters of range.

Several research prototypes employed alternative wireless technologies. The Place Lab project, created by Hightower et al. (2006), had shown that using Wi-Fi hotspots and GSM-based cellular phones would efficiently provide vehicle location tracking in downtown of cities. Position error of the system was in the range of 20-30 meters even for different weather conditions. The main disadvantage cited was the dependence on Wi-Fi technology, which is not commonly used in portable devices, mainly due to the high power requirements of Wi-Fi devices and their relatively high cost compared to Bluetooth.

Hull et al. (2006), the authors of the MIT CarTel project, developed a computing system for collecting and processing information from mobile sensors mounted on automobiles. An embedded system on the automotives interfaces with different sensors in the car and transmits the sensor information to a server for processing. CarTel focused on handling intermittent network connectivity inherent in WMNs. For that purpose, a special network stack was developed. However, since CarTel relies on GPS to collect location information, the platform may not perform reliably within "urban canyons."

Wireless Mesh Networks

Wireless Mesh Networks (WMN), also known as municipal wireless networks (Lee, Jianliang, Young-Bae, & Shrestha, 2006; Akyildiza, Wang, & Wang, 2005; Farkas & Plattner, 2005), are posed to be a key infrastructure for enabling new applications in public safety, business, and entertainment. They are typically deployed in a quasi-stationary manner, where some mesh routers are stationary. This wireless infrastructure enables routing of information in a multi-hop manner. WMN nodes comprise mesh clients and mesh routers. Mesh clients, also known as On-Board Units (OBU), can be desktops, laptops, cellular phones. Mesh routers, also known as WMN Access Points (AP), can self-configure themselves to automatically build the wireless infrastructure that establishes and maintains mesh connectivity. Mesh routers typically provide access to a fixed structure network or to the Internet. Each mesh router has a domain of wireless coverage. An OBU is associated with one AP at a time, as long as it is in the router coverage domain. OBUs can move freely and associate themselves with different mesh routers, and may use Bluetooth or Wi-Fi for communication with the WMN APs. Although WMNs can be used for a large number of applications (Spirito, 2001; Khemapech, Duncan, & Miller, 2005), a number of general requirements and characteristics are shared among most of these applications. These characteristics include geographic coverage, cost-effectiveness, scalability, fault resilience, and privacy and security (Ilyas & Mahgoub, 2005; Karl & Willig, 2005; Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002).

The effectiveness of real-world WMNs for monitoring applications is determined largely by its ability to reliably cover larger areas for longer durations (Hać, 2003). WMNs may be formed by deploying hundreds or thousands of APs across large geographical areas (Ahmed, Shi, & Shang, 2003). APs are generally designed to have sufficient intelligence to gather and disseminate data, and to exchange information and cooperate in processing gathered data, thus enabling the monitoring of a large geographical area through distributed data processing and communication. WMN scalability involves ability to increase the size of coverage area in a manner that does not adversely affect WMN performance (Stoianov, Nachman, & Madden, 2007; Khemapech et al., 2005). Robustness involves ability of sensors and WMNs to tolerate faults or errors in operations (Cardell-Oliver, Smettem, Kranz, & Mayer, 2004). This requires WMN APs to have autonomous capabilities such as self-testing, self-configuring and self-healing (Yu, Prasanna, & Krishnamachari, 2006). The design of WMN must also incorporate security mechanisms in order to prevent unauthorized access and attacks (Wu & Tseng, 2007).

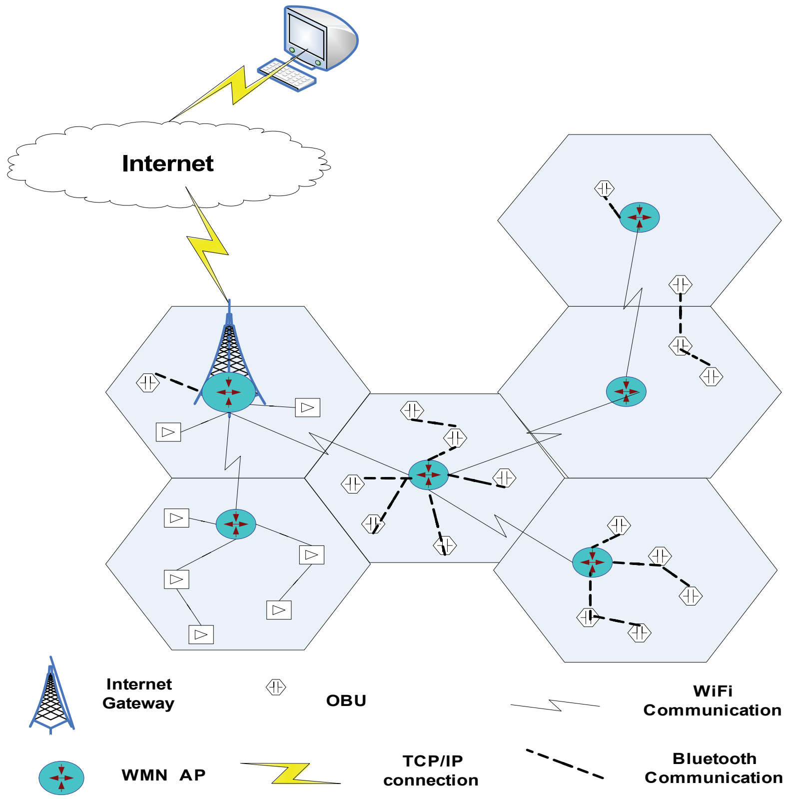
The autonomy of APs simplifies WMN installation and maintenance. Routers exchange data packets to update their routing tables. WMNs typically implement two types of routing protocols: proactive and on-demand routing protocols (Huhtonen, 2004; IETF RFC3626, 2003; IETF RFC3561, 2003). Proactive routing protocols are table-driven. Optimized link state routing (OLSR) is a proactive and table driven routing protocol where APs exchange OLSR “hello” messages periodically to build and maintain the routing table. This dynamic method of building the table enables self-configuring of the AP’s. “Hello” messages advertise the one-hop interfaces of each AP. This enables each AP to find information about its neighboring nodes and hence allows the AP to build and maintain its routing table. Since OLSR is a multi-hop protocol, each node forward a message to its immediate neighbor based on the contents of this routing table. The periodic exchange of hello messages also enables the WMN to recover from a failed link or node (IETF RFC3626, 2003). Whenever a change happens in the topology of the WMN, control messages are propagated through the network to announce this change, and update the routing tables maintained in various routers. The flooding of these messages, may potentially span a very large part of the entire network, may be disadvantageous.

On-demand routing protocols, or reactive protocols, do not require this flooding of update messages. The ad-hoc on-demand distance vector (AODV) routing protocol is an example of the reactive routing protocols. These protocols do not maintain routing tables for the entire network, but only requested routes are maintained. That is, routes are calculated only when there is a request to send data from a source node to a destination node. AODV maintains vectors of destinations’ routes and costs to use. This renders AODV as a better alternative for more static networks. In addition, AODV requires lower memory and processing power.

ARCHITECTURE AND OPERATIONS OF THE PROPOSED TRAFFIC MONITORING PLATFORM

The proposed platform uses traveling cars as probes transmitting information about traffic as they progress through the road network. The proposed platform adopts a hierarchical networking architecture, shown in Figure 1. With this hierarchical architecture, a geographic area is divided into adjacent but distinct hexagonal clusters/cell. Each cell is controlled by a centralized “head.” A WMN AP is configured to operate as a cluster head. It communicates with cars travelling in its geographical cell in order to gather application data. OBUs are sensors in the sense that they generate and transmit data to nearby WMN AP. APs will run software programs for gathering, and pre-processing of raw data. Only a few of WMN APs, called gateways, are connected to the Internet. APs exchange information to identify

Figure 1, A reference architecture for the proposed platform



their neighbors and identify gateway AP. WMN APs collaborate and forward collected data towards gateways. The WMN is used to transfer monitoring information, generated by OBU, to a centralized server typically at headquarters offices over the Internet. The set of OBUs represent the lowest level in the hierarchical network. WMN APs represent the next higher level of the hierarchy. The third level in the hierarchy consists of Gateways. The top most level of the hierarchy consists of the servers at the city headquarters. This architecture enables network as a whole to monitor a larger geographical area through large-scale distributed processing and communication of data performed by many devices.

In this hierarchical architecture, different devices at different levels perform different functions. At the lowest level in the hierarchy, traffic and travelling cars data required for applications are gathered. Travelling cars equipped with Bluetooth OBU devices communicate with WMN AP. The middle layers in the hierarchy consist of WMN APs and Gateways that process, aggregate, and forward data, typically for longer distances using Wi-Fi and the Internet. The upper layers of the hierarchy consist of centralized servers that perform decision-support functions. A particular function may be carried out by more than one layer, for instance, each layer could perform a specialized role in computation (Stoianov et al., 2007; Yu, Mokhtar, & Merabti, 2006; Toumpis & Tassiulas, 2006).

This hierarchical architecture provides operational scalability and allows for phased deployment of a network and for node upgrades. However, imposing a logical structure on an existing flat network may result in potential inefficiency. For example, organizing nodes into a hierarchy typically introduces overhead (e.g., execution of clustering algorithm) into the network.

The network model for our platform consists of WMN AP mounted on light posts. The APs can be laid out at arbitrary distances depending on deployment conditions. Each AP is configured to run the OpenWRT Linux distribution (http://www.openwrt.org) for embedded devices. Some APs are connected to the Internet and are configured as gateways. In addition, all APs are configured to run OLSR. OLSR enables AP to automatically configure the WMN and enables self-healing in case of the failure of one AP. Bluetooth dongles are attached to AP through USB ports. We integrated BlueZ (http://www.bluez.org) open-source Linux-based implementation of the Bluetooth stack in each AP. With this setup, each AP can communicate with other nodes using Wi-Fi and/or Bluetooth.

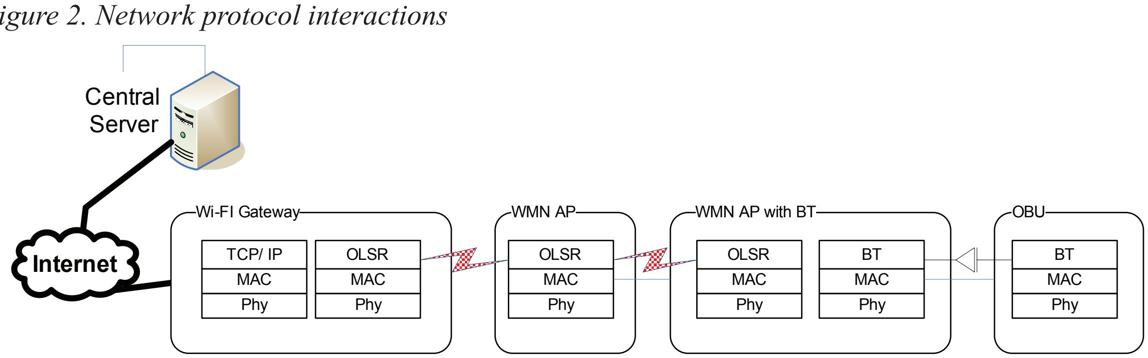
BlueZ is controlled to scan the wireless medium for Bluetooth devices in proximity. We assume monitored cars are equipped with Bluetooth devices. We developed a Linux shell script that is capable of retrieving the Bluetooth (BT) address of near-by Bluetooth devices. The script gathers other information about the detected device including the time a device is detected. The gathered information is then relayed to car tracking server on the Internet using TCP/IP. The route from the AP that detects the Bluetooth Device to the server is controlled by the WMN routing tables maintained at each AP and configured automatically by OLSR.

Figure 2 illustrates the communication model within the platform between Bluetooth OBU device, different APs, gateway and server. The OBU device in the car communicates with the Bluetooth dongle on the AP "Wi-Fi router with BT." Information about this communication is extracted and saved at the AP using a Linux shell script. The AP collects information such as the MAC address of the detected device, the RSSI, the time the device was detected, and the ID of the AP that detected the device. This information is packaged and sent to the Internet server via the WMN. AP "Wi-Fi router with BT" sends an OLSR message to a neighboring AP "Wi-Fi router" that, in turn, forwards it to a neighboring AP "Wi-Fi gateway." The gateway AP forwards the information using TCP/IP on the Internet where packets are rerouted to reach the Internet Server. The server correlates the information it receives from different devices and determines the location of the Bluetooth device at different times.

IMPLEMENTATION AND FIELD TESTING OF THE PLATFORM

In this section, we describe a small-scale deployment of the proposed platform and describe the experiments carried out in order to demonstrate the capability of tracking cars. We carried out two deployments one at the borders of the city to avoid interferences and achieve near-ideal line of sight between sender

Figure 2. Network protocol interactions



and receiver; and the second deployment was in a residential area with interference and reflection from passing-by cars.

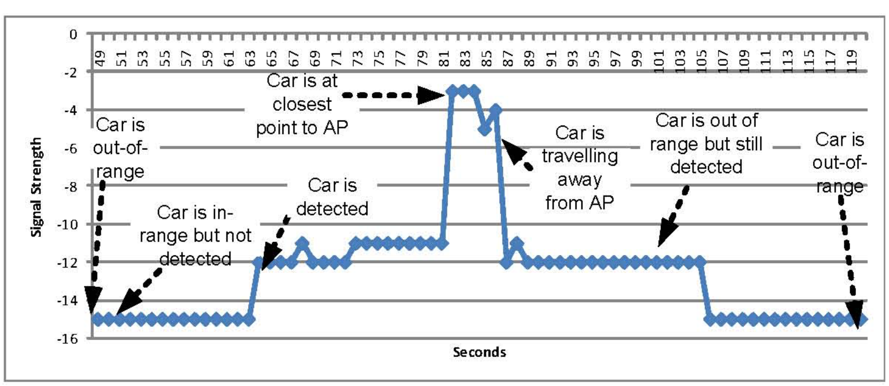
APs were implemented using ASUS® WL-500g Premium AP, with a 266 MHz and 8M flash CPU, 32M RAM, an external dipole antenna, and 2 USB 2.0 ports. Travelling cars were equipped with ultra-slim Bluetooth V1.2 dongles with USB 2.0 and operation range of 100m with built-in antenna and maximum data rate of 3MB. We gather the results on the AP by running a Linux shell script. To enable OLSR message exchange, the OpenWRT firewall was opened at port 698 and forwarding rules were added to the firewall configuration files. For the purposes of preliminary experiments, we do not allow Bluetooth devices to establish connections with AP in order to avoid security and bluejacking issues.

In general, a major issue with Bluetooth detection of devices is the lengthy scanning period of Bluetooth devices. A Bluetooth device may take up to 10 seconds in order to fully detect all the Bluetooth devices in range. We avoided this problem by storing (caching) the information of the to-be-detected Bluetooth module in APs. Caching this information allows Bluetooth to detect a device without performing the standard time-consuming (inquiry and scan) processes. Algorithms for storing, caching, sharing, and managing Bluetooth address is out of the scope of this paper. It has been proven that caching Bluetooth information can reduce detection time by up to 90% (Sang-Hun et al., 2002).

The signal strength, i.e. RSSI received at the AP from the Bluetooth device in the travelling car was measured. RSSI is a measurement of how well the device is receiving a signal and is typically measured in dBm. Generally, the closer the RSSI to zero the stronger the signal level received. Figure 3 and 4 show the RSSI levels (vertical axis) versus time (horizontal axis) as a single car travels towards, by, and away from an AP. In the figures, the horizontal axis represents the second at which we measured the signal strength. An RSSI = 0 dBm indicates that the Bluetooth device is at the closest distance from the AP. In contrast, an RSSI = -13 dBm indicates the Bluetooth device is out of range of the AP.

Figure 3 shows results for the near-ideal deployment in an environment with almost no interference at edges of the city. We realize that the AP started to detect the Bluetooth device at the 64th second, but the car actually entered into range of the AP at the 51st second – an offset of 13 seconds. This delay can be attributed to the slow response of Bluetooth devices in detecting new vehicles. Since the car was approaching the AP, the RSSI started to rise towards 0. The car became at the nearest point to the AP at the 81st- 83rd second. After that, the RSSI level started to decline indicating the car is travelling away from the AP. At the 100th second, the car physically left the Bluetooth range coverage, however the AP

Figure 3. The signal strength of a traveling car in a near-ideal environment



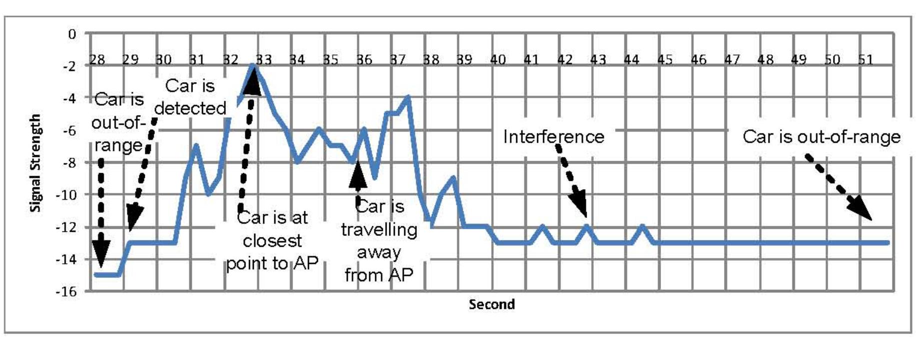
still detected its signal. At the 117th second, the Bluetooth device became completely out of range from AP as indicated by RSSI level, an offset of 17 seconds. This offset is used to correct the measured data for each AP. Repeated experiments on different areas, show that the offset depends on the geographical area surrounding the AP.

In Figure 4, we report the results in the residential area deployment with interference from passing-by cars and signal reflection from houses and parked cars. We realize that the AP started to detect the Bluetooth device at the 30th second. Before that the car was out of range of the AP because RSSI was about -15 dBm. Since the car was approaching the AP, the RSSI started to rise towards 0 dBm. The car became at the nearest point to the AP at the 33rd second. After that, the RSSI level started to decline indicating the car to be travelling away from the AP. We realize that for the following 7 - 8 seconds the Bluetooth device was in the range of the AP. In the figure, we note that Bluetooth RSSI is affected by radio interference from other devices and from signal reflection and refraction from cars and other objects in proximity. For example, the curve at the 34th, 35th, and 36th second indicates that the car is roughly at the same distance from the AP, which is not the case because the car was in constant movement. At the 37th second we realize that the signal strength indicates that the car became closer to the AP which was not the case. The car was actually travelling away from the AP at that instant. It is important to note that not all the Bluetooth dongles that we used showed such inaccuracies. We attribute this to the accuracy in manufacturing the dongles, in addition to the conventional signal fluctuation in complex environments.

Correlating information from the deployed 4 AP, the proposed platform can be used to identify the path of travelling cars and approximate car speeds. The central server maintains a database of the location and identity of each AP. During the experiments, APs detect passing-by cars and notify the central server. Information about which AP the car was close to at what time is gathered at the central server. The central server processes this information to track travelling cars based on the time and location of each Bluetooth device detected by the WMN. In Figure 5 we show the map of our actual AP deployment in the residential area. The squares indicate the locations of the APs. The directed thick line indicates the path and direction followed by the car. This line is constructed at the central server by connecting the squares in the figure. At this stage of development, we used straight lines to connect the triangles, which can be extended to follow actual roads.

Our platform enables the calculation of approximate speed of the car based on the time and location information collected from different APs. We parsed the information collected from each AP to find out the time the car was closest to each AP (the second in time the RSSI received from the car was at

Figure 4: Signal Strength detected for a Car in a residential area



highest value). Before deployment, the time at each AP is synchronized with a centralized server and the distance between APs is measured and reported to the central server. The server calculates the average of the travelling speeds between each two APs and considers this average to be the traveling speed of the car in the area of deployment. Comparing the calculated speed against the actual speed the car traveled at we found out a 10- 15% of difference. We had the car traveling at 20, 30, 40 and 50 km/hour, and repeated for three times, with approximately the same approximated percentage.

DISCUSSION ON LARGE-SCALE DEPLOYMENT OF THE PLATFORM

Here, we report on aspects affecting large-scale deployment of the platform, which provides a roadmap for expanding this work. Large-scale deployment involves units at the lowest two levels in the hierarchy, that is the OBU and the WMN AP levels.

At the lowest level in the hierarchy, OBUs can transmit traffic information using standard wireless communication protocols, of which IEEE 802.15 (Bluetooth), 802.15.4 (ZigBee) and 802.11 (Wi-Fi) are the most common. Of the aspects affecting the design of OBU communication, transmission range of an OBU is one of the most important factors of large-scale deployment. The higher the transmission range of an OBU, the smaller the number of WMN AP required to cover larger geographic areas. A smaller transmission range is typically associated with a multi-hop architecture versus a single-hop architecture.

Another factor that affects OBU design is its transmission rate. The higher the data rate offered by a transceiver device, the smaller the time needed to transmit a given amount of data. Higher data transmission rates are mandatory for vehicle tracking applications (Sarangapani, 2007) because vehicles typically travel at relatively higher speeds. This will allow only a few seconds for OBU-RSU data exchange. OBUs report data to RSU either continuously or in response to an event. With the first model, traffic is continuously monitored and data gathered is continuously reported to the centralized server. In the event-based reporting, the OBU report data if they detect the occurrence of an event or in response

Figure 5. Tracking a traveling car (map courtesy of Google Maps)

to receiving a query request. A hybrid model is also possible using a combination of continuous, event-driven and query-driven data delivery (Akkaya & Younis, 2005).

At the next higher level of the hierarchy, large-scale deployment of WMN AP is controlled by a set of economical and operational factors. Economical factors include the number of AP, the unit price for each AP, and AP installation and maintenance cost. Operational factors include traffic flow characteristics, coverage quality, and surrounding environment.

The number of WMN AP is affected by several factors such as area of deployment region, nature of deployment region, and fault tolerance requirements. The WMN cell size is a design factor for the platform that depends on many factors such as AP transmission range, application type, and required coverage accuracy. In addition the general characteristics of the geographic cell affect WMN deployment. For example, downtown areas typically have higher density deployment of WMN APs as compared to suburban or rural areas because of the density of cars and interference from other wireless devices. The same applies for highways when compared to small city streets.

In addition, WMN deployment always considers a trade-off between AP capabilities and unit price, and power consumption. Since a WMN contains a large number of APs, the cost of a single AP is very important to maintain the overall cost of the network within acceptable limits. The price of an AP is affected by capabilities of its components, such as communication devices, power supplies, and processing units. For the communication device, for example, enhanced features include distinct communication address, enhanced data rates, power consumption efficiency, wider communications range, precise receiver sensitivity, carrier sense capabilities, RSSI, wake up radio, ultra wide band communication, and dynamic modulation scaling (Krishnamachari, 2005; Cheekiralla & Engels, 2005; Khemapech et al., 2005).

A third economic factor to be considered is WMN installation and maintenance costs which largely depend on the number of nodes, mobility of sensors, and type of deployment. Deterministic deployment is almost always expected to have higher installation costs than random deployment. Another aspect of cost is whether the installation is automated or manual. The installation process may also involve costs for licenses, permits, insurance and labor. WMN maintenance and fault tolerance are of the most important network management issues. A WMN is required to provide reliable monitoring in severe circumstances and even if some AP fail. WMNs are, therefore, required to automatically recover and reconfigure themselves. WMNs are typically designed with redundancy in AP to enhance tolerance to faults. The number of WMN AP is affected by the redundancy level required to fulfill QoS or fault tolerance requirements. The higher the fault tolerance level required, the higher the redundancy level and the larger the number of sensors that will be required. In Gao et al. (2004), the problem of evaluating redundant sensing areas among adjacent wireless sensors was analysed and recommendations on the minimum and maximum number of neighbours required to provide complete redundancy were presented.

WMN deployment also depend on operational factors such as interference from unwanted wireless signals available in the environment and weather conditions affecting the WMN operation. Interference may come from other transmitters sending in the same frequency band at the same time. There exist two kinds of interference: co-channel and adjacent-channel (Khemapech et al., 2005). Weather also affects the deployment of WMNs. Snow and rain have an effect on packet loss with the effect of rain being with less severity than of snow (Stojmenovic, 2005).

CONCLUSION

In this chapter, we described how the integration of Wi-Fi based wireless mesh networks and Bluetooth technologies can be used for detecting and tracking travelling cars as well as measuring their speeds. We described our proof-of-concept implementation and deployment of a wireless platform for enabling this. The platform was able to track cars travelling at speeds of 0 to 70 km/hour. We did not test the platform at higher speeds which require unavailable (at the time of the experiment) WMN setups on highways. The tested platform was able to track cars on roads and as they travel through and make turns on different streets. The platform calculated car speed by correlating information gathered at different synchronized AP. Preliminary results indicated that speeds can be measured with ± 10%-15% accuracy. We plan to incorporate more advanced algorithms to enhance speed calculation accuracy in the future.

The proposed platform is cost-effective for three reasons: 1) the platform uses unlicensed wireless technologies; 2) it leverages investments made in municipal WMNs; 3) the platform was built on common hardware and open-source software. Using open source elements makes the developed platform flexible and easily modifiable by us or others. To decrease the number of units required to cover required parts of the city, one can use longer-range Bluetooth devices. The developed platform can be extended to provide many applications and services such as congestion identification and quantification, traveler information systems and navigation and route guidance services. This system has the potential to contribute to reducing fuel consumption and air pollution by reducing traffic congestions.

We identified the following sources of inaccuracy in this experiment due to: 1) difference in manufacturing of Bluetooth dongles and implementations of the Bluetooth stack; and 2) we also realized that signal refractions and interference can affect RSSI measurements. There are different versions of Bluetooth each with a different coverage area and data rates. The availability of metal objects (such as other cars) and other wireless signals in the spectrum affects these measurements.

With the steep growth and expansion of WMNs and the increasing popularity of Bluetooth and Wi-Fi mobile devices, it is logical to predict extensions to this research. The developed system has the potential to use widely available and rapidly expanding components to enable new ITS services in a cost effective manner. Future work will include investigating more accurate algorithms for tracking cars and calculating their speeds, assessing the impact of device quality on and tracking cars and as well measure their speeds as a proxy to congestion level. We will use more complicated algorithms and Geographic Information Systems (GIS) information to draw more accurate tracking of the path that the car traveled. We believe that a large-scale deployment of the platform can track cars in urban areas such as downtowns where other wireless technologies are more expensive (such as GSM) or cannot operate at all (e.g. GPS). Our future studies will include characterizing the effect of differences in manufacturing of Bluetooth dongles on the accuracy of our measurements. We will also study how Bluetooth limits the performance of this infrastructure. In particular, we will study the effect of the delay in detecting a car on the ability of the infrastructure to perform as the speed of travelling car changes. We will also try to quantify the maximum number of cars that can be detected in a second. We also would like to investigate the potential of the platform for two way communications with the mobile devices. This will enable the gathering of traffic information from vehicles as probes and using this information to provide navigational services and traveler information to traveling cars, i.e. enabling each device to be a contributor and beneficiary at the same time. In the future, wider WMNs can be established using private citizens' routers at residences and offices. Consequently, users can join online communities with their AP devices and benefit from the resulting information and services, provided by WMNs.

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