An Intelligent Architecture for Metropolitan Area Parking Control and Toll Collection

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Abstract— U.S federal and State governments invest millions of dollars for enforcing parking control in the metro city area. Tasks like parking enforcement, towing of illegally parked vehicles and maintenance require many man-hours and resources. The parking control and revenue system in the metro are essentially dependant on devices like coin or token based parking meters, which require the use of exact change and is therefore cumbersome. Also a patrol officer is required to monitor these spaces constantly. This entails the need for a more efficient and redundant system. In this paper, we propose an architecture for automated parking meter and driver assistance system that shall be connected to a centralized traffic control authority responsible for parking enforcement and toll collection. This system would provide a more efficient and redundant way of enforcing parking control and toll collection and also assist drivers in metro area for searching an available parking space. The above-mentioned architecture enables automated parking toll collection.

Key words— Intelligent transportation systems, vehicle detection system, ad-hoc subsystems, video image processor sensors, automatic toll collection.

I. INTRODUCTION

The main objectives of parking control and enforcement systems include efficient and effective monitoring of meter and lot violations. This aims at providing adequate space for parking in downtown/metro city area, optimize the use of all city parking spaces to maximize revenue. To achieve these objectives, further development and up gradation of the present parking system is required. The parking authority has to employ personnel for enforcing the regulations; some of these include police officers, parking control technicians and maintenance personnel. The above-mentioned services add up to make significant cost.

The Parking meter program includes meter and zone enforcement, meter maintenance, meter collections and debt services. The revenues from these go into the overall improvement of the parking enforcement infrastructure. According to the estimates done by the parking enforcement office of the city of Lawrence, Kansas [1] it would take $700,000 - $800,000/year to enforce the parking control in its metro area. These costs include, employing the manpower apart from the resources like patrol vehicles, gasoline, towing trucks, etc. Lots of man-hours are spent in enforcing parking control and related activities such as towing of illegally parked vehicles.

The parking toll collection in metro areas is mainly based on the coin or token-based parking meter systems [2]. The coin-based meter requires the use of exact change and is a quite cumbersome process, because the user has to tender exact change in order to park. During odd times like night or wee hours or some event when there is scarcity of parking, it is quite troublesome to look for parking space elsewhere, due to lack of change. In such an event, the driver would not be fully aware of existing parking spaces nearby and it would be very time-consuming and frustrating for the driver to look for one. This requires the need for developing a parking toll system, which shall be free from all the above-mentioned issues and would be user friendly, efficient and redundant. Also it is important that such a system should exist on top of or be an extension of the existing architecture, because it is unfeasible to implement a totally new system.

Our proposed system is called Intelligent architecture for Metropolitan Parking Control and Toll collection (IMPACT). We propose the use of a wireless device with a software function that shall be embedded in the parking meter and would be having wireless ad-hoc networking capabilities. We also propose that the parking meter be embedded with two FM-CW radar sensors and a low cost video camera. These two sensors ensure vehicle detection and that the driver has parked his/her vehicle in the correct place. The small video camera is placed to eliminate the possibility of false alarm. A tower, known as the Parking Gateway (PG), shall be wirelessly linked to all the parking meters and would act as a gateway between the parking meters and the centralized parking authority.

Our architecture enables more effective monitoring of parking lot violation through the use of radar sensors and wireless ad-hoc networking. It shall automatically notify.
the central parking authority about meter violation without the interface of a patrol officer. This shall be explained in the latter sections. Since our system is fully automated, it eliminates human error and is therefore more redundant and efficient. Our proposed system also provides a better revenue model for the parking authority. We propose the use of ad-hoc networks because we assume that in future all the cars shall be enabled with a wireless networking capability and would be able to wirelessly exchange data with other devices in its vicinity. Our architecture can be easily implemented by upgrading the present infrastructure. This means that it will exist as another layer on top of the present parking meter system architecture. This makes it scalable for future system up-gradation.

The rest of the paper is organized as follows. Section II presents some background material. Section III describes our proposed architecture. Section IV describes the IMPACT protocol. Section V shows bandwidth, memory and security requirements, and Section VI presents the conclusions.

II. SOME BACKGROUND MATERIAL

Some of the current parking and toll architectures that are in use are NextPark [3], SmartPark [4] Park-and-Display [5] and Pay-by-Space [5]. A brief description about these systems are as follows:

NextPark: This is a new architecture for parking control that is implemented in Finland by the Oulu Telephone Company. It makes use of the GSM mobile phone network to monitor the whole metro area for parking enforcement. In this system, the user registers on the Telephone Company’s website and gets a unique ID or PIN. When the motorists want to park they dial NextPark number. Once they are identified, they are asked for details like the parking zone and the amount of time they need to park. This information is then forwarded to the NextPark server that confirms all the details and chooses to accept or modify them. When the patrol officer enters the zone he/she dials the NextPark number, the server responds giving the details about the vehicles parking time allowed and license plate number. It warns the owner 15 minutes before the parking time expiration and is asked if he wishes to extend the time.

SmartPark: This technology requires the use of In-Vehicle Car Parking Meters or ICPM [6]. The ICPM is a small pocket calculator-size electronic device. This SmartPark device uses a smartcard that is loaded with a prepaid amount of parking hours. The smartcard is inserted into the SmartPark, which is then placed inside the vehicle and displays the parking time purchased. An initial onetime refundable deposit for the SmartPark unit is $55 and customers must purchase the smartcard for $10. Customers can preload the SmartCard in increments of $25, $50, $75

and $100. The SmartPark is then placed inside the vehicle and displays the parking time purchased.

Park-and-Display and Pay-by-Space: The park-and-display version is used in France. In this system, the driver deposits the money and the machine prints a receipt with the expiration time. The receipt is pasted on the Dashboard for the meter reader to see.

The second is a pay-by-space method in which drivers deposit money for their numbered space. A red light by a number on the monitor indicates that the corresponding parking space has expired.

III. THE PROPOSED IMPACT ARCHITECTURE

Figure 1 shows the proposed architecture with its components. Here we present and discuss the Intelligent architecture for Metropolitan Parking Control and Toll collection or IMPACT. We have assumed that, within a metropolitan area, there will be a well-defined network infrastructure for Intelligent Transportation Systems (ITS) [7]. The ITS devices will be ubiquitous and would be performing multiple functions. We also assume that the ITS infrastructure would be on top of the existing infrastructure like the internet or the mobile network. Our architecture has the following sub-system entities:

Ad-Hoc subsystem: This would consist of a device with wireless ad-hoc networking capabilities [8] and would be embedded in each of the parking meter. This device would be connected wirelessly to all the neighboring parking meters.

Parking Gateway subsystem: This would be a tower located at the beginning of the parking lot and would be linked to all the parking meters in its vicinity. Each parking meter would be having a unique ID or a number associated with it. The gateway would link all the parking meters to the centralized server of the parking authority. We assume that it would be done using an ITS entity like an Intelligent Transportation Tower, which would be responsible for many other functions apart from routing information, such as parking meter ID, to the centralized server. The purpose of routing the parking meter ID or PID to central server is to keep track of the information related to that particular parking space such as illegally parked vehicles, available parking space at that location etc. The parking gateway could be a Wi-Fi [9] router linked with all parking meters and further connected through a Wi-Max connection to a nearby ITS entity such as the Intelligent Transportation Tower, that shall route the information to the central parking server.

Vehicle Detection subsystem: The vehicle detection subsystem uses the vehicle detection technology [10] to detect the vehicle when it is in the parking space. This subsystem is embedded into the parking meter itself and consists of two frequency modulated continuous wave
(FMCW) microwave radar sensors assembly that sense the presence in the manner described below.

The FMCW microwave radar sensor transmits a frequency that is constantly changing with respect to time. The FMCW radar operates as a presence detector.

**Figure 1:** The architecture of the IMPACT system.

The term microwave refers to the wavelength of the transmitted energy, usually between 1 and 30 cm. This corresponds to a frequency range of 1 GHz to 30 GHz. Microwave sensors designed for roadside traffic data collection and monitoring in the U.S. are limited by FCC regulations to operating frequency bands near 10.5, 24.0, and 34.0 GHz. The sensor manufacturers satisfy these requirements, as well as others that restrict the transmitted power. Radars at frequencies above 30 GHz operate in the millimeter-wave spectrum since the wavelength of the

**Figure 2:** The sensors of the IMPACT system.
transmitted energy is expressed in terms of millimeters. Commercially available microwave radar sensors used in traffic management applications transmit electromagnetic energy at the X-band frequency of 10.525 GHz. Higher frequencies illuminate smaller ground areas with a given size antenna and thus gather higher resolution data.

**Video Image Processor (VIP) Sensor subsystem:** This subsystem is also located in the parking meter and consists of a very low-cost camera that has the capability of taking the picture of the parking space. There are many small low-cost cameras that are available are under the price of $15 [11]. If these cameras were bought in wholesale then their price would be lower. The resolution for these cameras is 100,000 pixels. Some of these cameras also have a built-in memory to store images of size 2 MB. Thus, we might not be required to install memory for storing images in the parking meter. This system also roots out the possibility of false alarm due to the presence of stray object or malicious intent of someone. The camera can notify the central server about the presence of an actual car or other stray objects or persons. We propose that the video image processor have an algorithm embedded in it that would be detecting whether the image is that of a person or a vehicle.

IV. THE IMPACT PROTOCOL

Our architecture takes care of two classes of vehicles, Class-I and Class-II vehicles. The class-I deals with current vehicles with no wireless devices embedded in them. The Class-II vehicles will be having in-vehicle wireless devices with ad-hoc networking capability embedded in them. Each of these vehicles would have a unique Vehicle Identification number (VID) assigned to them.

A parking meter consists of two sensors that are embedded in it and are positioned at different angles, as shown in Figure 2. Sensor-1 consists of a laser beam or an infrared beam pointing to the direction that is perpendicular to the pavement. Sensor-2 is a FMCW radar sensor that is pointing towards the center of the parking space. The ad-hoc subsystem goes through an inquiry process. It checks whether there has been an output detected from the radar sensor assembly. If the output is from Sensor 1 it knows that the vehicle is not parked properly because it has crossed the parking space boundary and reached into an adjacent space. It issues a warning to the vehicle’s driver through an audio message or a flash signal. This tells the driver that he/she should prepare to backup into the proper parking space. If there is an output from Sensor 2, which is pointed towards the parking space, then it knows that there might be a vehicle. It counter checks the object, on the parking space, with the camera output about the possibility of a false alarm and also at the same time checks whether it has detected a VID. If the object is a vehicle and if the parking meter has not detected a VID, then the parking meter automatically knows that the object is a Class-I vehicle. It time stamps this event by a parameter $T_v$ (vehicle entry time) and waits for a specific time interval known as the wait period, $T_w$. We propose that the wait period $T_w$ would be longer than the average time needed to park a vehicle in a parking space. If the parking meter has not received toll for the parked vehicle during the waiting period $T_w$, then it knows that the vehicle is illegally parked and initiates a warning message. The meter then routes, through the Parking Gateway, the automated warning to the central server of the parking authority. After looking at the incoming warning message, the centralized server knows that it came from a particular parking space. It keeps this information in its database and notifies the patrol officer in that area for issuing a ticket and/or calling a towing facility.

For Class-II vehicles, the parking meter ad-hoc subsystem goes through the same process of inquiry. This time it looks for Vehicle Identification Number (VID). As soon as the parking meter receives a VID, it time stamps this event and remembers the vehicle entry time $T_v$. After that, the meter waits for the waiting period $T_w$, and then starts counting time for which the vehicle has been parked. When the vehicle owner returns and starts moving the vehicle, the parking meter knows that the vehicle is ready to move away. The meter calculates the time for which the vehicle was parked and sends the amount to the vehicle owner. The owner can use his credit card or a prepaid card to debit the amount from his account. The system could also be configured to automatically debit the amount from a prepaid account. If the vehicle owner drives off without paying, the system notifies the central server about the same with the VID of the vehicle and the server writes it an electronic ticket. The central server also maintains a log file about the vehicle in which all the details about the parking are saved.

**False Alarm Detection:** This section discusses the false alarm detection by the parking meter. Figure 2 shows the top view of a parking lot. False alarms can be generated by the malicious intent of a person or accidentally by a pedestrian who might be standing at the parking spot. The system protocol eliminates such an alarm in the following manner. When the system detects the output from Sensor-2, i.e. the FMCW radar sensor that is pointed to the center of the parking space, it checks the output from the video image processor. If the camera does not detect a vehicle, it knows that it’s a false alarm and informs the system about it.
**IMPACT as a Driver Assistance System:** Our architecture can be used as a driver assistance system for parking in a metro area where it is difficult to find a spot. We propose that each parking meter periodically sends its parking status, i.e., whether it is vacant or occupied, to the nearest parking gateway. The parking gateway then sends that information to the centralized server. Thus, the centralized server and all parking gateways are aware of the availability of the parking spaces within a particular area, such as near a stadium, shopping center, bus station, airport, etc. This way, as soon as a vehicle enters a particular area, it can inquire about the availability of nearby parking spaces. In turn, the parking infrastructure can let the vehicle know about the available parking spaces within the vicinity of the vehicle.

**V. BANDWIDTH, MEMORY AND SECURITY REQUIREMENTS**

**Bandwidth and Memory Requirements:** The bandwidth and memory requirements mainly depend on the type of video camera and the image size that we use for the IMPACT system. We propose the use of a very low-cost camera with a resolution of 500 X 500 pixels that should be good enough for taking a picture of the license plate of a vehicle. If we choose to use black and white pictures with 256 gray levels, then we need a memory of size 250,000 bytes for a picture. Apart from this, we would have 10-20 bytes of extra information that would be sent along with the vehicle’s picture. These extra bytes would include information like parking meter number, VID of vehicle, etc. Since we are not processing this information in real time, we do not require that all this information reach the parking gateway immediately. It would be acceptable if the information from a parking meter reaches the nearest gateway within a few minutes, say in two minutes. Since a parking meter needs to send approximately 250KB of raw data in two minutes, we need a bit rate of 2083 bits/sec for raw data. However, for wireless communications there is a huge overhead for sending raw data. The actual amount of overhead depends on the specific coding technique used for the wireless communication. For example, for the Rate 1/3 FEC (Forward Error Correction) coding, three copies of every raw data bit are sent through the air. Thus, for the Rate 1/3 FEC coding the overhead is going to be more than 200%, because some more additional bits will be necessary for packet headers, synchronization bits, end of frames, etc. Similarly, for the Rate 2/3 FEC coding, the overhead is going to be more than 50%. Even if we assume an overhead of 250%, each parking meter would require a bandwidth of 7.29 kilobits/sec to send its warning message along with a picture of the license plate of the violated vehicle. It is very unlikely that under a parking gateway, there would be many parking violations at the same time. If we assume that there are 500 parking meters under one parking gateway and in the worst case 10% of these meters would like to send warning signals at the same time, then the bandwidth needed by the parking gateway would be approximately 365 kilobits/sec. A bandwidth of 365 kilobits/sec can be easily obtained using today’s wireless technology.

**Security Requirements:** There are certain security issues related to wireless communications [12]. Wireless networks are more vulnerable to security attacks than wired networks. Thus, appropriate security mechanisms must be implemented in our IMPACT system. Otherwise, the parking areas would be the playgrounds of various types of hackers. The sensor based wireless links among the parking meter, vehicle, and the parking gateway must be secure. Otherwise, hackers may inject wrong information into the system; read the VID number of a vehicle by eavesdropping on the link between the vehicle and the corresponding parking meter. Later on, the hackers may
use this VID number to park his/her vehicle without paying any toll. In our future work, we would like to present a model in order to secure the communications of our IMPACT system.

VI. CONCLUSIONS

In this paper, we presented architecture for metropolitan area parking and toll collection. We have discussed in detail the IMPACT architecture and its algorithm. We have discussed the feasibility of using various sensors for automatic toll collection. The IMPACT system will significantly reduce the operating costs of a metropolitan parking system. Less number of parking officers will be required by a city to manually issue parking tickets. There are still numerous implementation-based issues that we have to study and research. Some of the issues might be related to securing the whole system from possible external security attacks.

REFERENCES