DEVELOPMENT OF ADAPTIVE TRACKING TECHNOLOGY FOR THE UNIVERSITY OF ILLINOIS AT CHICAGO SHUTTLE BUS

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ABSTRACT. At the University of Illinois, Chicago, a bus-tracking technology for the campus shuttle bus fleet is currently under development. The current design shares common system features with previous designs, but differs from prior implementations in several important aspects. In common is the use of Global Positioning System (GPS) location derivatives as the head-end of the tracking mechanism, and the use of processing and web servers as the tail end. Ethernet is used to connect data-communication link-receiving site locations to the servers in all versions. This adaptive approach to data handling at the vehicle has potential for transmission of video, mechanical vehicular data, Wi-Fi and Bluetooth connectivity for users, alarm notification and whatever parameters are considered of value, along with the core transmission of GPS coordinates at intervals down to one second if required.

INTRODUCTION

As one of the largest employers in the center of the Chicago region, as well as the travel destination of 25,000 students, the University of Illinois at Chicago (UIC) is rapidly transforming itself from a commuter school to a 24-hour residential center in the middle of a vibrant, livable community. Although the UIC campus has excellent service (Figure 1) by the Chicago Transit Authority (CTA) – in terms of fixed-route bus and light-rail service within Chicago (see http://transitchicago.com) – and Metra (the commuter-rail service, primarily serving the Chicago suburbs, see http://metrarail.com), students and employees primarily travel to the campus by car. Moreover, demand for parking exceeds supply, even though UIC offers extensive parking services.

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For those who must travel between the East and West Campuses (an area larger than 3.2 km by 1.6 Km as seen in Figure 2), free shuttle buses (Figure 3) are operated throughout the day and evening on weekdays. They do have a set schedule and are generally on time with a headway of 10 or 15 minutes during the day, and longer in the evening. A UIC (fee-based) commuter bus operates between the two downtown Metra stations and the UIC East and West Campuses on a set weekday schedule from 7:00 to 9:00 am and 4:00 to 7:30 pm.
Enhancing mobility within, as well as from and to the UIC campus is a part of UIC’s Campus Transportation Plan and of paramount importance to the UIC community. One of the ways of improving the efficiency, effectiveness and quality of service of transportation operations is by using computerized scheduling and dispatching systems (Metaxatos and Pagano 2004; Pagano et al., 2002) in combination with automated vehicle location (AVL) systems (Casey et al, 2000; Kessler, 2004).

AVL systems are computer-based vehicle-tracking systems that measure the real-time position of each vehicle and relay this information to a control center. With advances in communications technology and computer hardware and software, AVL systems have become components of a larger architecture that offers additional video and audio capabilities to both transit agencies and their clients. This paper reports on the incremental deployment of such a system in UIC that came about with minimal financial support but persistent commitment from a core of UIC communications hobbyists, computer experts, and regular engineering and planning students.

OTHER AVL SYSTEMS IN UNIVERSITY CAMPUSES IN THE UNITED STATES

It is evident from a preliminary scan that other universities in the United States have recognized the value of an AVL technology for their bus fleets and a few of them have encouraged entrepreneurial student teams to be involved in in-house developments. Such efforts are a win-win situation for the parties involved because they provide invaluable educational benefits to the students and provide considerable cost savings to the university. This section reports on two recent such efforts. Similar efforts are undoubtedly happening in other countries. Regrettably, we did not have the resources to pursue such worthwhile developments in this paper.
The University of Michigan Magic Bus Project uses wireless technology and GPS-equipped buses to display real-time bus location data and predict arrival times for upcoming stops (UMTRI, 2006). Bus riders can access arrival times through a website and by instant messaging. Riders can also use America Online’s Instant Messenger Robot (AIM Bot) to access bus arrival times either online or with a mobile phone.

The University of California at Berkeley provides shuttle-tracking services through Berkeley Innovations, a nonprofit organization (http://innovation.berkeley.edu/STS/shuttleposter.pdf). GPS-equipped buses transmit data using Wi-Fi through Internet access points along the path of designated shuttle route. End-user services provide real-time shuttle tracking and reminder features.

PREVIOUS DEPLOYMENT EFFORTS AT UIC

Previous efforts to develop an in-house bus-tracking technology at UIC resulted in a deployment costing less than $1,000 (2003 dollars) per bus (excluding staff time, see http://liu.ece.uic.edu/~dliu/Sdesign/g2003F) compared to commercial deployments costing $5,000 to $30,000 per bus at the time (a median value of around $8,000 per vehicle is reported in Casey et al., 2000). Jim Limber, a co-author of this paper, participated in this effort from the very beginning and offers an account of events between 1997 and 2003.

In the Fall of 1997, following preliminary planning in 1996, the “Amateur Radio and Technology Club” at UIC was formed and started discussions of potential projects including Global Positioning System (GPS) bus tracking. The project was affectionately named the 'TBT' project (The Bus Thing).

As an aside, the GPS system (NAVSTAR GPS) utilizes a constellation of at least 24 (31, as of September, 2007) medium Earth orbit satellites distributed among six circular orbital planes that have approximately 55° tilt relative to Earth's equator. Orbiting at an altitude of approximately 12,600 miles (20,200 kilometers) each satellite makes two complete orbits each day, so it passes over the same location on Earth once each day. The orbits are arranged so that at least six satellites are always within line of sight from almost everywhere on Earth's surface. The system transmits precise microwave signals – more specifically, ultra-high-frequency (UHF) signals in the 1.5 GHz band – and enables a GPS receiver to determine its location, speed, direction, and time (http://en.wikipedia.org/wiki/Global_Positioning_System).

In 1998, work began on software and the first hardware prototype was built. In 1999, a small UIC grant made possible the installation and testing of the first prototype system in three shuttle buses. In the same period, work on second-generation GPS hardware and server software development began. Additional support from UIC provided the funding necessary for hardware development in 2000. In 2001, work began on third-generation hardware and software support for 15 buses. In 2002, a dedicated server was brought in at UTC and began HTML broadcast of a preliminary tracking software program. In 2003, senior engineering students participated in embedded server Internet system expansion, a third-generation modem project, and investigated the compatibility and applicability of Bus HTML broadcasting with plasma display information screens at two UIC student centers.

A preliminary sensitivity analysis (Ortega and Wennink, 2003) reported that this configuration achieved utility gains of four minutes reduction of system-wide waiting time
for each percent increase in ridership while the UIC shuttle bus is in operation (7:00 AM to midnight).

**Hardware Components**

In early deployment efforts (Figure 4), the project team installed in each bus a Global Positioning System (GPS) receiver with an embedded antenna (Garmin 36 TracPak, [http://www8.garmin.com/products/gps36/spec.html](http://www8.garmin.com/products/gps36/spec.html)), a packet modem and a two-way radio transceiver. The GPS receiver using raw location data from satellites transmitted positional coordinates (in bits) to the modem. The programmable modem – a TigerTrac TM-1, ([http://www.tigertronics.com/tm1spec.htm](http://www.tigertronics.com/tm1spec.htm)) initially, upgraded to a TinyTrak3, ([http://www.byonics.com/tinytrak](http://www.byonics.com/tinytrak)) later – converted, at user-defined intervals, the bits into tones for the radio receiver that, in turn, transmitted to the receiver antenna on a tall campus building. Later, two additional locations were installed across the more than three kilometer span of campus real estate. The location information (along with altitude, speed, heading, a status message and a timestamp) was then transmitted across campus, initially via telephone wire from and to a Kantronics (protocol AX.25) modem ([http://www.kantronics.com/support/glossary.html](http://www.kantronics.com/support/glossary.html)), and later upgraded to Ethernet link connection to a dedicated server hosting the website (IBM Netfinity 5000) in the UIC Urban Transportation Center (UTC). A second and third receiver site were later installed to provide data redundancy in the 2.5 miles (4.02 Km) by 1.6 miles (2.6 Km) area of operations of the UIC campus shuttle bus.

![Diagram of AVL system](image-url)
**Software Components**

Most of the hardware in Figure 4 was configurable to optimize the physical system to (UIC) campus requirements. Moreover, the shuttle bus routes within campus were mapped into a digital file using actual GPS location information for computer display. Initial attempts to refresh bus location information met with difficulties due to large jpeg map files. The bus routes were later mapped using Java resulting in smaller files for map updating. Additional rollover information regarding information about each particular bus stop or building was later added along with capabilities for visually and hearing impaired persons. In addition, each bus route was displayed in different colors for daytime/nighttime shuttles.

**CURRENT DEPLOYMENT EFFORTS AT UIC**

Currently, the system deployment is transitioning to Phase 4. Phase 4 shares common system features with previous designs, but differs from prior implementations in several important aspects. In common is the use of GPS location derivatives as the head-end of the tracking mechanism, and the use of processing and web servers as the tail end. Ethernet is used to connect data-communication link receiving-site locations to the servers in all versions.

**Phase 4 Hardware Components**

In Phases 1, 2, and 3, the buses transmitted location data periodically, every ten seconds, via a standard Very High Frequency (VHF) radio channel utilizing modified radio transceivers and modems suitable for the purpose of the data transmissions being detected at selected sites on campus. One advantage of this system was the avoidance of recurring costs of data transmission via commercial services. A disadvantage was the quite limited bandwidth available and the dependency upon appropriate receiving sites for the data-link equipment.

Phase 4 (Figure 5) addresses these issues in several important ways, which greatly leverages the capacity and flexibility of the TBT system. Among the key changes is a total hardware upgrade from the GPS head-end interface to the servers' back-end Ethernet converters. Instead of dedicated hardware subsystems such as radio transceivers and modems, Phase 4 uses a Software-Defined-Radio-System (SDRS) approach (http://en.wikipedia.org/wiki/Software_defined_radio).
There are several definitions of software-defined radio (SDR) all of which are not totally consistent with each other perhaps because of the broad and complex nature of the technology itself, and the variety of possible means for implementation of SDR systems (http://www.wsdmag.com/Articles/ArticleID/6509/6509.html). For example, the United States Federal Communications Commission (FCC) defines SDR as a “generation of radio equipment that can be reprogrammed quickly to transmit and receive on any frequency within a wide range of frequencies, using virtually any transmission format and any set of standards” (http://www.fcc.gov/Bureaus/Engineering_Technology/News_Releases/2000/nret0004.html).

On the other hand, the SDR Forum, an international, non-profit organization promoting the development of SDR, offers a broader definition: “Software defined radio is a collection of hardware and software technologies that enable reconfigurable systems architectures for wireless networks and user terminals” (http://www.sdrforum.org/sdr_brochure_10_24_02.pdf).

The SDRS approach in Phase 4 involves a compact, ruggedized mobile computer and high-speed Evolution-Data Optimized (EVDO) – a telecommunications standard for the wireless transmission of data through radio signals, typically for broadband Internet access – wireless service communications data card, along with a full complement of input/output ports for extensive sensor/data input/output processing. Ethernet connectivity ties the computer to the EVDO on-board server, which supports both 10baseT copper-based (category 5, see http://en.wikipedia.org/wiki/10BASE-T) cable running at 10 megabits per second (Mbps), and 802.11 wireless (Wi-Fi) standards.

It is expected that the SDRS/EVDO approach would eliminate occasional interference for transmitting the data to the WWW/server. This is because the EVDO data service is
supported by a dense network of cellphone base units operated by every major national
carrier. Moreover, extra connectivity might be added or maintained using Wi-Fi and
Bluetooth/cellphone access point backup support.

In addition, a current trend is emerging in Japan among consumers in which demand and
usage of PC's for communication purposes is mitigating in preference for highly portable
personal devices with significant computing power for user applications mainly related to
physical embodiment of this developing trend is the mobile cellphone, which in many ways is
becoming a tiny but powerful feature-rich computer. To achieve equity in supply-demand
anticipation, an equally powerful SDRS on the transport vehicle will provide adaptive
services to the evolving mobile computer (http://www.nytimes.com/2007/11/06/technology/06google.html?r=1&oref=slogin#).

This adaptive approach to data handling at the vehicle has potential for transmission of video,
mechanical vehicular data, Wi-Fi connectivity and handicap facilitation for users, alarm
notification and whatever parameters are considered of value, along with the core
transmission of GPS coordinates at intervals down to one second if required. One function of
Bluetooth, for example, could be to beacon ahead the bus ID and route information to the
blind or handicapped individual possessing an appropriate ‘open-systems’ cellphone with
task-specific software, to announce by special ring-tone or voice generation that the bus is
less than 100 meters distance (the nominal maximum range of 100 milliwatt Class 1
Bluetooth). A cellphone equipped with GPS could further analyze actual bus distance based
upon differential calculation. A full or malfunctioning bus could also message that it would
be bypassing a bus-stop location due to conditions. A cellphone might also serve as a radio-
frequency identification (RFID) method for expedited hands-free bus passenger validation.

The path toward such advanced functionalities can only be facilitated by the rapid evolution
of wireless standards (e.g., mobile WiMax) that will allow for faster (2-10 Mbps depending
on reception, compared to the existing 500-1400 Kbps) communication among laptops,
smartphones and GPS units within the next few years. Such developments will be further
motivated by the pressure for change to open-systems for the telephone companies from
industry developers who are keenly interested in rapid and diverse changes in upcoming
0ccab69b8&ei=5070&emc=eta1#).

For any given system, location and time, various options for primary communications will
become available which compete for price/performance optima. It is obvious that analysis
and selection of the best available technology is a parameter of each system design. UIC's
phase-4 bus-tracking system has been optimized for current technology, but that equation
might quickly change with ongoing advances in services.

It is interesting to note that although there are no very tall buildings in the vicinity of the UIC
campus, emerging technology has the potential to minimize satellite signal reflections,
deflections and blockages in “urban canyons”. This is achieved by means of a relatively new
technologically hybrid chip going into the latest GPS receivers. It is called the SIRF chip and
it involves on-board gyroscope dead-reckoning to fill in the blank spots (http://www.engadget.com/tag/SiRF). While dead-reckoning systems have been integrated
into AVL systems previously (see Denaro, 1991 for such an early integration effort), the
technology has been segmented as separate subsystems which had to be integrated with embedded microprocessors. With the complete integration onto a single chip, the cost and form of the technology is optimal for universal incorporation into new systems.

**Phase 4 Software Components**

In Phase 4, the core software (GPS, EVDO, Wi-Fi, and Bluetooth drivers) is evolutionary and generally following vendor and operating system guidelines for developers’ integration. Higher-level application software is written based on programmer expertise and language suitability for given algorithmic tasks. An example of a (beta) mapping implementation is given in Figure 6.

Phase 4 implements the mapping of bus routes and bus GPS location using the latest Web technology in order to make the web interface more responsive and user friendly (Figure 6). We have used a combination of the Google Maps JavaScript application programming interface (API) and AJAX (Asynchronous JavaScript and XML – Extensible Markup Language).

![Prototype: UIC Day Shuttle Route](image)

This technology solves some of the challenges and drawbacks of previous implementations. The use of Google Maps API has allowed for easy embedding of UIC shuttle routes on the Google maps. In addition, this API offers some of its built-in features such as zooming in/zooming out, and dragging the mouse that make navigation intuitive and fast.

On the other hand, AJAX allows for faster refresh rates because it is designed to exchange only small amount of data without interfering with the display of the webpage. Also, implementation of pop up information or other mouse events is made relatively easy in this framework.
Requests for updated bus locations are sent to an AJAX server every 2 seconds using the XMLHttpRequest (XHR) object. The server then sends a query to the database and retrieves the latest location coordinates for the shuttle. These results are stored in XML format which the XHR object can parse and display on the screen.

CONCLUSIONS

The efficient and effective management of a university shuttle bus fleet can be greatly facilitated with the use of tracking technology. Indeed bus-tracking technology using off-the-self equipment has become increasingly more affordable and robust. Moreover, advances in communications and AVL hardware and software allows for additional system functionalities that has the potential to meet the quality of service needs. Yet, financial considerations and the lack of an advocate rarely allows for a full system deployment in a design-and-build fashion.

This paper has discussed an incremental deployment effort that has been implemented in UIC for the last 10 years. Clearly, the advocacy of a few technology enthusiasts among staff and students has been instrumental during the on-going implementation. Additional work, including routine completion of phase 4 beta construction, programming, installation, debugging and implementation, needs to occur before the UIC bus-tracking system becomes fully functional and provide anticipated benefits to students, staff, and the surrounding community in the vicinity of the expanding campus. The cost effectiveness of such efforts will be reported in the future.

ACKNOWLEDGEMENTS

We would like to thank all the students in the University of Illinois at Chicago (UIC) Colleges of Engineering and Urban Planning and Public Affairs who participated in this project since 1996. The UIC Urban Transportation Center (UTC) has supported this project since 1999. The Metropolitan Transportation Research Initiative (METSI) at UTC has offered additional support since 2000.

REFERENCES


