An Application of IEEE 802.11 and 802.3 for a University Bike-Share Program

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Abstract—A recently-started university bike-share program was in need of improvements in existing capabilities. The program utilized an honor system which lacked bike security, user accountability, and administrative control and monitoring. The program administrator approached the engineering college for a solution, which was taken up as a senior project. The team set out to create a system consisting of three components: (1) kiosks distributed across the campus for checking in and out bikes; (2) a database for logging all transactions and system information; (3) a web application for simple reporting of system data and management of system rules. An embedded microcontroller system with a variety of identification, security, interface, and communication peripherals, enclosed within a weatherproof case, was designed and constructed as a prototype for the kiosk. A schema was implemented in MySQL to act as a central repository for all relevant system data. Finally, a web application was built using the PHP scripting language and Apache web server to handle user interaction with the system. The TCP/IP stack connects these modules and provides ease of implementation and distribution. Kiosks utilize IEEE 802.11 and 802.3 modules for communication over existing university network resources. Once integrated, kiosks successfully provide check-in/out functionality based on system-wide rules and log transaction information which is then presented to administrators through the web application. Currently, the program administrator is taking steps to acquire funding and production capabilities in the hopes of deploying this system across the university campus within the next several years, as well as examining the feasibility of implementing the system city-wide.

I. Introduction

In 2009, the University of Nebraska at Omaha (UNO) began a campus bike share program. A small assortment of low-quality used bikes were donated to the university and serve as the backbone of the program. These bikes are "floating"; the bikes are never locked. Rather than having a system to check-out bikes, an honor system is in use in which students simply hop on a bike when they come across one and leave it where they stop.

UNO consists of three campuses in a straight line, with about a mile between adjacent campuses. Bike trails exist between the campuses. The northernmost campus is the primary campus, although the central campus is sizable and growing. Shuttle buses run between these two. The southernmost campus is much smaller, and because of this, the university does not run shuttles to this campus. Taking a city bus from the primary campus utilizes a very indirect route that takes almost an hour [1]. This can be particularly difficult for certain groups of students who are likely to lack adequate transportation, such as low-income and foreign students.

There are two main problems presented by the current system: tracking and theft. There is currently no method for collecting current system information. Students have no way of knowing where to find a bike, and must search for one if they wish to use one. Likewise, administrators have no hard usage data. The administrators hope to expand the system to the campuses of other local colleges and even city-wide, and are using UNO as a kind of test-bed. Simple use data, such as number of checkouts per day, would be critical for both administrative decisions and funding proposals. Finally, there is no method of preventing undesirable use, such as late at night or by users with a history of abusing the system.

The second problem, theft, is much more important to consider; some of the bike-share bikes have already been stolen. The program bikes have been painted bright yellow, so between the bright paint and the lower quality, the current bikes are unlikely to be stolen. However, there is desire to put better bikes in the system for a number of reasons. First, higher-quality bikes would be more likely to be used for longer trips; they would be more reliable and easier to ride. Many of the current bikes are single-speed, which are difficult to use on hills. Second, bike-share administrators are seeking funding in the form of corporate sponsorships with the idea that companies may place their name on the bikes and kiosks they sponsor; of course, the bike must be in good shape for a company to want to put its name on it.

To find a solution to these shortcomings, the program administrator contacted the chair of the Computer and Electronics Engineering (CEEN) department. Using systems implemented by other cities, such as Montreal's BIXI [2] and Paris' Vélib' [3], as examples, he asked the CEEN department to develop a system specifically tailored to the needs of the UNO bike-share program. The authors took this on as a thesis project, and this paper describes the system developed.

II. System Overview

An automated system of checking out bikes was developed, which consists of three components. Kiosks are distributed across the UNO campuses and connect to the university network via IEEE 802.11 "Wi-Fi"[1]or 803.2 "Ethernet" modules. Student ID cards are swiped to check out a bike, which

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[1]Although the phrase "Wi-Fi" actually refers to a certification standard for devices built on IEEE 802.11 and is not truly a synonym for the 802.11 standard, for the purposes of this paper, no meaningful distinction exists, and the two phrases are used interchangeably.

is uniquely identified by a Radio Frequency Identification (RFID) tag as part of the locking mechanism on the bike. Other commercial bike-lock systems utilize only one model of bike throughout the system; since the UNO system uses bikes of all shapes and sizes, the locking mechanism was designed to fit most any bike.

Kiosks communicate with a central server over the university's data network through an Ethernet connection where practical and over Wi-Fi otherwise. This server runs a variant of the LAMP stack, which consists of the Apache web server, MySQL database, and PHP scripting language. The web application and database are hosted on this server. Student users are able to look up system information through a web-browser, such as current locations of bikes. An interface for reporting damaged bikes is also provided. Once logged in, administrative users have a large variety of information and functions available; they may add bikes or kiosks to the system, view transaction history and data on currently checked-out bikes, and set up rules such as banning abusive users or limiting the number of simultaneously checked-out bikes for a single user.

Security and privacy are two large concerns for this system. Kiosks have measures in place to note improperly checked-in bikes (see Section III-A for greater detail). Web communication involving sensitive information is done over an encrypted HTTP connection, and wireless communication uses WPA encryption on top of this. When noting transactions, kiosks must provide the transaction scripts a password, to prevent malicious users from spoofing a kiosk and adding fake transactions to the system. Individual passwords, specific to each kiosk, are utilized, so that in case a password is revealed, only one of the many kiosks will have to be updated with a new password. Administrator and kiosk passwords are stored in the database as a SHA-1 hash with salt, an industry-standard method which prevents users from being able to gain access to passwords, even with full access to the database [4]. Since the project team did not have access to the university student information system, there is currently no method for preventing unauthorized use of a student ID card. However, the system has been designed so that the ID card reader [5] may be replaced with a nearly-identical reader featuring a numeric keypad [6], which would use already-existing student PIN numbers to verify user identity. In short, the system uses modern security technology to ensure that user-specific data is only available to those who need the data to prevent theft and keep the system running properly.

III. COMPONENTS

A. Kiosk

The kiosk is a custom-designed microcontroller-based system. It utilizes four "end-of-cable" (EOC) units, which are attached to the main kiosk body with a strength cable to secure the bike and a data cable to communicate with the main board, enclosed in a weatherproof sheath. Each EOC unit consists of a solenoid bolt lock and an RFID reader. The EOC cases are weatherproof and feature a button for selecting individual bikes.

The EOC units lock together with a small piece of hardware permanently attached to the bike. This consists of a small RFID tag for uniquely identifying each bike and a bracket which locks into the solenoid lock in the EOC unit.

The main kiosk unit controls the four EOC units, a magnetic card stripe reader, a Wi-Fi module, and an Ethernet module. Switches are on the main board for selecting between Wi-Fi and Ethernet as the primary communication method, as well as for uniquely identifying each kiosk.

The kiosk firmware consists of repeated scanning of all EOCs. When a bike is noted where no bike was before, the kiosk runs the check-in script. If a bike disappears, an error script is run. This allows the system to note false check-ins, which can be the result of either incomplete locking the bike or intentionally holding the EOC unit so as to make it read the bike tag without locking the bike. After scanning all four bikes, the kiosk updates a timestamp in the database to note that it is still up and running.

When an ID card is swiped, the checkout code is run. It begins by running a "verify" script to ensure that the user is allowed to check out a bike. The kiosk uses audible and visible indicators to inform the user of this initial decision. From here, the user must press the button on the lock corresponding to the bike he or she wishes to check out. The kiosk updates the database with this checkout and then unlocks the bike for several seconds. Following this up, a few seconds after closing the lock again, the system checks if the bike is still attached and notes this as a special case of a check-in. Repeat occurrences of this special case serve as an indicator of a failed lock.

B. Database

The database has multiple responsibilities. To begin with, it is charged with storage of bike information, such as a description, photo, number of checkouts, and current location. It holds a list of locations, which includes a description and login password hash for each kiosk, as well as a list of transaction types.

Most importantly, the database tracks all transactions that occur in the system, noting transaction type, bike ID, location, student ID, and timestamp. These transactions include check-in/outs, errors such as false check-ins, checkout denials, and addition of bikes to system. A separate table holds a list of information regarding currently checked-out bikes.

One table in the database handles storing checkout rules. These rules include bans on specific users or ID ranges, maximum number of simultaneous checkouts per user, hours to deny checkout, and holds on bikes in need of maintenance.

C. Web Application

The web application can be split into two different sections. The kiosk section serves an interface between the kiosk and the database. The user section consists of pages for students to view current system information and for administrators to track checked-out bikes and alter system settings.

1) Kiosk Interface: PHP scripts are set up for check-ins, checkouts, and error conditions. The check-in script simply notes the transaction, updates the location of the bike, and removes it from the checked-out bike list. A checkout is a two-step process. First, the kiosk calls a script to check whether the user is allowed to check out a bike. The kiosk then indicates the result to the user, and if successful, runs a second script to log the checkout, change the location of the bike, and add it to the checked-out table. If, after a checkout, the bike is still present, the bike is checked back in, although the transaction is listed as an error, so that repeated occurrences of this may alert the administrators of a failed lock.

A check-in error script is run when a bike is no longer detected by the system. This script looks up who was last responsible for the missing bike and checks it out to this user. Rather than listing this as a true checkout, a "check-in error" is listed as the transaction, instead, so that administrators may have a better idea of what has happened. Unfortunately, there is no way of being able to determine the cause of the disappearance from just this, but rather, this error exists to provide administrators with information to be used in determining the cause. Most likely, this event would be caused by a user incompletely locking a bike, although it could also be caused by a malicious user faking a check-in, a thief cutting through the cables to steal a bike[2], or a hardware failure. As such, it would be unreasonable to immediately have the system hold the user responsible for the missing bike.

Regardless of the transaction type, communication is performed in the same fashion. Secure HTTP connections are made with the server, and the user ID (if applicable), bike ID, kiosk ID, and kiosk password. These are passed using HTTP's POST command, which ensures that the information does not appear in server logs. The script replies to these requests by generating simple HTTP packets.

2) User Interface: A webpage was built to provide students and administrators with a simple interface to the system. On the student side of the application, users may view basic information on the system's bikes, including locations of specific bikes and where to find open bikes. A screen for reporting problems is also available. For further capabilities, a user with administrative capabilities must log in.

The administrative screens include many of the same screens as the student side, although more information is provided; for example, the bike details screen contains the basic bike information available on the student screen, but also states the student ID of the user who has checked out this bike. A sortable and filterable list of all transactions is provided. A screen allows administrators to add or remove system-wide rules. Finally, maintenance functions, such as adding new kiosks and administrative users, are also available from this website.

IV. COMMUNICATION INTERFACES

Since the system consists of a number of distributed kiosks which communicate with a central server, communications interfaces are critical to system operation. Since IEEE 802.11 "Wi-Fi" and 802.3 "Ethernet" are standards with wide implementation readily available across the UNO campus, they were the clear choice for communications between the kiosks and the server. Both Wi-Fi and Ethernet exist as part of the TCP/IP stack, which has become one of the most common, well supported, and easy to use data transmission methods, ideal for this project.

The circuit board for the kiosk has sockets for both a Wi-Fi module and Ethernet module. This allows each kiosk to only include the necessary module, cutting down on expense.

A. IEEE 802.11 Wi-Fi

Utilizing Wi-Fi is perhaps the more flexible option of the two interfaces. Since the university already has existing Wi-Fi access points across the campus, the only factor limiting the placement of a kiosk is power[3]. As such, wireless data transmission requires little to no change to existing infrastructure, a huge plus for ease of adoption. In addition, if multiple access points are within range of the kiosk, the system becomes more robust; one failed access point does not cut off the kiosk. Finally, encrypted communications methods, such as WPA, may be easily utilized for extra security. Although the data has already been encrypted by secure HTTP, Wi-Fi security schemes can make it more difficult to spoof a kiosk and provide an extra level of encryption for very little extra processing cost.

Wi-Fi does present a few disadvantages, however. To begin with, Wi-Fi equipment is typically more expensive and offers lower bandwidth than Ethernet counterparts. However, very little bandwidth is needed, and the expense of installing a cable out to the kiosk may easily offset the cost, so these are not critical issues. Although Wi-Fi offers encryption above and beyond that already provided by secure HTTP, tools such as Aircrack-ng can crack this, making it no more secure than Ethernet [7]. The current university wireless network is not set up for encryption, and more importantly, requires use of a virtual private network (VPN) to access private resources, so kiosk update scripts must be available outside of the university network in this configuration.

Some of the disadvantages to using Wi-Fi are inherent in the wireless physical layer in use in place of a wired physical layer and are present in any form of wireless communication. The IEEE 802.11 standard states that the physical layers used in Wi-Fi:

1) Use a medium that has neither absolute nor readily observable boundaries
2) Are unprotected from other signals that may be sharing the medium

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[2]The kiosk has been designed to prevent theft, although much like a commercial bike lock, use of tools such as a hack saw can defeat the locking mechanism.

[3]In the future, alternative powering schemes, such as photovoltaic, may be looked into; if implemented, a kiosk would need no wired infrastructure connection at all.

3) Communicate over a medium significantly less reliable than wired physical layers
4) Have time-varying and asymmetric propagation properties
5) May experience interference from logically disjoint IEEE 802.11 networks operating in overlapping areas [8]

IEEE 802.11 uses techniques to nullify or minimize these issues, resulting in a connection almost as reliable as a direct wired connection. Thus, the primary disadvantage of using Wi-Fi over Ethernet for this system is the need to work around existing network policy. Overall, the benefits gained by wireless offset the aforementioned disadvantages, so Wi-Fi remains a practical option for a communications interface in this system.

B. IEEE 802.3 Ethernet

Ethernet has many advantages in this application. To begin with, the Ethernet module in use is significantly less expensive than the Wi-Fi module used. In addition, so long as hardware is not damaged, the connection between the kiosk and router is very reliable and does not vary appreciably in different conditions. Unlike Wi-Fi, which can be simply "overheard" by interested parties, a physical link to the cable is required to sniff packets. Finally, Ethernet provides better bandwidth and is less prone to interference than Wi-Fi.

There are two primary disadvantages to using Ethernet. First, a cable must be run to the site of the kiosk. Since the kiosk will be outside in most cases, this will often require burying a cable, although if a power line is not already present and needs to be installed, it may be possible to install the data cable with the power line for little additional cost. Second, although intentional damage is unlikely, damage from digging or weather is a possibility. Unlike Wi-Fi, which can switch to another access point, the kiosk has no way of recovering if its link to the router is severed. The kiosk will remain down until the cable is fixed or replaced. In spite of these drawbacks, so long as a cable is practical to install and maintain, Ethernet is an excellent option for the kiosks' communications interface.

C. Other Possible Alternatives

Other communications interfaces were considered, but discarded in favor of Wi-Fi and Ethernet. A ZigBee wireless network was examined as a possible solution; however, the lack of existing ZigBee infrastructure and associated need for specialized hardware to implement the necessary infrastructure made it impractical. In addition, the use of cellular internet access was briefly considered, but discarded due to cost.

There are cases where both of these alternative solutions could be practical, although not in the current implementation. If the system was spread city-wide, and kiosks were added in locations where internet access may be impractical, such as a park or the beginning of a bike trail, either of the two above mentioned solutions are viable. Cellular internet access would allow communication from anywhere inside of the city, and ZigBee could be used to "hop" data across kiosks until reaching somewhere with network access. However, for the system as currently defined, Wi-Fi and Ethernet are far better suited to fit the needs.

D. Recommendation

It was determined that Ethernet and Wi-Fi were the two most practical interfaces for the current scope of the system; as such, the kiosks were designed to accommodate both methods. If a data cable is available or easily added to a kiosk location, the design team suggests using Ethernet, for the above mentioned reasons. If Ethernet is not practical, Wi-Fi is a suitable alternative.

V. RESULTS

Perhaps the most important metric of success in a project such as this is the satisfaction of the client. Using this metric, the project may be considered a success; the bike-share program administrator is pleased with the outcome and hopes to deploy this system on UNO's campuses and create derivative systems tailored to the needs of other local colleges, the downtown Omaha area, business campuses, and even city-wide. Beyond the immediate needs of the client, however, a number of other results are worth noting.

A. Demonstratables and Deliverables

A prototype of the system was constructed, consisting of a server hosting the database and one prototype kiosk. The kiosk consisted of all necessary hardware and electronics housed inside of a weatherproof enclosure. The kiosk and an instructional sign were mounted on a portable vertical pole in much the same fashion as it would be when deployed. During prototyping, the system was kept on a local area network (LAN) hosted by a small consumer wireless router, which allowed portability for demonstration purposes and consistency for performance testing.

Since it was a senior project, the original design team is no longer actively involved in the bike-lock project. A packet containing design decisions, source code documentation, schematics, construction instructions, a bill of materials, and a list of suggestions for improvement was provided to the bike-share administrators and the UNL Computer and Electronics Engineering (CEEN) department. Using this, the CEEN department may hire a number of student workers to continue working with the bike-share administrators to improve, implement, and deploy the system across the UNO campus in the upcoming year.

B. Usability

A number of usability goals were set during the design phase. In order to keep make the system easy to use, the interface is very minimal, consisting only of a card reader, two indicator LEDs, a buzzer, and a button for each bike. A graphic sign provides instructions for checking bikes in and out, as well as information about the system and a link to the program website.

The kiosk is very straightforward to operate. To check out a bike, a user swipes his or her student ID card, presses the

button on the desired bike, and slides the lock off. Checking in a bike is even simpler; the user slides the lock onto the bike's locking bracket, and the kiosk handles the rest. Adding a new bike to the system is not difficult. When a bike is checked in, if it is not already in the database, the system adds whatever information it can and shows the transaction as a bike addition rather than a check-in. Thus, rather than having to look up the RFID tag on a new bike, an administrator simply connects the bike to the kiosk, then looks up the newly-added bike in the transactions list page of the web application and adds a description and a photograph for the bike.

Because a slow or difficult-to-understand system would likely be abandoned, two time constraints were set. First, a user familiar with the system must be able to check out a bike in under 10 seconds. Typical results for this test were 2 to 5 seconds, with the primary constraint being network congestion. A second requirement was for users unfamiliar with the system to be able to complete a transaction in under two minutes. All new users tested were able to check a bike out in less than a minute, and one even took less than 20 seconds.

C. Environmental and Health Benefits of Implementation

Based on available information and conservative assumptions[4], the success of the bike share program has a number of environmental and health benefits. Over the course of a year, students will bike over 22,000 miles. The exercise associated with this will burn over half a million calories. Biking will prevent over 10,000 miles of car travel and have a net carbon footprint savings of over 7 tons of CO_2 per year.

VI. FUTURE PLANS

Currently, there is a strong possibility of the bike-lock system described by this paper being deployed within the next two years. The program administrator is seeking funding from a variety of sources, most notably corporate sponsorships. Some companies have expressed interest in deploying similar systems on their corporate campuses for building-to-building transportation or for short rides to nearby restaurants. A number of Omaha-area educational institutions are also interested in implementing a bike-share program utilizing this system.

On a more long-term scale, a city-wide bike-share program utilizing this bike-lock system is the hope of the program administrator. Unlike many other commercial systems, this could remain free to use by securing all funding through

[4]Assumptions made include: 8 kiosks across the three campuses, 50 (one-way) single campus trips (0.25 miles), 70 north/central trips (30 of which are in place of driving a car), and 10 central/south trips per day. These trips are assumed to only occur 180 days per year (due to weather and holidays), although the system is assumed to be drawing power every day. System power is only calculated from kiosks; it is assumed that the networking hardware and server are already in use, and that the added load from the bike-lock application would be negligible. For calculating gas and carbon, a 2006 Ford Taurus is taken to be representative of an average vehicle and electricity for the kiosks is assumed to be from coal or petroleum. For calculating calories burned, which increase with speed and weight of rider, a 155 pound student riding at a leisurely 10 mph was assumed. For further information on health and environmental calculations, please contact the authors at skenealy@unomaha.edu.

corporate sponsorships of kiosks bikes. As a starting point, kiosks would be set up along Omaha's bike trails and points of interest, such as the newly constructed "Aksarben Village" shopping area, and then expand from there.

One goal of the bike share program is make the roads of Omaha safer for cyclists. There is a bit of a culture war going on between cyclists and non-cyclists in Omaha; the opinion pages of the local newspaper frequently feature heated comments from both sides [9], [10]. Very few cyclists bike on the roads for fear of being hit, but at the same time cyclists are so uncommon that motorists don't learn to watch for them, and as a result, Omaha remains less than ideal for bike-transportation to anywhere not near a bike trail. The administrator believes that many residents do not own bikes precisely because of this, but hopes that a broader based bike-share program, along with an upcoming "Share the Road" campaign, will get more cyclists on the streets, in turn teaching motorists to share the road and making Omaha bike-friendly.

There are several improvements that can be made to the bike-lock system. To begin with, the design team's packaging abilities were limited to components available at hardware stores. A custom weatherproof enclosure would be far superior. Likewise, the team did not have a member who specialized in web design, so while the web application is practical and fits the needs of the project, there is room for improvement. Of course, powering the kiosks with renewable energy, particularly solar, would improve the public reception of the system, as well as remove the need to run any wires through the ground to the kiosks.

Perhaps the best improvement that can be made to the system is the ability to check out a bike lock chain with a bike. By allowing users to borrow a lock, a bike is no longer limited to locations with kiosks; users may ride to restaurants, shopping, and more. This addition creates a great deal of freedom to users. In much the same manner, the system could be improved by including the ability to check out a helmet at kiosks.

VII. CONCLUSION

The UNO bike-share program has grown successfully in its inaugural year, but shortcomings still need to be addressed. The primary shortcomings of the current "honor" system are a lack of tracking, administrative capabilities and an inability to prevent theft. By implementing an automated check-out system, these needs can be met. Such a system was designed and prototyped as a senior design project. Due to special needs, such as the ability to accommodate a wide variety of bikes, existing commercial systems were inadequate for UNO's needs. Two IEEE standards – 802.11 and 802.3 – served as a critical component of this system. They allowed the system components to easily and efficiently interact. The prototype system met the needs of the bike share program, and measures are being taken to deploy the system across UNO's campuses.

FURTHER INFORMATION

For further information on the UNO bike-share program and related Omaha bike initiatives, please see `www.unomaha.edu/bikeshare/` and `www.unomaha.edu/bikeblast/`. If you are interested in starting a similar bike-share program in your community, please contact Dr. David Corbin at `dcorbin@unomaha.edu`.

REFERENCES

[1] (2010, May) MAT trip planner. Metro Area Transit. Omaha, NE. [Online]. Available: http://trip-planner.metroareatransit.com/hiwire

[2] (2010, May) BIXI home page. BIXI Montreal. Montreal, Quebec, Canada. [Online]. Available: http://montreal.bixi.com/home

[3] "Thousands of bicycles in Paris give you lib'erty," Vélib' Paris, Paris, France. [Online]. Available: http://www.velib.paris.fr/content/download/3122/27013/version/3/file/V%C3%A9lib%27+-+English.pdf

[4] *Secure Hash Standard (SHS)*, NIST Std. FIPS 180-3, Oct. 2008. [Online]. Available: http://csrc.nist.gov/publications/fips/fips180-3/fips180-3_final.pdf

[5] *MR-5 Magnetic Stripe Card Reader*, rev. 09/97 ed., Mercury Security Corporation, 1997. [Online]. Available: www.mercury-security.com/manuals/Mr5.pdf

[6] *MR-10/MR-20 Magnetic Card Reader*, rev. 1.03 ed., Mercury Security Corporation, 2005. [Online]. Available: http://mercury-security.com/Installation_Manuals/mr20_m.pdf

[7] (2010, May) Aircrack-ng homepage. [Online]. Available: http://www.aircrack-ng.org/

[8] *IEEE Standard for Information technology - Telecommunications and information exchange between systems - local and metropolitan area networks - specific requirements; Part 11, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE Std. 802.11-2007, June 2007.

[9] "The public pulse, April 8," Omaha World-Herald, Apr. 2010. [Online]. Available: http://www.omaha.com/article/20100408/NEWS0802/704089981/-1

[10] "The public pulse, April 15," Omaha World-Herald, Apr. 2010. [Online]. Available: http://www.omaha.com/article/20100415/NEWS0802/704159997