REMOTE WIRELESS COMMUNICATIONS FOR CONSTRUCTION MANAGEMENT: A CASE STUDY

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ABSTRACT

The recent advances in urban wireless communications and protocols that spurred the development of city-wide wireless infrastructure motivated this research, since in many cases, construction sites are not conveniently located for wired connectivity. Large scale transportation projects for example, such as new highways, railroad tracks and the networks of utilities (power-lines, phone lines, mobile towers, etc) that usually follow them are constructed in areas where wired infrastructure for data exchange is often expensive and time-consuming to deploy. The communication difficulties that can be encountered in such construction sites can be addressed with a wireless communications link between the construction site and the decision-making office.

This paper presents a case study on long-range, wireless communications suitable for data exchange between construction sites and engineering headquarters. The purpose of this study was to define the requirements for a reliable wireless communications model where common types of electronic construction data will be exchanged in a fast and efficient manner, and construction site personnel will be able to interact and share knowledge, information and electronic resources with the office staff.

KEY WORDS

Wireless, remote connections, local area networks, data transfer, communications.

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INTRODUCTION

Wireless communications have been significantly explored in the last decade to develop devices and protocols that work well in indoor and controlled environments. Recently, as more outdoor wireless applications emerge, experimental research has become necessary to tackle practical issues related with connectivity in outdoor environments like construction sites.

The recent advances in urban wireless communications and protocols that spurred the development of city-wide wireless infrastructure are the main motivation for this research. In many cases, construction sites are not conveniently located for wired deployment. Large scale transportation projects for example, such as new highways, railroad tracks and the networks of utilities (power-lines, phone lines, mobile towers, etc) that usually follow are constructed in areas where wired infrastructure of utilities is often expensive and time-consuming to deploy. The same problem is encountered in other types of typically rural projects like underground water or sewage pipeline installations, dams, and others.

One of these necessary utilities is internet/intranet connectivity with the decision-making (main) office. Currently, access to the main office database can be a critical aspect for the success of a construction project. Without this access for example, a site engineer who drives to the site only to realize that a set of drawings needed for the upcoming tasks was left at the office, can only drive back to retrieve it. Also, data collection devices that frequently monitor construction areas or items like cameras, video, sensors of all types, and others produce large amounts of data that need to be transferred from the site to the main office. Traditionally (without a communications link), the data is collected periodically by site or office personnel. As a result, high capacity data storage is needed, the data is mostly historical (typically arrives too late to be used proactively to avoid delays, construction defects, etc) and manual labor (often extensive for large sensor networks) is needed to collect it each time. Wireless communications can provide an efficient alternative to periodic data collections, especially when combined with the recent advances and technologies in wired and wireless mobility for construction that have enabled construction site staff to collect, carry and modify construction data in electronic format.

Remotely located rural projects are excellent candidates for the utilization of such technologies that can possibly reduce the effort needed for data exchange and interactivity of site and office personnel. In the absence of such connectivity, for example, site personnel (inspectors, site engineers, sub-contractors, etc) have to travel for long distances to be "on site" more frequently. Thus, in such cases, it is important to minimize the amount of people needed at the site (or the number of trips that they need to make) and automate tasks like data collection, certain types of inspections, quality control, etc.

Also, originality and timeliness of the information exchanged between the site personnel and office decision-makers are usually compromised. For example, in many projects site engineers report the progress of the daily activities when they return to the office at the end of each day. The construction manager must then rely on this information to make the necessary schedule adjustments/additions for the upcoming work. The disadvantage of this process is that the information arrives "second-hand" and is thus subject to the interpretation of the site engineer, who is perceiving and explaining the information in a certain way and the interpretation of the construction manager, who is perceiving the words of the site engineer in another way. Also, in many cases, the lack of an up-to-date visual perception of the construction site from the office staff results in lengthier explanations of the site conditions and thus less time spent on the important decision making tasks that follow.

In summary, the communication difficulties that can be encountered in today's construction sites which result from the lack of an effective and efficient communications link between the construction site and the decision-making office are the issues that this research investigates. The ultimate goal is geared towards overcoming these difficulties, and giving site and office personnel secure and stable data exchange and interaction capabilities.

This paper presents a case study on long-range, wireless communications suitable for data exchange between construction sites and engineering headquarters. The purpose of this study was to define the requirements for a reliable wireless communications model where common types of electronic construction data can be exchanged in a fast and efficient manner, and construction site personnel can interact and share knowledge, information and electronic resources with the office staff.

CONSTRUCTION SITE WIRELESS TOOLS

WIRELESS SENSOR TECHNOLOGIES AND NETWORKS

Wireless sensor technologies are commonly applied at constructed and under-construction projects. Chase (2001) claims that existing inspection methods employed by the Federal Highway Administration's National Bridge Inspection Program (that requires the states to report the condition of its bridges as determined by visual inspection so that the FHWA uses this data to apportion its $3 billion budget toward replacing or rehabilitating the most deficient bridges) is not reliable enough. Visual inspections are not sufficiently detailed, nor reliable enough, to predict where significant but not-yet-critical damage is developing in the nation's thousands of bridges. So the FWHA is developing and testing many types of technologically sophisticated ways to monitor and inspect bridges for damage that is either undetectable by the human eye or that is simply in its beginning stages. Some of these new technologies use wireless radio transmitters to send their data to control centers.

Zhang and Cheng (2005) claim that wireless sensor networks offer several benefits over conventional sensors for civil engineering structures monitoring. Therefore, applying wireless sensor networks to health monitoring of large-scale civil infrastructures has received considerable interest over the past few years. In this area, current research lies on solving practical issues that emerged from implementing wireless sensor networks for large-scale civil infrastructure monitoring, such as sensor location identification, robustness of sensor network, and data compression techniques and their effect on vibration-based structural health monitoring.

Chen et al. (2005) demonstrated the need to develop new architecture and networking protocols to match the unique topology of chain-type sensor networks, and investigated special classes of wireless sensor networks for monitoring critical infrastructure that may extend for hundreds of miles in distances. Such networks are fundamentally different from traditional sensor networks in that the sensor nodes in this class of networks are deployed along narrowly elongated geographical areas and form a chain-type topology. These researchers proposed a hierarchical network architecture that consists of clusters of sensor nodes to enable the chain-type sensor networks to be scalable to cover a typically long range of infrastructure with tolerable delay in network-wide data collection. They also devised smart strategies for the deployment of cluster heads to maintain energy efficient operations and maximize the lifetime of such a chain-type sensor network. Their work also produced protocols for network initialization and seamless operations of the chain-type sensor networks to match the hierarchical architecture and cluster head deployment strategy.

Establishing a real-time continuous flow of sensor data on a stable wireless communications link will enable real-time monitoring of constructed and under-construction infrastructure projects. Many state-of-the-art sensors can work seamlessly with wireless technology since outdoor construction site conditions rarely permit the use of sensitive electronic cables. For example, sensors ranging from image acquisition (Nobles and Halsall, 2001; Yates and Madnayam, 2000; Agan et al., 1998) to crack detection (Schoess, 1996; Washer 1998) are wireless-ready, both in terms of data acquisition and remote sensor control.

WIRELESS POSITIONING SYSTEMS

The popularity of wireless site positioning mechanisms is also increasing. Smith et al (2004) claims that wireless location technologies have been developed to allow mobile wireless devices (the most common of which are cellular telephones) to be geo-located. Probe-based traffic monitoring systems using wireless location technology have been developed, and wireless technologies still have unexplored capabilities that could possibly enhance the precision of existing tools.

ADVANCED DATA COLLECTION TECHNIQUES

Hwang et al. (2004) claim that collecting accurate field data plays a key role in the success of a construction project. Field data related construction progress, process, productivity, quality, safety, and costs must be collected, synthesized, and archived for project records and improvements. Advances in information technology have gradually changed how construction data are managed in the field. These advances, such as mobile computers, wireless communications, video conferencing, collaboration systems, 3D laser scanning, digital close range photogrammetry, sensors, and project ASPs (application service providers), have provided new ways for collecting and managing project information. With these tools come both opportunities and challenges to researchers, educators, and practitioners. Opportunities exist for companies in the Architecture, Engineering and Construction (AEC) industry to use these advances to increase efficiency, productivity, and quality. These researchers also claim that close partnership with the industry practitioners will shorten the duration of technology transfer and reduce the cost and uncertainties associated with new technologies.

DEVICE COMMUNICATIONS AND INTEGRATION

Singhvi et al. (2003) developed a context-aware information system designed to deliver up-to-date project information from the main office to the construction site. The objective was to help the user manage the complexity of the construction data by proactively tracking current resource requirements and proactively obtaining access to context-relevant information and services. To achieve this, the system used off-the-shelf handheld computing devices and an on-site wireless network for local communication. This allowed continuous access to data and resources as users moved around the job site. This work highlighted the benefits of context-aware computing for on-site information delivery at a construction site and the need for better communication methods.

Overall, the common aspect of the construction site tools and methods described above is their capability to transmit the collected data wirelessly. In some cases, this advantage is utilized by setting up a temporary wireless connection to an on-site storage location (e.g. a laptop) for each data collection phase. In other cases, high volume storage is deployed and replaced at regular intervals. An alternative to both is the direct establishment of communications between the decision making office and the construction site. Wireless tools can then transmit data directly to the final repository on a permanent basis without the need for laborious periodic data collection trips or outdoor temporary data storage. This solution ensures data integrity (one-step transfer), security (less equipment deployed on-site) and real-time data access (data transferred when acquired, not periodically).

CASE STUDY DESCRIPTION

The main objective of this case study is to expose the practical limitations of procuring, deploying, aligning, operating and maintaining a long distance wireless point-to-point connection suitable for construction site to main office communications. The long term goal is to take advantage of the mobility provided by wireless communications to allow real-time, convenient interactivity and data transfers without the need for a cabled, Ethernet-like infrastructure that is time-consuming and impractical to deploy each time a new project is initiated (especially in remote locations).

The following steps summarize the mechanics of the wireless network deployed for this case study (Fig. 1):

- Office and site facilities are wirelessly connected via radio frequency standards.
- Compatible wireless devices (Cisco Aironet 1310 bridges/access points, with 13dbi integrated directional antennas) are placed at distance-permitting intervals to achieve this connection.
- Outdoor robotics (Pan-Tilt-Zoom) cameras with TCP/IP control capabilities (D-Link DCS 6620G) are mounted on top of each wireless device, and serve as the “rifle scope” for aligning the directional antennas remotely.
- Signal strength detectors and vision-based automatic device detection algorithms (that will be developed as the next step of this research) are used to compute the optimal position and directionality of each wireless device, as well as for line-of-sight obstacle detection.
- Wireless-enabled devices commonly used in projects are used to test the performance of the connection. Specifically, device detection and communication compatibility

were tested, and integration needs were defined. Cameras, for example, should be tested for interactivity with the office and video data collection, while wireless structural health monitoring sensors should be assessed for real-time continuous monitoring.

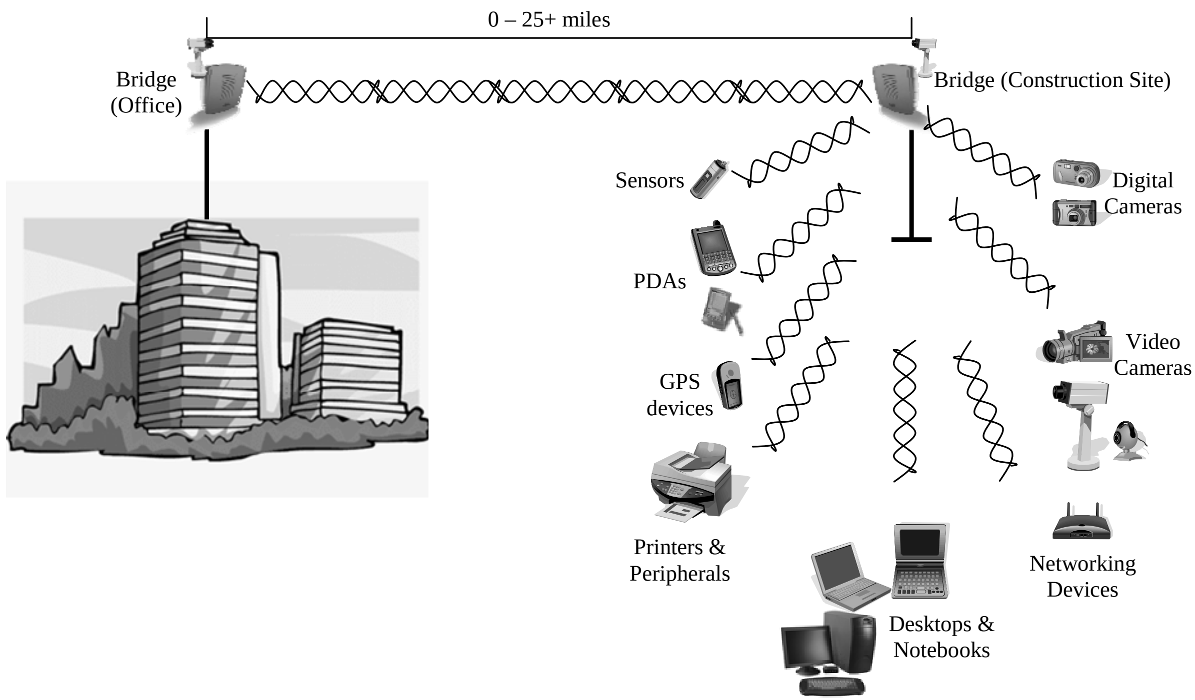

Figure 1: Overview of Proposed Communications Model

To implement each of the aspects above in this preliminary case study, the following three steps were followed: 1) Simulating actual conditions, 2) Procuring equipment, 3) Testing. The details of these steps are described in the following subsections.

SIMULATING ACTUAL CONDITIONS

The purpose of this case study was to study the applicability and limitations of long-range wireless local area network technology when applied to a main office – construction site scenario. Thus, a decision-making office location and an actual construction site were needed to simulate actual conditions. The Construction Information Technology Lab (CITL) at the University of Michigan's North Campus was selected as the main office facility to simulate the convenience of using an in-house facility for exchanging information with local construction sites. Based on this choice, the selection of the site depended on the limitations of the existing hardware technologies for long-distance wireless connectivity. As will be later explained, the main criteria for this selection were distance and line-of-sight.

In terms of distance, maximization was sought with the chosen equipment maximum range as the only limitation. However, due to the moderately-steep elevation changes of the area, this criterion was not a significant limitation. The defining factor was line-of-sight, and thus, the highest elevation points were sought. These points were determined using 3D elevation maps (Arlinghaus, 2003; Fig. 2) and on-site observations as shown in Fig. 3 and 4, where the highest elevation points of both main office and selected construction site are indicated.

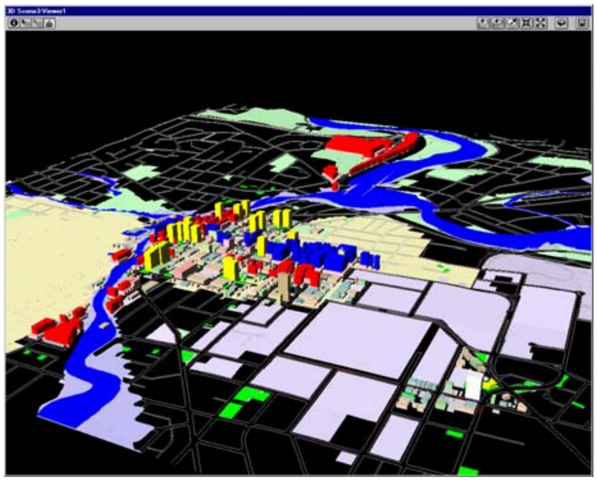

Fig. 2: 3D interactive elevation map of Ann Arbor (Arlinghaus, 2003)

Fig. 3: UM North Campus, Bell Tower identified as heighest point

Fig. 4: UM Central/Medical campus
School of Public Health construction site identified as highest point

The School of Public Health project site at the Medical Campus of the University of Michigan was selected as the actual construction site. The site is located a few miles away from the chosen office facilities and is partially visible from North Campus.

PROCURING EQUIPMENT

For the purposes of this case study, the first part of this step was to define the methods needed for reliable long-distance outdoor wireless communications. This part involved investigating traditional (commercially available) and new wireless protocols and identifying the strengths and weaknesses of each regarding this application. Standards like 802.11 a-g for Wi-Fi and newer WiMAX technologies were evaluated. Different signal propagation frequencies were considered, ranging from radio frequencies (2.4 – 5.0 GHZ) to microwaves (e.g. 50 GHz). Hardware support, applicability, affordability and availability as well as feasibility were taken into account.

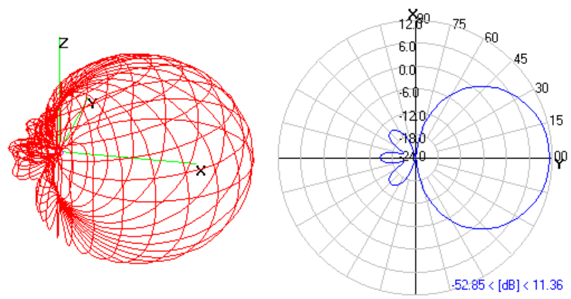

Figure 5: Typical 5GHz directional antenna signal strength distribution

From this investigation, similar to case studies for other industries (Geier, 2003), it was determined that higher frequencies in most cases are equivalent to: i) shorter range, ii) greater spectrum (Fig. 5), iii) higher theoretical performance (due to more non-overlapping channels), iv) less interference (e.g. 5GHz traffic is much less congested as opposed to 2.4 GHz), v) less compatibility (most existing wireless devices operate on the 2.4 GHz spectrum), vi) higher security (due to smaller range), and vii) higher costs, with higher performance and less interference as a way to offset the extra expense. With these characteristics in mind, the 802.11b/g 2.4GHz standard was selected since range, compatibility and affordability are more important than breadth of spectrum and very high performance (>11 Mbps).

The selected standard was used to define the communications devices for the case study; a pair of Cisco Aironet 1300 series outdoor wireless bridges with integrated 13dbi directional antennas. This bridge is specified (Cisco, 2005) to operate under extreme weather conditions (temperature, wind, humidity), can sustain an 11 Mbps bandwidth at 14 miles of clear line-of-sight and can seamlessly interface with the existing local area networks at each node. In this case, the main office operated a hard-wired local area network and an 802.11b/g wireless network. The construction site, on the other hand, was not operating any local area network, and so local wireless networking was provided also from the outdoor bridge.

After determining the locations and equipment, this research was presented to the owner of each facility (University of Michigan) and the contractor of the project site to receive permission for installing the selected equipment on the selected locations. The effect of this work on the aesthetics of the buildings, other wireless and radio networks in the area and the privacy of employees was evaluated.

TESTING

The wireless equipment (as well as a host of wireless devices) was scheduled to be tested in three phases. The goal of the first phase (in-lab testing) was to determine the compatibility of all equipment with each other and with the existing network (wired & wireless), the actual maximum performance/bandwidth and the software/integration requirements for the final deployment. The goal of the second phase (outdoor/mobile testing) was to test the equipment limits in terms of distance and line-of-sight. Specifically, both bridges were mounted in vehicles (Fig. 6) and the bandwidth was tested under several configurations of the distance, terrain elevations (line-of-sight) and the angle of the directional antennas. The goal of the final phase (outdoor/fixed testing) is to test all of the above at the locations selected previously for final deployment.

Figure 6: Bridge mobile test configuration

LESSONS LEARNED AND FUTURE RESEARCH

From the first test, it was determined that traffic monitoring, securing, data integration and other data administration applications are needed to handle the diverse types of data that are communicated with the construction site. These applications should consider the importance of each construction data type and allocate the available bandwidth accordingly, protect the data from unauthorized access, alert the users of connectivity issues (low signal strength, bandwidth limit reached, etc.), and most importantly provide a unified framework for handling the various types of data that need to be transferred. Finally, methods for limiting the interference with other networks that operate in the same frequencies are necessary.

From the second test, it was determined that methods and algorithms for automatically aligning/re-aligning the antennas and choosing the optimal distance between nodes are needed. Proper directional antenna alignment can significantly increase the signal strength of a network at a given range or significantly increase the range of the network at certain strength (Fig 5). Similarly, methods for calculating the optimal distance of nodes are needed since long range linear connections perform only as good as their weakest link. Incorrectly spaced nodes can create wireless “bottlenecks” and significantly reduce the performance of the network overall. The third test reaffirmed the previous findings on a stable deployment.

These identified needs are the next target of this on-going research. The author plans to address these limitations and then test the research outcomes with a larger deployment at the City of Champaign, where the department of Public Works has agreed to test the outcomes for their projects.

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