LONG-DISTANCE WIRELESS NETWORKING FOR SITE – OFFICE DATA COMMUNICATIONS

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SUMMARY: *Effective data communications between the project site and decision making office can be critical for the success of a construction project. It allows convenient access to centrally stored information and allows centrally located decision makers to remotely monitor the site and collect data in real-time. However, high bandwidth, flexible data communication networks, such as wired local area networks, can often be time-consuming and costly to deploy for such purposes especially when project sites (dams, highways, etc.) are located in rural, undeveloped areas where networking infrastructure is not available. In such construction sites, wireless networking could reliably link the construction site and the decision-making office. This paper presents a case study on long-distance, site – office wireless data communications. The purpose was to investigate the capability of wireless technology in exchanging construction data in a fast and efficient manner and in allowing site personnel to interact and share knowledge and data with the office staff. This study took place at the University of Michigan's campus where performance, reliability, and cost/benefit tests were performed. The indoor and outdoor tests performed demonstrated the suitability of this technology for office-site data communications and exposed the need for more research to further improve the reliability and data handling of this technology.*

KEYWORDS: *local area networks, data communication, network design, data collection, remote sensing.*

1. INTRODUCTION

Modern construction sites are increasingly flooded with high tech equipment that tries to tackle the problems generated by the ever increasing complexity of modern infrastructure and the needs for better project control, efficient operations and cost reductions. Laptops, digital cameras, laser scanners, video cameras, sensors (e.g. for structural health monitoring) and other devices assist site personnel in a host of daily tasks such as various inspections and data acquisition. In urban construction sites, transferring the information recorded by the equipment to and from the decision making center (main office) can be accomplished to a certain degree with the established local internet or mobile phone services. Similar to powering electric equipment, local internet providers (cable, DSL, mobile, etc) can provide such services for a standard fee.

However, in remote project sites, such as those located in rural areas, these providers might not be available. Under these circumstances, data communication options with the project site are severely limited and the actual distance (remote site - office) increases the significance of this problem. For example, if a site engineer is missing a set of drawings that is not available at the site, the engineer will have to travel back to the main office to retrieve it instead of conveniently downloading it with a laptop at the site. Satellite internet providers can provide such connectivity but with certain limitations in value, performance (bandwidth) and reliability, the latter of which is a critical flaw in a business environment.

Traditionally, when local suppliers of materials (i.e. concrete) or services (i.e. power) are not available or the available product/service does not meet the needs or specifications of the project (e.g. high strength concrete), contractors usually assume that role themselves and create facilities to produce the missing material or service. For example, when building a concrete dam far away from urban surroundings, it is common for contractors to produce their own concrete by installing a temporary batch plant. Similarly, in the case of data communications, the author suggests that a analogous strategy should be followed. However, deploying a wired network that spans, for example, from the contractor's office to the remote, rural location can be a very costly and time consuming solution. Instead, this paper proposes an alternative solution based on outdoor wireless networking principles that can reliably link project sites located several miles from the decision making office in an inexpensive and timely manner.

The proposed solution is based on IEEE wireless radio frequency communication standards and off-the-shelf hardware. It consists of communication “nodes” that can be spaced at certain intervals (several miles apart) to propagate the wireless signal to and from the project site. The resulting directional signal path can be repeated multiple times to accommodate for multiple projects administered from the same location or multiple sites of the same project (e.g. a highway project spanning over several miles, with multiple concurrent project sites). Each node can be configured to send/receive signal from one or multiple nodes, which allows numerous network configurations. This provides greater deployment flexibility to accommodate for the physical (landscape elevation) constraints of each project. The nodes can be re-used and re-configured in future projects or activities to comply with the dynamic needs of construction. Analogous solutions have been proposed recently (Ward et al, 2003; Ward et al, 2004) for on-site connectivity that can be easily combined with the proposed remote communications network.

The proposed solution was tested in several phases. Initial tests were conducted in indoor/controlled environments to record the actual optimal performance of the equipment and test network integration and device compatibility issues. The next testing phase involved mobile outdoor testing to investigate the performance at different distances and the effect of common outdoor signal obstacles in rural environments such as trees and elevation changes. The last phase involved re-testing the model under different weather conditions for durability, performance and stability and included a benefit/cost comparison with the alternative remote wireless technology, satellite internet. The full scale deployment of the model established communications between the Construction Information Technology Lab at the University of Michigan and the project site of the under construction School of Public Health.

This paper provides an overview of the data communication issues and limitations encountered in construction sites and the Wi-Fi ready tools that are commonly found in project sites, and could significantly benefit from the proposed model. Following that, the proposed solution that was followed by the case study is presented in detail and how it addresses the data communications issues of projects located in rural and remote areas is explained. The testing processes and results that validate this case study are discussed, and the paper concludes with a summary of this research’s outcomes and some research issues that need to be addressed in the future.

2. OUTDOOR WIRELESS NETWORKING

Wireless networks are gradually replacing wired local area networks as the standard for data communications. Wireless communications have been significantly explored in theory so as to develop devices and protocols that work well within indoor and controlled environments. These recent advances spurred the development of outdoor, urban wireless communication protocols and hardware for city-wide wireless infrastructure deployments (Reardon, 2005a), and many cities around the world are exploring such options (Reardon, 2005b). For example, Cleveland, Ohio; Corpus Christi, Texas; Philadelphia; Portland, Oregon; Dusseldorf, Germany; Jerusalem, Israel; and Taipei, Taiwan, are among the urban communities participating in Intel's city-wide Wi-Fi deployment initiative (Singer, 2005a). Also, U.S. local authorities and state governments are working together in creating and modifying policies to pro-actively address this new wave (Hu and Reardon, 2005; Hardy, 2005; Charny, 2005) and regulate its deployment.

The private sector is also gradually responding to such endeavors. The automobile industry is constantly adding more electronic gadgets and services in vehicles with the ultimate purpose of turning vehicles into mobile offices/workstations that will take advantage of public (or private) Wi-Fi services for internet connectivity (Kawamoto, 2005). The electronics industry is championing this wave by constantly replacing mobile devices such as digital cameras and personal digital assistants with their Wi-Fi enabled counterparts (Singer, 2005b; Kingson, 2005). These developments justify extensive investigation of the potential gains that the construction industry can benefit from wireless communications and highlight the need for experimental research to tackle practical issues related with deploying wireless networks in outdoor environments like construction sites.

3. DATA COMMUNICATIONS IN CONSTRUCTION

The construction industry has also embraced such technologies by utilizing them mainly for on-site communication needs. For example, Ward et al. (2003; 2004) developed and implemented a wireless mobile data collection system for piling works. This system allowed real-time data collection to an on-site server, which in turn allowed for easy access and manipulation of the timely construction data for project management purposes. These benefits led to enhanced information flow throughout the site, reduced remedial costs and improved contract performance. Beyh and Kagioglou (2004) proposed and tested the use of IP Telephony for voice communications over an established on-site wireless network. Zou et al (2006) presented the necessity of mobile computing in construction and the research in solving on-site communication problems with mobile computing. Kuladinithi et al (2004) presented an ad-hoc wireless communications framework for on-site communications. The applicability of this framework was validated through a detailed scenario that described how this technology could be used in construction sites and presented solutions to implementation and deployment issues of the ad-hoc networking protocol involved. However, the limited bandwidth of ad hoc networking and the limited range (up to 100m) (Kuladinithi et al, 2004) limits the applicability if this approach to dense, high traffic construction environments with limited networking needs.

3.1 Communications between project sites and the decision making center

At the beginning of each project, it is common for contractors to contact several utilities providers (e.g. water, electricity, phone, and internet) who can provide their services to the project site and rent these services for the duration of the project. For example, in most cases, it is more convenient to have leased power lines instead of power generators, municipal water instead of water trucks, and cable internet for office-site data communications instead of manually transporting the data to and from the project site. However, such infrastructure and utilities providers are not always available or cannot meet the needs of the project. The lack or deficiency of such infrastructure commonly found in rural, remote areas is 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 highways, railroad tracks and the networks of utilities (power-lines, phone lines, mobile towers, etc) that usually follow them are constructed in areas where permanent infrastructure of utilities is often expensive and time-consuming to deploy. The same problem is frequently encountered in other types of typically rural projects like large-scale underground water or sewage pipeline installations, dams, and others.

One of these necessary utilities is internet/intranet connectivity with the main office. Reliable access to the main office database can play an important role in the success of a construction project. Without this access, for example, a site engineer looking for cost and performance data needed to choose between alternative solutions to a problem that emerged regarding a time-critical activity (i.e. concrete pouring) 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 the 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. Dedicated data communications are 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.

Satellite internet technologies are capable of providing such site – office data communications and are readily available on the market. However, the excessive costs and limited performance/reliability issues associated with this networking solution have created market space for cheaper, more efficient technologies. Specifically, with satellite internet a) it is very difficult to use multiple communication devices (i.e. construction cameras and a laptop) even with multiple internet connections, since the bandwidth is not dedicated to each connection (the bandwidth is shared among the users in that area), and b) a relatively clear sky is needed to maintain connectivity, and c) the monthly costs involved in maintaining the service is significant when compared to the network performance that is provided. These issues were considered in the cost/benefit analysis of this case study. Still, under certain circumstances (i.e. project sites located several hundreds or thousands of miles away from urban infrastructure) this technology is the only option for data communications. In any other case of rural project sites (i.e. when project sites are located within a few hundred miles from urban infrastructure) efficient wireless communications can provide an effective alternative to expensive, hard wired solutions while maintaining their advantages such as high bandwidth and reliability.

Therefore, most 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) need travel 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 and automate tasks like data collection, certain types of inspections, quality control, etc.

Originality and timeliness of the information exchanged between the site personnel and office decision-makers is another issue. 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 author hypothesizes that the communication difficulties that can be encountered in most rural construction sites, and result from the lack of an effective and efficient communications link between the construction site and the decision-making office, can be surmounted using wireless technologies. This case study intends to investigate this hypothesis and outline a wireless solution that is was geared towards overcoming these difficulties and giving site and office personnel secure and stable data exchange and interaction capabilities.

4. CONSTRUCTION SITE WIRELESS TOOLS

4.1 Wireless sensor technologies and networks

Wireless sensor technologies are increasingly 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 involves solving practical issues that emerge 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 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.

4.2 Wireless positioning and data collection and management techniques

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.

Reinhardt et al (2004; 2005) explained that conceptual representations of information contained in product and process models are often difficult to use for accessing data when performing engineering tasks. This is especially true if project-management information contained in product and process models needs to be made accessible on a mobile computer on construction sites. To make this information accessible, customized conceptual and visual information representations were needed. Based on these facts, Reinhart et al (2005) developed a navigational model framework that effectively and efficiently creates and manages different views of information contained in product and process models.

Caldas et al (2004) investigated data and technology requirements for the implementation of integrated real-time materials management on construction job sites. Specifically, the research aimed (1) to formalize methods for accurate and timely materials tracking and (2) to define data integration needs between sensing technologies, materials management, and project control systems. The first phase of this study focused on materials locating technologies.

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.

4.3 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 or local wireless networks (i.e. Ward et al, 2004) can then seamlessly integrate with the remote communication network and 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 improves data integrity (one-step transfer), security (less equipment deployed on-site) and real-time data access (data transferred when acquired, not periodically).

5. PROPOSED SOLUTION DESCRIPTION

The proposed solution is an alternative solution to wired or satellite configurations and is based on outdoor wireless networking principles. It was designed to reliably link project sites located up to a few hundred miles from the decision making office in an inexpensive and timely manner (distance limits are determined by the cost benefit analysis described below). Note that for longer distances (many hundreds to thousands of miles from an urban location) other technologies (i.e. satellite) should be considered. This solution provides a stable data transfer bandwidth and can exchange common types of electronic construction data in a fast and efficient manner. Also under this model, construction site personnel can interact and share knowledge, information and electronic resources with the office staff. The main difference with previous configurations is that it takes 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).

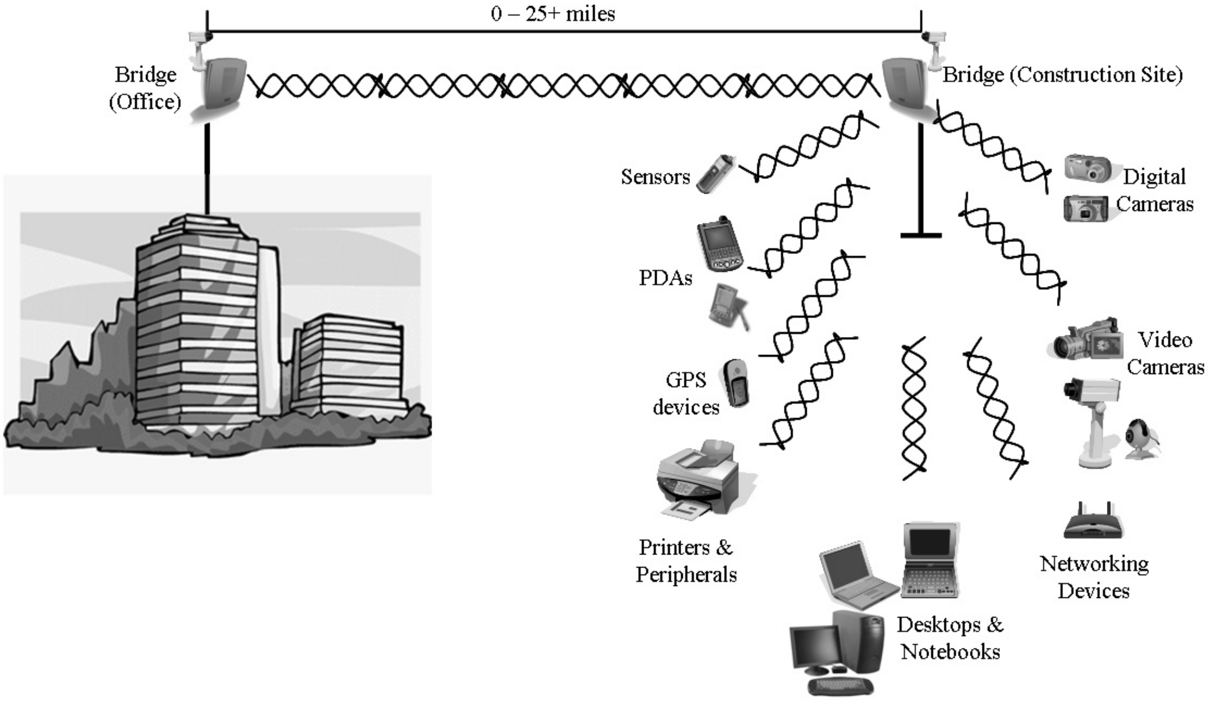

FIG. 1: Overview of Proposed Communications Model

The following steps summarize the mechanics of the proposed communications model (Fig. 1):

- Office and site facilities are wirelessly connected via IEEE wireless radio 802.11a/b/g standards.
- Compatible wireless devices (the ”nodes”), typically bridges/routers/access points with mounted or integrated directional antennas, are placed at distance-permitting intervals to achieve this connection.
- Nodes are spaced up to 65 km or more (Ticktin, 2005) apart provided adequate radio line of sight is available.
- Outdoor robotics cameras with TCP/IP control capabilities are mounted on top of each wireless device and serve as the “rifle scope” for aligning the directional antennas remotely.
- Signal strength detectors are used to compute the optimal position and directionality of each wireless device, as well as for line-of-sight obstacle detection.

The communication “nodes” can be spaced at certain intervals (several miles apart) to propagate the wireless signal to and from the project site. The resulting directional signal path can be repeated multiple times to accommodate for multiple projects administered from the same location (Fig. 2) or multiple sites of the same project (e.g. a highway project spanning over several miles with multiple concurrent project sites). Each node can be configured to send/receive signals from one or multiple nodes, which allows numerous network configurations. This provides greater deployment flexibility to accommodate for the physical (landscape elevation) constraints of each project. The nodes can be re-used and re-configured in future projects or activities to comply with the dynamic needs of construction.

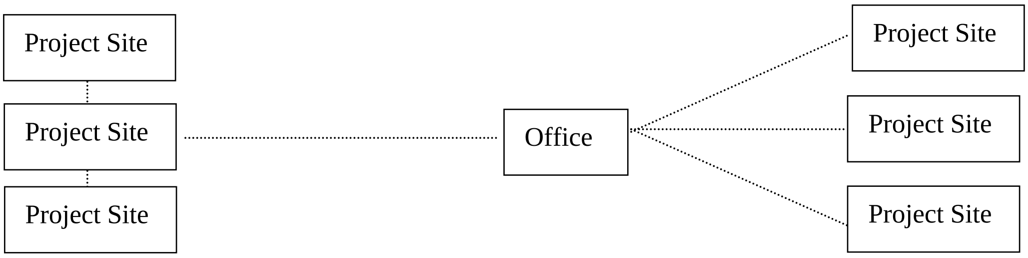

FIG. 2: Example node configurations based on location. On the left: a central node is selected; nearby sites connect through it. On the right: parallel connections link the office node with each site node.

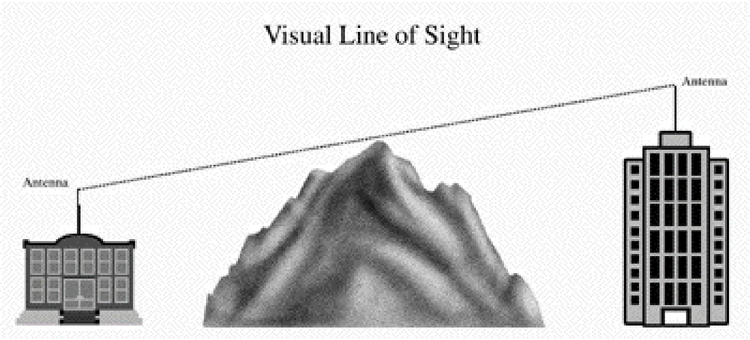

FIG. 3a: Visual Line of Sight (Ticktin, 2005)

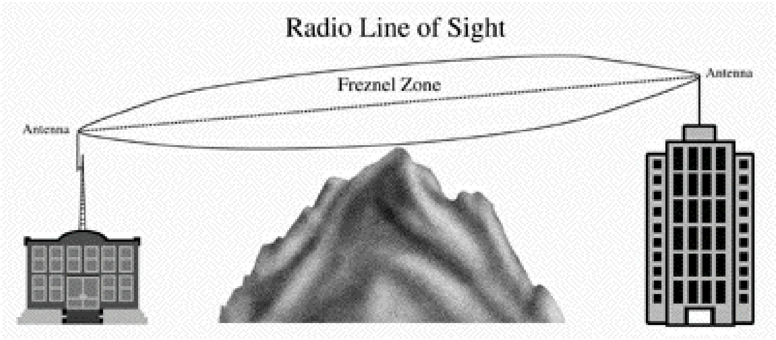

FIG. 3b: Radio Line of Sight (Ticktin, 2005)

Wireless networks need a fairly clear signal path to operate (Ticktin, 2005; Ward et al, 2004). This not only means visual line of sight, but radio line of sight (Fig. 3a). Visual line of sight is the straight line connecting any two nodes. While it is possible for the signal to propagate along this line, optimally a complete clear radio line of sight is preferred. Radio line of sight takes into account the shape of the zone that the radio waves travel in. This is called the “Freznel” zone. In other words, the radio waves travel between the nodes covering an ellipsoid area (Fig. 3b) and so the clearance desired halfway between the nodes is greater than at each node location.

Therefore, to achieve a near optimal signal path in multiple node configurations (Fig. 4), intermediate nodes must be spaced at elevated locations such as hilltops, tall buildings and others. The strength of the signal is a good indicator of correct placement. Previous case studies (i.e. Ward et al, 2004) have highlighted the importance of on-site optimal node placement. Correspondingly, in the case of long-distance communications, it is recommended that practitioners survey the selected locations before final placement with signal strength software. This will allow for optimizing the placement and alignment of the node antennas, and avoid the creation of bottlenecks. With these considerations in mind, the central office node should be mounted on the top of the office building or at a nearby highly elevated location (e.g. taller building) and connected with a wired network. The project site nodes can be mounted in similar locations. In certain cases however, mounting wireless nodes on mobile construction equipment (cranes, trucks, etc.) could be a better alternative. The topmost parts of cranes, in particular, are often the highest locations of a project site and are not easily accessible from the ground which increases node security. Tall cranes can span over 300 feet tall which makes them clearly visible several miles away.

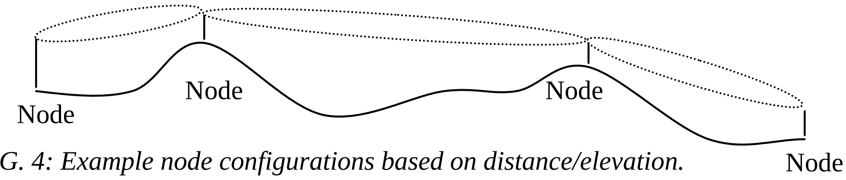

FIG. 4: *Example node configurations based on distance/elevation.*

6. SIMULATING ACTUAL CONDITIONS

To test the proposed solution, it was necessary to: 1) Simulate actual conditions, 2) Procure equipment, 3) Perform tests. The details of the 1st step are described in this section. Simulating actual conditions was needed to study the applicability and limitations of long-range wireless local area network technology when applied to a main office – construction site scenario. For this purpose, a decision-making office location and an actual construction site were selected. 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 explained in the previous section, the main criteria for this selection were distance and line-of-sight.

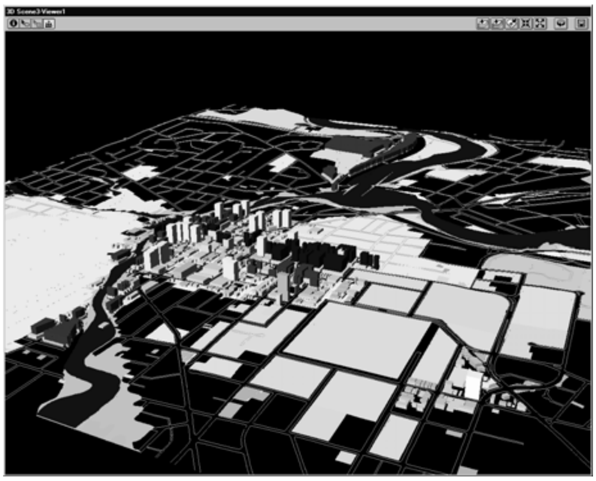

FIG. 5: 3D interactive elevation map of Ann Arbor (Arlinghaus, 2003)

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 signal line-of-sight, and thus, the highest elevation points were sought. These points were determined using 3D elevation maps (Arlinghaus, 2003; Fig. 5) and on-site observations as shown in Fig. 6 and 7, where the highest elevation points of both main office and selected construction site are indicated. 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.

FIG. 6: UM North Campus, Bell Tower identified as highest point

FIG. 7: UM Central/Medical campus School of Public Health construction site identified as highest point

7. PROCURING EQUIPMENT

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.

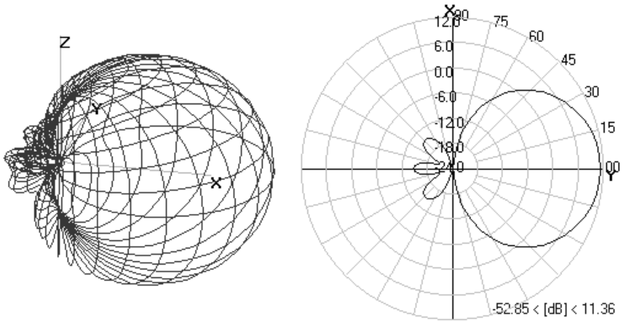

FIG. 8: Typical 5GHz directional antenna signal strength distribution

From this investigation it was determined that (Geier, 2003) higher frequencies in most cases are equivalent to: i) shorter range, ii) greater spectrum (Fig. 8), 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 owner evaluated 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.

8. TESTING

The wireless equipment (as well as a host of wireless devices) was scheduled to be tested in phases. The goal of the initial phase (indoor 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 next 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. 9) 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) was to re-test all of the above under different weather conditions and examine their effect on the performance of this solution.

FIG. 9: Bridge mobile test configuration

The indoor test demonstrated that common wireless ready devices (laptops, digital cameras, sensors, etc.) can easily connect and transfer data to a central computer using this wireless solution. Provided that at least minimal signal strength is present, the wireless network is automatically detected and data are transferred real-time, minimizing the need for local storage. The preliminary signal strength tests highlighted the importance of proper antenna alignment and radio line of sight. Fig. 10 shows the signal strength loss (dbm = power level in decibels relative to 1mW) as measured at different indoor distances. Measurements on the continuous and dashed lines were acquired with a signal detector (installed in a personal digital assistant) that had a 90 degree and 0 degrees angle from the optimal alignment respectively. Obstacles (walls) were present at every 4m and the cumulative degrading effect on the signal was the main signal loss factor. It is important to note that, at 90 degrees, after passing through 4 walls the signal is lost, whereas at proper alignment, the signal is still detected after 6 walls. This is possible due to the high gain (13dbi) directional antenna of the selected bridge.

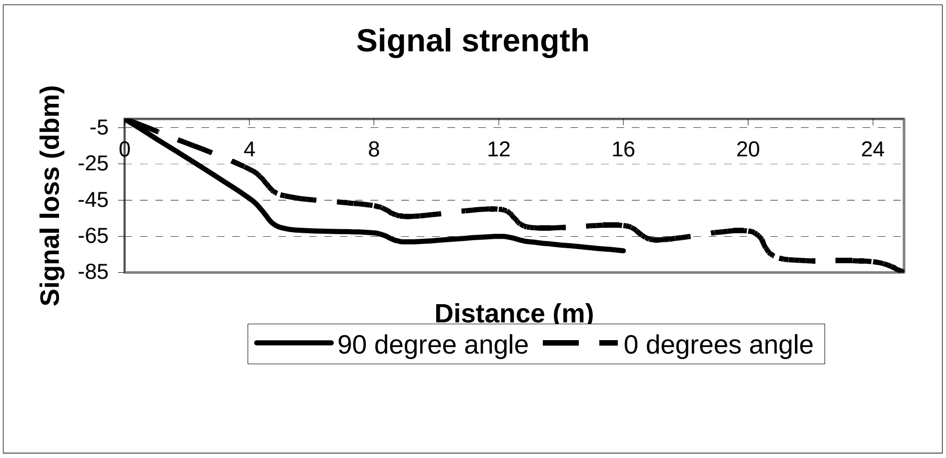

FIG. 10: Indoor signal strength results

The outdoor tests (mobile and fixed) verified the equipment specifications in terms of range and antenna signal spectrum. Under clear radio line of sight and proper alignment, a pair of wireless nodes was able to steadily maintain i) 54Mbps bandwidth at 2km, ii) 11Mbps bandwidth at 15km. Also, as the distance increased, the signal strength was more consistent. Trees and buildings had an expected degrading effect on the signal strength if the radio line of sight crossed them. Tree foliage coverage and snow accumulation increased this effect and highlighted the need for further testing under severe weather conditions, e.g. snowstorms (Iain, 2005). At last, the time required to mount the nodes in vehicles was only a few minutes, which highlights the flexibility of this solution. Nodes can be switched from vehicles to equipment to temporary and permanent structures in minutes, thus allowing for greater flexibility at the construction site. Wireless-enabled devices were also tested outdoors, specifically a wireless pan-tilt-zoom (PTZ) camera, laptops, personal digital assistants and others. Device detection and communication compatibility was effortless. Also, the data transfer rate remained high throughout the test. At 15 km, the PTZ camera, for example, transferred one mega pixel video at 30 frames per second while a laptop was concurrently downloading a large file.

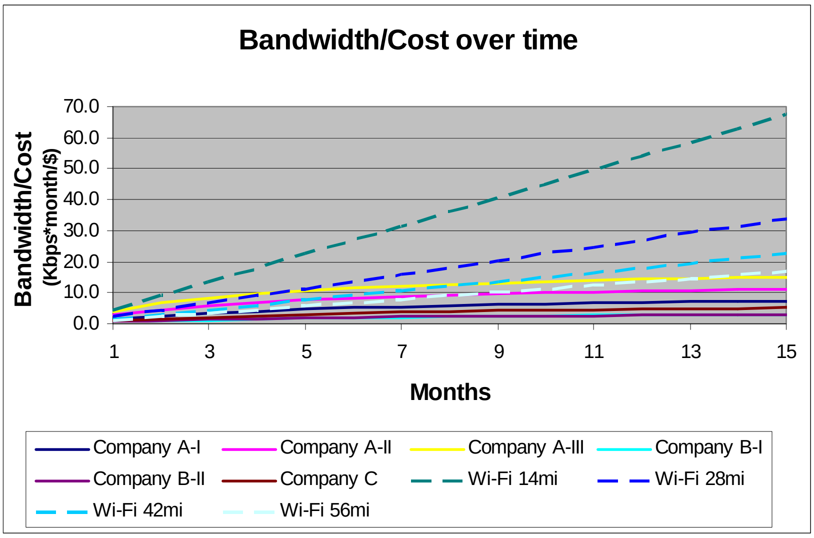

FIG. 11: Value (Bandwidth/Cost) over time

A cost/benefit analysis with cost information from 3 satellite internet providers (6 solutions) and linear Wi-Fi configurations at different distances was also performed. The value (bandwidth/cost) over time of usage was calculated and plotted in the following graph (Fig. 11). From the graph, it is clear that in 0-28 mile range applications, wireless solutions provide higher value even for short usage spans (1-5 months). In longer ranges however (>56mi) it can take over 15 months for the wireless option to break even. These conclusions are depicted in Fig. 12. The upper left region represents time/distance combinations for which the proposed wireless configuration has higher value than satellite internet, and the lower right region represents combinations where the opposite is true.

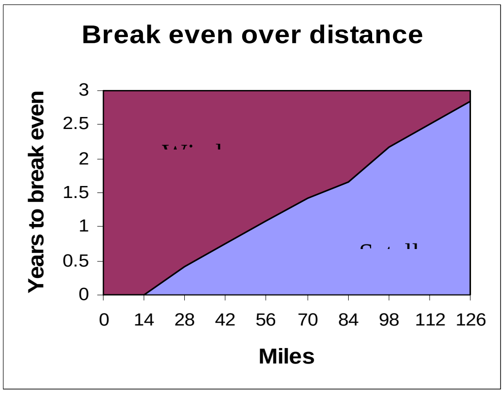

FIG. 12: Highest value solution for all time/distance combinations

9. CONCLUSIONS

This research presented an alternative solution to long distance data communications between construction sites and the decision making office. This solution utilizes IEEE wireless radio standards and equipment to provide an easy to assemble and disassemble network of nodes that is characterized by flexibility and length of coverage. It is inexpensive when compared to equivalent wired alternatives since it can cover significant distance (tens and if needed hundreds of miles) with minimal investment on equipment and labor. The indoor and outdoor tests performed demonstrated the suitability of this technology for office-site data communications. However, these tests also exposed that the need for more research to further improve the reliability and data handling of this technology.

Specifically, it was verified that the development of traffic monitoring, securing, interference reduction, data integration and other data administration applications can improve the way diverse types of construction site data are handled. 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.

It was also realized that significant time savings could occur for node deployment with the development of new methods and algorithms for automatically aligning/re-aligning the antennas and choosing the optimal distance between nodes. Such methods would also allow for remote re-alignments. Improvements that assist in the 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 9), while 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. These identified improvements are the next target of this on-going research. The author plans to further investigate and improve this solution, followed by more tests with larger deployments.

Eventually, this work is also expected to be the first step towards the development of automated tracking, alerting and inspection tools. The resulting wireless infrastructure that was deployed at the University of Michigan’s campus as an initial test bed for the wireless data communications model will be utilized in the future as a data collection mechanism that will provide multimedia and sensor data. This data will then be employed to conduct research on the development of cognitive, vision-based tools that will automatically detect and recognize construction related items (materials (Brilakis et al, 2005), objects, equipment, personnel, etc). Such tools have the potential to conduct real time productivity measurements and constantly monitor the progress of construction activities remotely.

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