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Evaluation of Rapid Deployment Mesh Networking for Work Zones

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16. Abstract

Communications between high-technology devices in work zones has long been a challenge. The problem is acute in rural areas where there is often little or no existing infrastructure to support wireless communication to the same extent as in urbanized areas. Despite this, there is often a desire to use real-time communications between new technologies to provide accurate work zone information to motorists or to remotely monitor work zone operations. An opportunity exists with new decentralized wireless communications technology known as mesh networks. Typically available in the license-free spectrums, a mesh network is by definition rapidly deployable and automatically configured, precisely what is needed to blanket a rural work zone.

The findings of this proof-of-concept study showed that mesh networking would be great fit to blanket the work zones in rural areas. The system used in this research was capable of providing enough bandwidth to allow over 500 kbps of continuous data at over 3500 m (2.17 mi), more than would be required for an online video conference (384 kbps) and also more than would be required for voice communications (120 kbps). This level of data transmission would far exceed that required to transmit GPS position data that would be required to update a CMS with an estimated time of arrival for queued vehicles waiting at a work zone.

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DISCLAIMER

This research was performed in cooperation with the Smart Work Zone Deployment initiative, a Federal Highway Administration (FHWA) pooled fund study administered by the Iowa Department of Transportation. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Smart Work Zone Deployment Initiative, the Iowa Department of Transportation, or the FHWA. This report does not constitute a standard, specification, or regulation. The engineer in charge of the study was Dr. Steven D. Schrock, Kansas P.E. #18989.

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1. INTRODUCTION

Communications between high-technology devices in work zones has long been a challenge. The problem is acute in rural areas where there is often little or no existing infrastructure to support wireless communication to the same extent as in urbanized areas. Despite this, there is often a desire to use real-time communications between new technologies to provide accurate work zone information to motorists or to remotely monitor work zone operations. An opportunity exists with new decentralized wireless communications technology known as mesh networks. Typically available in the license-free spectrums, a mesh network is by definition rapidly deployable and automatically configured, precisely what is needed to blanket a rural work zone. This research examined in detail the feasibility of incorporating mesh networks into rural work zone environments as the backbone of real-time communications and monitoring.

RESEARCH OBJECTIVE

This research examined the potential benefits of incorporating mesh networks into non-infrastructure environments as the backbone of real-time communications and monitoring. The measures of effectiveness conducted are based on an ftp client-server model set up at different distance ranges. The performance metrics employed in the test were signal strength, range, communication rates.

This research was conducted in two phases. Phase I (Tasks 1-3) involved an examination of the state of the literature and the state of the art regarding the use of mesh networking for work zones. Phase II (Tasks 4-6) involved field testing and analysis of data at several non-work zone locations. The work plan consisted of the following tasks:

- Task 1: Develop System Plan
- Task 2: Acquire Components and Assemble Mesh Networking System
- Task 3: Development of Measures of Effectiveness
- Task 4: Proof-of-Concept Data Collection and Analysis
- Task 5: Field Testing
- Task 6: Data Analysis

The literature review is presented in Chapter 2; the results of the proof-of-concept data collection and analysis are presented in Chapter 3; the results of the field data testing and discussions of future research are presented in Chapter 4.

2. LITERATURE REVIEW

Mesh networking is defined as a technique to route data between communication nodes to allow continuous network connections and reconfigurations around broken paths by locating alternatives until the destination is reached. Such a network is intended to be modular in nature, and would not require access to an Internet service provider. As originally conceived, this wireless network system allowed real-time communication in large urban areas, while provide reliable information to users through a series of wireless mesh router connections, as shown in Figure 1.

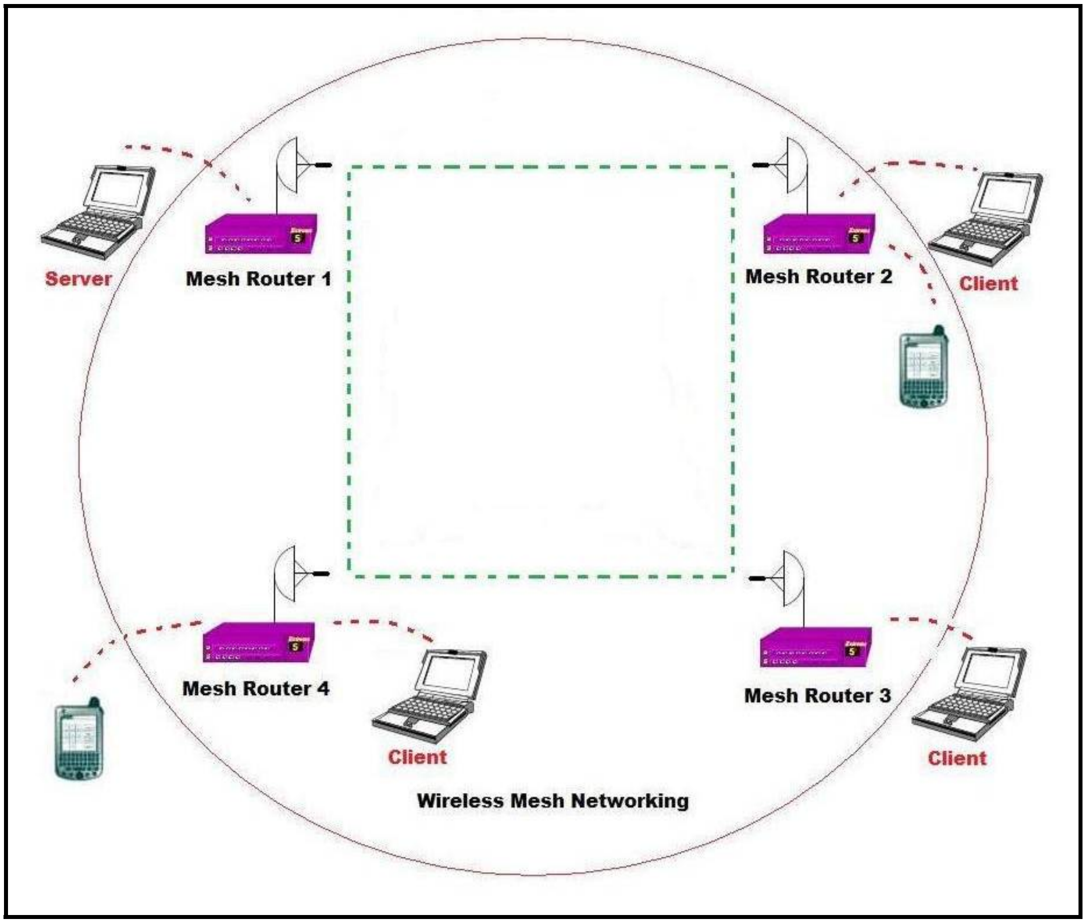

FIGURE 1 Wireless mesh networking.

The advantages of this wireless network system are described as follows (*1*):

- This technology allows the system to be created locally without having to go through a service provider;
- The connection automatically searches for alternative routes as topology changes;
- Each node (or mesh router) does not need an internet gateway, instead they share fast and reliable connection;

- The technology is easy to install and manage, and backup technology can be cooperatively deployed;
- Location of the nodes can be added, removed or relocated without the effort of traditional administration;
- This network system has low power consumption and offers redundancy when nodes get disconnected; and
- Mesh network reduces interference between clients.

These systems are still in the early phases of implementation. Prior mesh networking projects found that the security systems of this wireless network required routing through other nodes, which is time consuming even though efforts have been made to eliminate this drawback (*1*). In addition to mesh networking, wireless technologies such as global positioning systems (GPS) and global systems for mobile communications (GSM) have been continually deployed for the use of transportation engineering (2). The advantages of these satellite-based systems include the capability of providing more bandwidth, and actuating faster and secure applications. Furthermore, these wireless systems can also supply higher data accuracy and richer information exchange than traditional wireless systems. The most distinct drawback in this system is the high operating costs as compared to earth-based wireless system approach such as mesh networking. In addition, a particular study area of interest may be located in a "dead zone" for certain GSM service providers, where the wireless connection could not be connected due to the unavailability of wireless network.

As technology advances, many sectors including the transportation engineering evolve from initial construction (such as building the highway network) to improving mobility services (such as incorporating technology systems to improve motorist mobility and safety). In the past, conventional methods such as the inductive loop detectors were utilized to gather traffic data to aid basic traffic control and performance evaluation. However, in rural areas where there may be limited communication infrastructure such as universal cellular coverage, fiber optic networks, etc. This lack of communication can be a limiting factor for utilizing some intelligent transportation systems (ITS) in rural areas.

Strix Systems, Inc. realized the importance of integrating the mesh networking for real-time communications and has since successfully deployed the system for transportation communications (*3*). Though substantial projects were deployed by them in the urban areas, findings showed that their prior projects such as the deployment of wireless mesh networking in recreation vehicle dealership and RV parks, and Korea's intelligent highway may be emulated for the use in other locations such as rural work zones. Furthermore, findings showed that Strix successfully deployed the mesh technology for the use in railroad industry. In the mesh network testing program conducted by the University of Nebraska regarding the deployment of WIFI (utilizing mesh technology) alongside railroad tracks, researchers found that the IEEE 802.11a/b/g model can be applied to railroad operation to enable high-speed mobile transmissions (*4*). Results also showed that future protocols such as the 802.16 and 802.20 enable significantly longer spacing access and thus is a feasible data network to improve safety, security and operational effectiveness in railroad operations, so future improvements in mobile networks appears possible.

Additionally, there are areas of research where a mesh network could be used to optimally route ambulances and other emergency response services (*5*). Through simulation, Yang showed that equipping ambulance services with the ability to access a mesh network to determine both their position and the traffic information between the ambulance and their location that response times can be optimized in real-time. This simulation study was concerned with urban area response times where mesh networks were already in place. Indeed, Wolff and Lee indicated that the computing and networking requirements for such a real-time routing is modest in terms of currently-available systems (*6*).

While there have been demonstration projects for mesh networking in various transportation modes such as rail operations and transit, these operations typically are long-term in nature. For example, once a transit organization installs a wireless network along its travel corridors it can be expected to utilize such a system unchanged for a long time period, perhaps for many years. (*4,7*). No previous instances were found in the literature of attempting to use a mesh network where it is the network itself that is mobile in nature, with a design requirement of being able to quickly relocate and use the network over and over again. The remainder of this report investigates efforts to develop such a portable system.

3. PROOF OF CONCEPT TESTING

As the first step of the field testing, the point-to-point access approach was tested in the laboratory to examine the communication capabilities of the router. This measure was intended to examine the limitations of the router to ensure that the field testing was conducted with minimal errors. For this field test, two wireless routers (Azalea Networks MSR 2000) (*8*) were utilized to examine the point-to-point access. Figure 2 shows the antennas of the wireless router described. This router consists of a multi-directional antenna that covers up to 200 meters and a unidirectional antenna that has coverage limit of up to 5 miles. The specifications of this wireless router include radios that support 802.11 a/b/g and 4.9GHz, and video transmission rate of 30 fps (frames per second). The following criteria were examined in both the laboratory and in the field:

- Maximum distance of reception;
- Minimum height requirement of the directional antenna and router;
- Connection compatibility (server-router or client-router) to ensure maximum access speed;
- Server-client connection rate; and
- Supplementary devices that may be needed for field testing.

FIGURE 2 Mesh Router with Multi-directional and Uni-directional Antenna

Initial efforts in determining the connection between the server/client and router found that the wireless connection 802.11 b/g, which is commonly used among portable notebook owners, was compatible and convenient for the server/client and router connection. This wireless selection has two advantages over the available options in the market. First, the 802.11 b/g wireless is a common component in laptop computers. Second, this connection does not require a wired connection, which is a plus as Ethernet cables may be needed if wired connections are chosen for this server/client and router connection. Clearly, for remote installations such as rural work zone locations running extensive wires to each component would be prohibitively expensive and time-consuming, both factors being disincentives for their use. The main disadvantage to using 802.11 b/g wireless connection option is that there are some line-of-sight limitations that would the non-line-of-sight linking, which can be difficult to maintain out in the field if needed. In other words, the various components would have to have a visual link between them, and would not be able to communicate through a hill, for example.

Through the preliminary tests, it was determined that point-to-point access test should be experimented prior to testing the mesh networking in order to assure that the technology can be successfully deployed at various types of location. Point-to-point access is a technique that is similar to mesh networking except it has no more than two nodes, unlike the mesh networking where the nodes in a loop can “hop” to the alternate node when there is a broken path (or node disconnection). This seems reasonable for a linear work zone setup. Based on the preliminary tests, point-to-point access was considered to be applicable, and could be considered as a small mesh network consisting of a single loop and thus the connectivity between two nodes can be equally be applied to multiple nodes, except for large data files where the access and information exchange rate would be much slower.

Initial observation of the preliminary field experiment showed that the connection between routers can be successfully connected up to a distance of 2 miles. However, the testing also found that the signal connection may be disrupted by obstructions such as tall buildings, trees or even traffic. Hence, the subsequent field trials were conducted on bridges and on the rooftop of a building maintain clear fields of view. The preliminary results of the testing validated the troubleshooting effort, where the signal of the routers must be clear of any large obstructions. Nonetheless, the field testing found that the mesh networking can be successfully deployed by setting the router at designated locations preferably without obstructions such as buildings, hills, and/or trees. Clearly, though, this gave an indication that in order for a mesh network to be actually used in a work zone great care must be taken to properly locate the radio antennas to maintain connectivity.

As shown in Figure 3, the directional antenna is externally connected to the router before the mesh networking connection can be successfully connected. In order to prevent connection disruptions while ensuring that this wireless connection is firmly connected throughout the field testing, a 6-foot portable stand, as shown in Figure 3 was fabricated to accommodate the router and the directional antenna. With the stand, the directional antenna, which has angle coverage of 120 degrees can be rotated accordingly based on the direction of the connection. Moreover, observation also showed that a portable camera trailer, lighting tower, or any portable boom trailer may be an alternative to link the mesh networking connection for locations where additional height may be needed to maintain connectivity over visual obstacles.

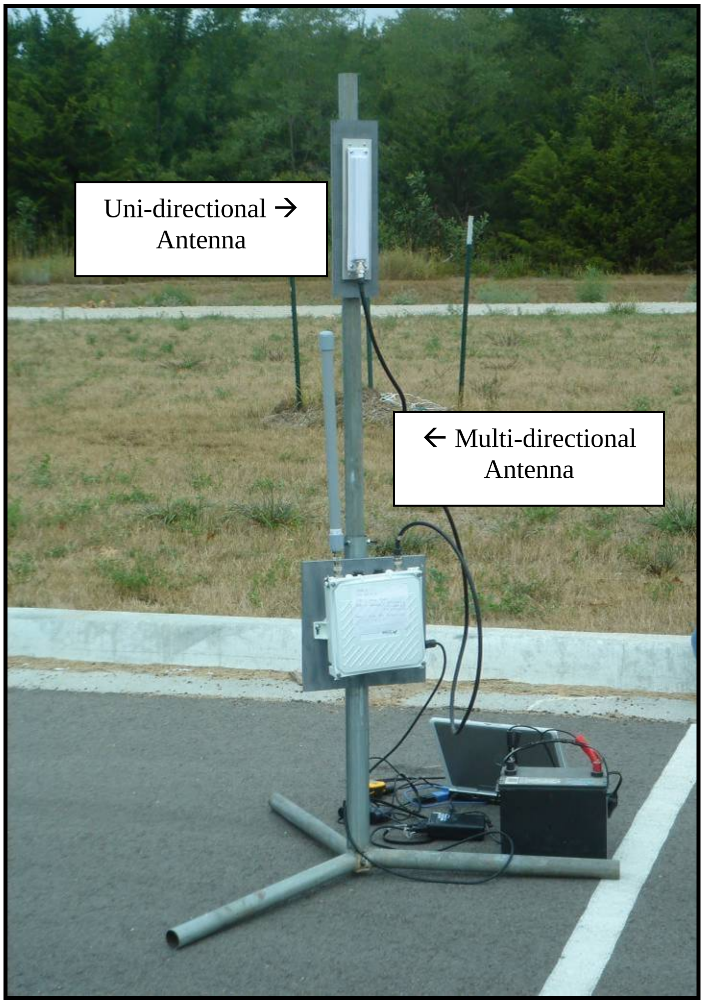

FIGURE 3 Wireless Router and Directional Antenna on a Fabricated Stand

In an effort to determine the feasibility of mesh networking in the field, four separate tests were conducted to examine the signal strength, range and communication rates of the routers. All tests were conducted in Lawrence, Kansas; Table 1 shows the field tests described. In all cases the network setup for each experiment is shown as in Figure 4 unless otherwise indicated. The preliminary test was the first outdoor testing; the client was a stationary vehicle along Iowa Street, while the server was located on the bridge on 34th street with the directional antenna connecting the two laptops at a distance of about 890 feet or 0.17 miles. Similarly, for the second test the client was a moving car in the KU Lied center parking lot, whereas the server was setup on the rooftop of Nichols hall at KU west campus. The distance between the server and client was estimated to also be 0.17 miles, while the height separation was approximately 50 feet. In an effort to corroborate the connectivity test, the experiment was further investigated by relocating the venue to the KU Park-and-Ride lot on Clinton parkway, a distance of 0.63 miles from the rooftop server. As the final step of this outdoor experiment, the field test was relocated farther to the Highway K-10 bridge over Iowa Street. For the third trial, the server was set up at the intersection Clinton Parkway and Wakerusa Drive, while the client (e.g., car) moved on Clinton Parkway from Wakerusa Drive to Crossgate Drive. In this third field experiment,

TABLE 1 Field Tests Locations and Results

Test No.	Server Location	Client Location	Length (mi) (Vertical Difference (ft))	Test Objective
1	Bridge on 34th Street	Moving car on Iowa Street (under the bridge)	0.17 (50 ft)	Examine signal strength and range
2	Rooftop of Nicholas Hall (KU West Campus)	Moving car on KU Lied center parking lot	0.17 (50)	Examine signal strength, range and communication rates
	Rooftop of Nicholas Hall (KU West Campus)	KU Park-and-Ride lot on Clinton Parkway	0.63 (50 ft)	Examine signal strength, range and communication rates
	Rooftop of Nicholas Hall (KU West Campus)	K-10 bridge over Iowa Street	2.00 (15)	Examine signal strength, range and communication rates
3	Intersection between Wakerusa Drive and Crossgate Drive	Moving car along Clinton Parkway	1.02 (Varies from 0 to 118)	Examine communication rates and execute mapping program
4	KU Park and Ride lot on Clinton Parkway	KU Park and Ride lot on Clinton Parkway	0.17 (0)	Examine communication rates and execute mapping program

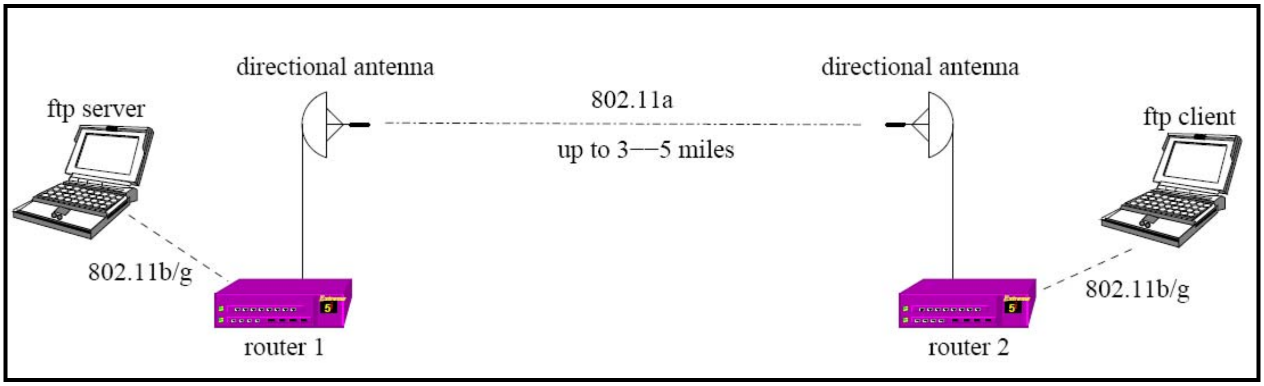

FIGURE 4 Network Setup for the Field Experiments.

Microsoft *Visual C#* socket program was used in both the client and server to determine the position of the client on server's computer screen. A program was run at the server that would take the position of the client (car) and determine the distance and estimated time of arrival based on the position information. Additionally, the program was able to create a simple map of the path the vehicle took as it moved back and forth along Clinton Parkway.

The fourth and final field test was demonstrated at the KU Park-and-Ride lot in presence of a Kansas Department of Transportation's (KDOT) engineer. One area of the parking lot was defined as a simulated work zone for the purposes of testing the communication system. The field experiment consisted of execution of the Microsoft *Visual C#* socket program and the mapping procedure of the client car as it moved back and forth through the simulated work zone. The main objective of this field test was to set up a communicative system that remotely transmitted the latitude-longitude position of a pilot car (acting as the client) to a server that processes the information received from the pilot car and mapped its movement. The raw data from the GPS was processed in the client and sent to server for mapping the real-time position of the pilot car along with its traversed route. The two ends of the route were named source and destination, respectively. The field test consisted of two major parts namely, client and server.

CLIENT SIDE

The client consisted of a moving car with the GPS device attached to the serial port of a laptop computer, which is also attached to a 4.9GHz wireless router. This car was meant to simulate a pilot car that would move back and forth through a work zone. This arrangement was set up to obtain the real-time latitude-longitude position of the pilot car. The laptop received the raw data from the GPS device every second, as shown in Figure 5 and sent it to the server for plotting. In order to account for the tolerance associated with GPS, the pilot car was instructed to move around the starting point (or source) for a test drive at the beginning of each trial. As the final step of this procedure, the car was driven through the simulated work zone and non-work zone areas to map the route into the server.

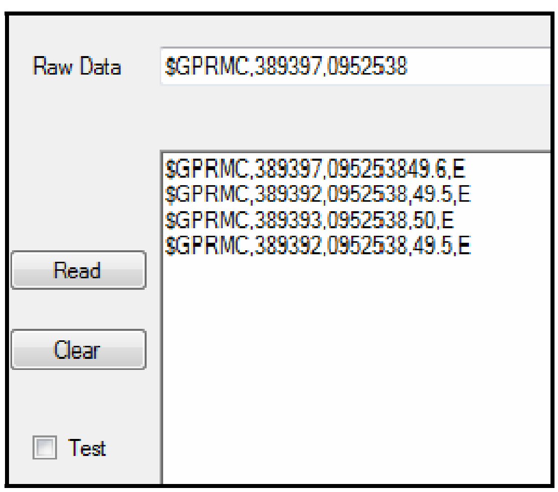

FIGURE 5 Client Screen

SERVER SIDE

The data received from the client was processed on the server side for appropriate latitude-longitude points. The information was then used to map the path as well as the position of the pilot car in real time. The movement of the car from source to destination and vice versa was observed graphically on the server screen as shown in Figures 6 and 7. Additionally, after the first few passes through the simulated work zone, it was possible for the server to determine the direction the pilot car was traveling, as well as the time remaining for the pilot car to reach the end of the simulated work zone.

FIGURE 6 Server screen - car moving towards destination.

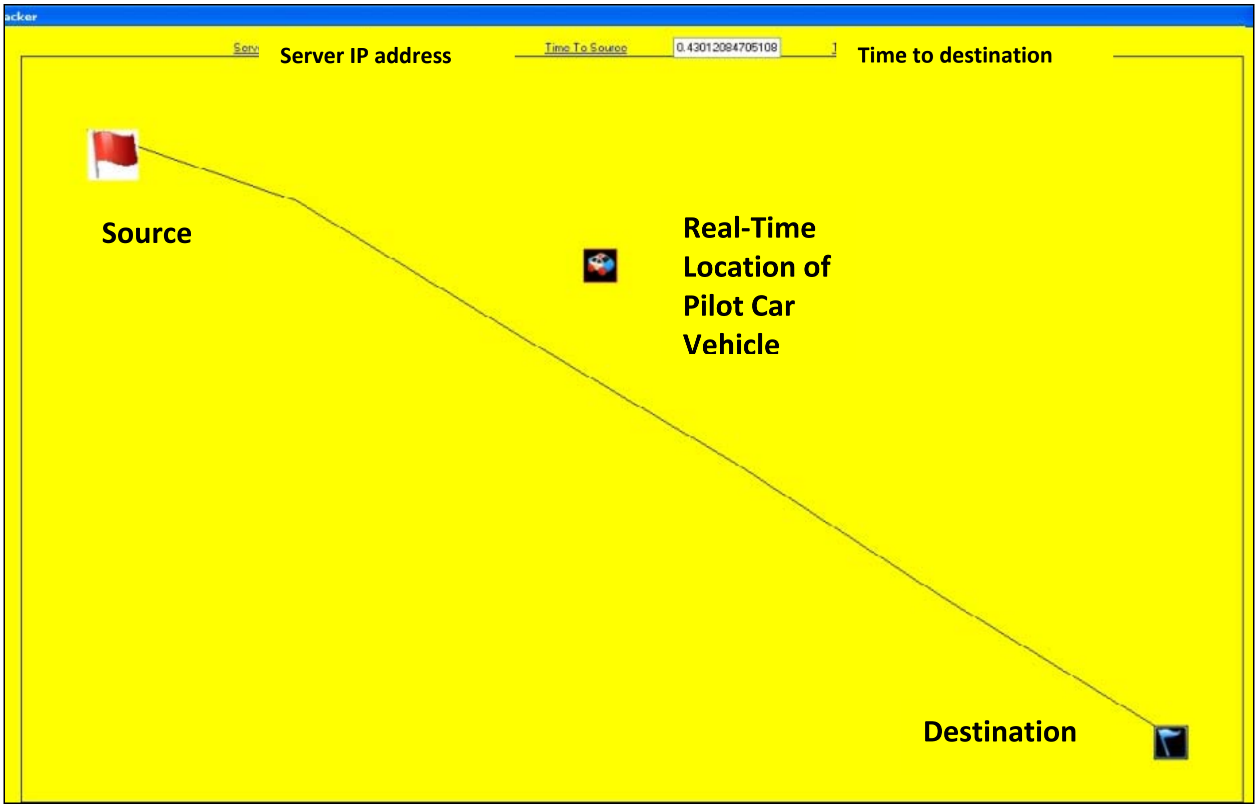

FIGURE 7 Server screen - car moving towards source.

SERVER CODE

The server code was structured such that the latitude-longitude points sent by the pilot car to plot the path of travel were fed into an Xml file. Trials showed that the data received from the GPS device contained multiple data points that may be applicable to the position of the pilot car (or client). In order to accurately assess the real-time position of the pilot car, a distance of 2 ft was selected at the beginning of each trial to locate the best (or last) available data point of the automobile. The procedure stated above was consistently executed until all of the points were compared and fed into the second Xml file. Once the procedure was completed, the latitude-longitude points in the second Xml file were used for plotting. These points were scaled to X and Y coordinates on the plot area for proper display on the computer monitor, to avoid having the vehicle symbol on the screen from “driving” off of the display. For the plot area, it was programmed such that the range of the coordinates including a 0.5-mile buffer on each side of source and destination to ensure that the graphic showing the vehicle location would remain on the screen. Due to this the on-screen representation of the work zone and pilot car would not be visible until after the pilot car had made one complete transit back and forth through the work zone. As the first step to execute the program, the coordinates of the pilot car were recorded when the automobile traveled from source to destination. A path was then mapped on the computer screen of server. During this procedure, the latitude-longitude points recorded provide the real-time position of the pilot car in the path that already being mapped.

In summary, four different tests were conducted with the developed communication system and demonstrated the following abilities:

- Point-to-point communication between stationary routers;
- Point-to-point communication between one stationary router and one router operating from a moving vehicle;
- Transmission of GPS-location information between routers when one router is in motion; and
- Using the vehicle position data to calculate the time remaining until the vehicle reaches a specific location (e.g., the end of a simulated work zone).

The success of the communication system to properly transmit useable location information, as well as the ability of the server to process the location information into a useful map and estimated time of arrival to the end of the simulated work zone proved the concept of this research. The following chapter contains a discussion about how to further develop such a system and areas for continued improvement.

4. FINDINGS AND DISCUSSION OF FUTURE RESEARCH

In an effort to examine the signal strength, range and communication rates of the mesh network, three different data types were used in the information exchange process: MPEG video, video conference and MSN messenger. The main objective was to transfer MPEG-quality video over to various distances and compare its performance with two other types of data, namely, video conference and messenger chat over the internet. Figure 8 shows the results of field experiments described. It can be observed from this illustration that the transmission rate is inversely proportional to the square of the distance between wireless routers, i.e., the rate of the transmission decreased exponentially as the distance between routers increased. This is an expected result typical of this type of communications.

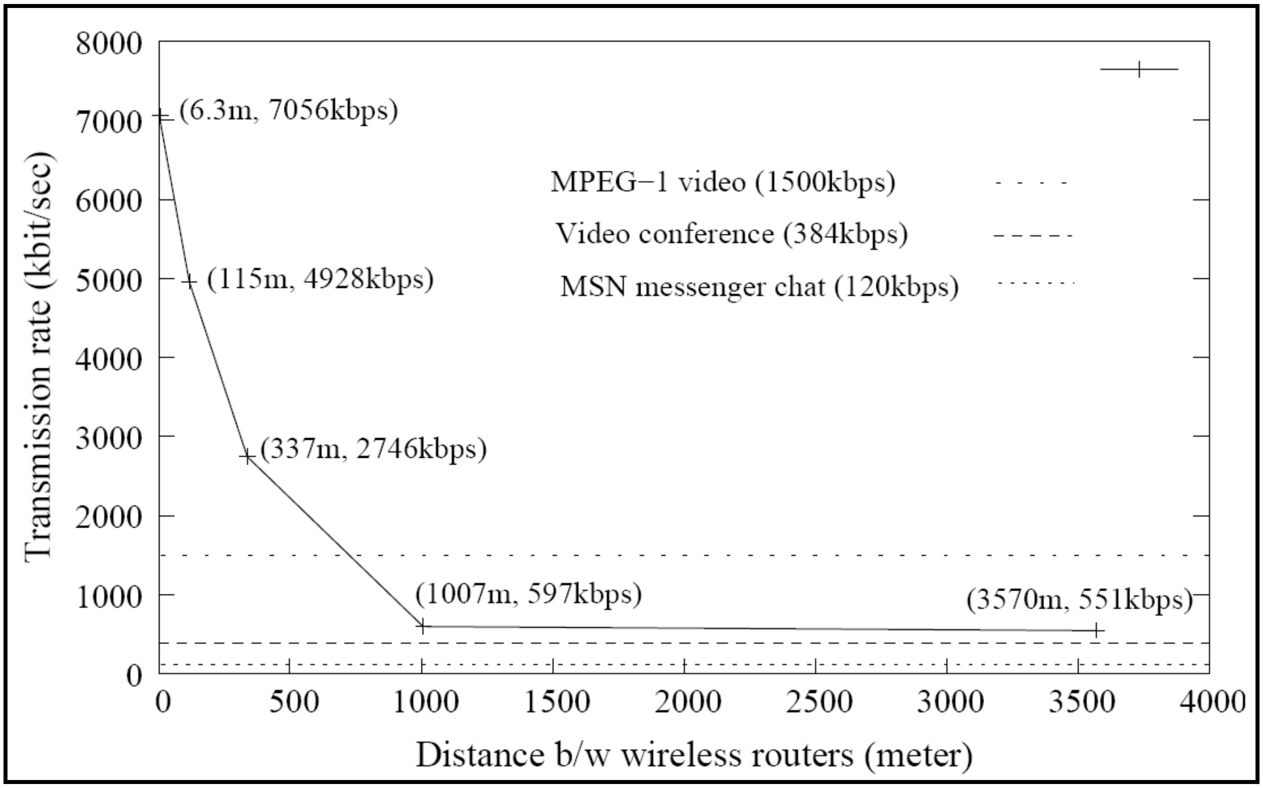

FIGURE 8 Transmission rates versus distance between routers.

The findings of this study showed that mesh networking would be great fit to blanket the work zones in rural areas. The system used in this research was capable of providing enough bandwidth to allow over 500 kbps of continuous data at over 3500 m (2.17 mi), more than would be required for an online video conference (384 kbps) and also more than would be required for voice communications (120 kbps). This level of data transmission would far exceed that required to transmit GPS position data that would be required to update a CMS with an estimated time of arrival for queued vehicles waiting at a work zone.

Based on these successful results, the researchers believe they have proven the concept that portable, easily installed wireless communications systems have the potential to be used in work zones for the purposes of tracking and reporting on the location and return times of pilot car operations.

FUTURE RESEARCH NEEDS

Clearly, there is more work to be done to take the current system from the prototype level to one that can reliably be installed and operated by field personnel. It would be a natural next step to conduct long-term tests to determine how best to "field harden" the equipment to provide for maximum long-term use without loss of communication. For example, while standard car batteries were used to power the system, there may be a need to use solar panels or some other supplementary power supply to ensure a continuous power supply for long periods of time.

A next step for along these lines would be to extend the communication system to include multiple intermediate wireless hubs, which could extend the length of work zone that could make use of a mesh network system. As this would be a linear mesh network, it would require the ability to pass information from one end (as when the "client" pilot car is at one end of the work zone) through several intermediate antennas to the server at the far end of the work zone. Additionally, basic research on how best to position the long-range antennas for maximum performance would be needed. For example, while the setup used in this research had the antennas between 6 and 8 ft above the pavement surface, it might be necessary to achieve greater elevations in order to maintain communications in hilly, wooded, or other terrain types. While mounting on portable masts was considered, the complexities of this were not explored in this research. Successfully expanding the system in the ways described should serve to make the system useful as a communications backbone for even longer work zones.

Additionally, while this research proved it is possible to calculate the return time for a pilot car in real time, that may not be the preferred information to be placed on portable CMSs near the flagger stations. In order to reduce driver frustration, it is critical that an accurate message be presented to drivers in a format that is both informative and easy to understand. Additional research is needed to develop the algorithm that would determine the text that should be placed on these signs.

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