Serial Wireless IP Networks for DOT Applications

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Abstract—**This paper presents the use of Commercial off-the-shelf (COTS) wireless Internet technology to meet needs of departments of transportation (DOTs). COTS wireless is an economical, scalable alternative to traditional fiber optics and telephony communications solutions. A virtual Ethernet network is created along a highway right-of-way (ROW) by installing wireless point-to-point links in a serial fashion that can extend upwards of 30 miles per section from a base node. This local area network (LAN) becomes a seamless extension of the DOT's communications for field devices such as cameras, RWIS, traffic sensors, and field personnel. This paper discusses the design and architecture issues of serial wireless LANs used in a transportation setting based on real world deployments and outdoor testing on Virginia's Smart Road transportation test bed. Digital video applications along wireless networks are specifically addressed.**

I. The Needs of the DOT

Departments of Transportation (DOTs) are under increasing pressure to maintain control over their widespread infrastructure. The desire to provide secure and accurate information to travelers is pushing the existing DOT communications infrastructure to the limit. In an ideal world, fiber optics would be available along every interstate right-of-way (ROW) and along every major arterial. Dedicated home-run fibers would be available for traffic monitoring cameras and the myriad of other DOT field devices, such as weather sensors (RWIS), acoustic sensors, variable message signs (VMS), license plate readers (LPR), and HAR. The quantity of field devices that DOTs desire can number into the thousands along ever major stretch of interstate and major arterial.

Traditional telephony solutions, such as DSL, ISDN, phone modems, and T1s, are viable alternatives to fiber; however, the bandwidth can be limiting, each individual installation incurs a monthly bill, and these options may not be available in highly rural areas.

II. The Wireless Alternative

Recent advances in wireless technologies have made this communications medium a viable, economical, and scalable alternative for DOTs. The infrastructure requirements are a fraction of fiber optic installation, with minimal disruption to existing infrastructure. With appropriate infrastructure in place, a wireless network can go online within hours, as opposed to the months of construction required for a fiber optic network. Wireless links can be used as temporary installations until a fiber optic network becomes available or can be made permanent for long-term use. From a scalability issue, adding another wireless link over a small distance is much more reasonable than extending a fiber optic network. Furthermore, the use of open standard wireless IP devices ensures that the owners do not cubbyhole themselves into one type of proprietary technology and costly services contracts from one vendor.

A limitation on long distances with many products is the requirement of clear line-of-sight (LOS). One advantage for the DOTs is that outside of owning a mountain top or having access to cell towers, the best line-of-sight through a region is the existing interstate infrastructure. Since the DOT owns the ROW along an interstate, it can use it to create wireless LANs easily. Non Line of Sight (NLOS) or near line of sight systems are available, however their advantages lie in the ability to deal with reflected signals and multi-path. This is an advantage in urban areas, however rural LOS obstructions caused by roadway geometry will not create multi-path.

A. Suggested Architectures

The design of a WLAN will depend on several factors, including desired capabilities, terrain, and available infrastructure. In general, they can be constructed in the following architectures: single point-to-point, point-to-multipoint, serial point-to-point, and client-Access Point (point-to-multipoint).

Point-to-multipoint architectures are the most robust because each link is independent of the other link. In serial point-to-point, each previous link is dependent on subsequent links. However, for most linear highway environments, a serial application is the only option. The number of "hops" that a serial network can go depends on the technology used and the requirements placed on the network. One drawback of a serial daisy- chained wireless network is that the available bandwidth begins to degrade over successive hops. This will be discussed in greater detail later. The serial LANs can be installed as a completely self-contained network terminating at a DOT office, or they can be set up to interface with the Internet through a T1 or better connection. With this type of design, the remote network and associated field devices can be accessed from anywhere on the Internet.

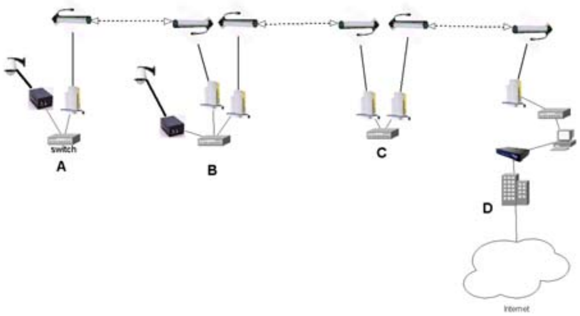

Figure 1 Conceptual diagram of a serial wireless LAN

A typical scenario on a highway ROW would involve telephone pole height towers placed approximately 1-3 miles apart, depending on the terrain and highway topography. With 802.11b technology, an 8-hop system still has over 500kb of bandwidth available at the furthest node, which is adequate to support a jpeg still or MPEG4 streaming video. A base node or Internet connection should be placed in the middle, with wireless nodes extending in two directions away from it. With an 802.11b system, this segment could span 16 to 24 miles of highway ROW.

Newer technologies, such as 802.11a and g point-to-point systems start out with a higher aggregate throughput than 802.11b and, therefore, could extend well past 8 hops and still have enough bandwidth to support MPEG 4 streaming video. The video or traffic data could then be disseminated to the agencies and public that needs it.

Figure 2 Typical installation of a repeater node and IP camera

B. *Interference and Security Issues*

With any use of unlicensed spectrum there is always the potential for interference. With linear serial wireless LAN's along DOT right of way, there are some ways in which interference can be mitigated. Narrow beam directional antennas are used with these point to point links. This limits the amount of interference from outside sources. Additionally, the distances between links are relatively small due to the distance constraint placed on the smaller heights of towers/telephone poles that will most likely be used. The smaller distance combined with using a higher gain antenna designed for long distance links also serves to limit potential interference. Finally, antenna polarities can be changed, and cycling through available channels for a quieter frequency can help mitigate around interference.

Securing these linear wireless networks follows the same strategy for securing any intranet system. There are no absolutes in security, only discrete levels of security where each stair step provides additional levels of security at the cost of time and money. The owner of the network needs to determine what they want to protect, who they want to protect it from and how much they are willing to pay in time and money. Securing a camera image from the roadside that may eventually be served out to the public may not pose a very high security priority. However, protecting a roadside variable message sign from unauthorized access certainly is a high priority.

General security recommendations include: only using backbone wireless links and not Access Point – Client links, turning on the vendor specific wireless encryption between individual links, using a router with a VPN system at the interface with the wireless LAN and the Internet, and authorizing networking for only known MAC addresses of roadside radios and devices.

III. Real World Deployments and Current Research

VTTI has worked with VDOT to deploy the serial wireless architecture in Virginia. In addition to real world deployments, VTTI also has a wireless test bed on a controlled research highway.

A. *Route 460 WLAN*

The Virginia Tech Transportation Institute (VTTI) installed its first serial WLAN with VDOT over two years ago along route 460 in Christiansburg and Blacksburg, Virginia. The system was designed to provide a communications infrastructure for digital IP cameras for traffic monitoring purposes. The wireless network extends in three directions from the VTTI Smart Road Control room. The entire WLAN is networked as a stand-alone private system. It interfaces with the Virginia Tech Internet network via a router. This particular system has a maximum of five wireless hops away from the base node. At the three endpoints of the system, a wireless access point is available for client access into the system. These APs are disabled unless required for use by field personnel.

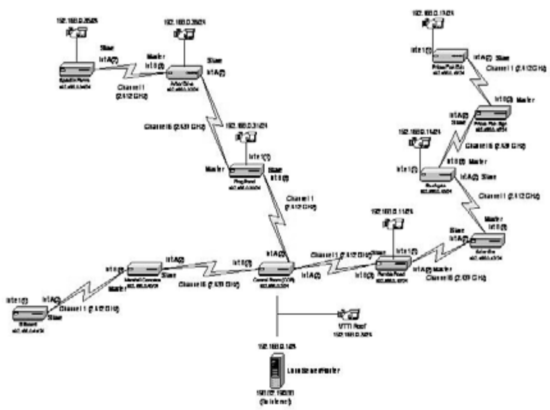

Figure 3 Network diagram of Rt. 460 Wireless Camera System

802.11b COTS products by Orinoco were used along with JVC network PTZ cameras. Most of the cameras utilize MJPEG compression. With a serial wireless network, all devices on the network share the available bandwidth. Streaming video from all the cameras at the same time places a significant draw upon the WLAN. VTTI recommends grabbing JPEG stills on a timed interval, displaying them in a matrix, and then streaming from one or two cameras at a time as needed. For a traffic monitoring concept of operations, this architecture is appropriate. This architecture is in contrast to the desired method of installing home-run fiber optic cables to each individual camera.

Figure 4 Matrix of JPEG still images

VTTI is currently tracking all operations and maintenance of the Route 460 WLAN to track the long term costs of the system. As part of this analysis, Knowledge Skills Assessments (KSAs) are being developed for the design, deployment and maintenance of the system to help VDOT determine what skills they have in house and what skills they will need to contract or hire to make use of WLANs in their operations.

VTTI is currently under contract with the Salem District of VDOT to design and install two 5-mile sections of WLAN along Interstate 81. The system consists of 21 nodes, 12 cameras, 7 acoustic sensors and 2 Internet backdrops. The system will utilize the newest 802.11a or 802.11g point-to-point solutions paired with current MPEG4 video servers used in conjunction with environmentally rated CCTV dome cameras.

B. Smart Road 2 mile wireless backbone with seamless AP coverage

Virginia's Smart Road is located at VTTI in Blacksburg. This highway is a closed test track used for various types of controlled transportation research. VTTI deployed a backbone serial wireless LAN down the highway and added access point coverage to create seamless coverage across 2 miles of 2 lanes and shoulders of the Smart Road. 802.11b technologies are not designed for mobile applications, and the intent in developing this system was to analyze the ability of the 802.11b standard to operate in a mobile environment.

The wireless backbone was created using Orinoco ROR-1000 outdoor routers, as used on the Route 460 WLAN. Directional Yagi antennas were mounted on the top of existing light poles to transmit the backbone signal up and down the road. Two 120º sector antennas were mounted lower on the light poles to provide AP coverage up and down the road.

Figure 5 Yagi backbone antennas and sector AP antennas

While the technology was not designed with mobile applications in mind, the system works admirably at speeds ranging from 5mph up to highway speeds of 60mph. A client laptop inside the vehicle connected to the first AP upon entering the roadway. As the vehicle continued down the roadway, the client computer would associate with a new AP further down the road as the signal strength from the first AP grew weaker and reached a threshold level where the client looks for stronger signal. This re-association to new APs continued through the length of the roadway. During mobile tests, VTTI used network analyzing software to measure throughput from the client computer to a stationary computer back at the command center. As mentioned earlier, the available bandwidth degrades as the number of hops away from the base node increases.

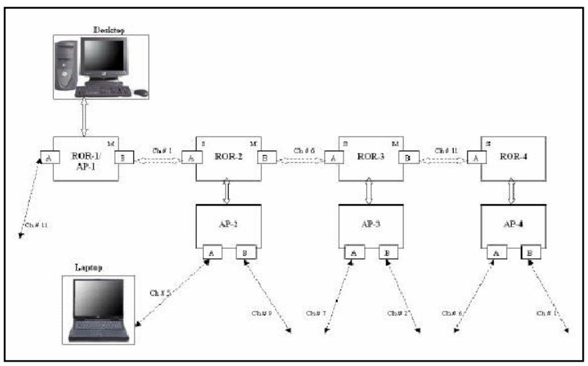

Figure 6 Diagram of Smart Road Wireless Backbone and AP system[1]

TABLE 1 THROUGHPUT FROM MOBILE CLIENT ON SMART ROAD WIRELESS NETWORK[1]

Connected to:	Static (Mbps)	20mph (Mbps)	40mph (Mbps)	60mph (Mbps)
AP-1	4.337	4.4023	4.1322	4.2823
AP-2	3.383	3.3654	3.1561	3.1568
AP-3	2.233	2.1893	2.1543	2.2058
AP-4	1.049	1.1986	1.1940	0.9824

C. Smart Road Reconfigurable Wireless Test bed

Currently, VTTI has developed a reconfigurable wireless test bed on the Smart Road. Using temporary antenna poles that are easy to move, networks of over 8 “hops” can be created. In addition, an AP can be added at each end of the system to connect to a client to simulate an additional two hops. At each node, custom-designed Single Board Computers (SBCs) have been installed. These mini computers are used with the top-of- the-line network simulation software to allow benchmark readings of the wireless network performance to be taken.

Figure 7 Aerial view of the Smart Road - Blacksburg, VA

The first system installed on the test bed was an 8-hop backbone Orinoco 802.11b system that could be expanded to 10 wireless hops with the addition of APs on either end. The Orinoco system is an older technology that is currently being phased out for newer products. In addition to 802.11b, we are testing 802.11a and 802.11g, point to point systems.

The test bed will be used to install varied devices in the field and then to benchmark their network performance. Criteria that will be measured include TCP and UDP throughput as well as ping delay times and signal-to-noise ratios in varied weather conditions. The UDP measurement is the most applicable for streaming digital video as it is a “connectionless” transfer. The research is not limited to just wireless devices: VTTI is also testing multiple digital video servers that assess their capabilities when used on serial wireless networks.

As discussed earlier, one of the major issues to consider when dealing with serial wireless LANs is the bandwidth degradation that occurs at each node. When dealing with devices on a network, especially digital video, the main design criteria is the bandwidth draw of the device in relation to the available bandwidth of the system.

D. Analysis of Orinoco ROR-1000 802.11b Eight Hop Serial Wireless Network

The network performance of an eight hop wireless LAN using Orinoco ROR-1000 802.11b radios was characterized using NET IQ Chariot, NET IQ Qcheck, and simple FTP transfers between laptop computers. Over 3000 records per hop were taken with Chariot for UDP characterization. Chariot would not work with Orinoco ROR product line for testing TCP throughput, so FTP transfers were used instead. Using regression analysis it was determined that the UDP throughput decreases by 4% per hop. There was a linear relationship between UDP throughput and number of hops for the Orinoco System that can be described by the equation:

Throughput = 4.524 – 0.159*(# of hops).

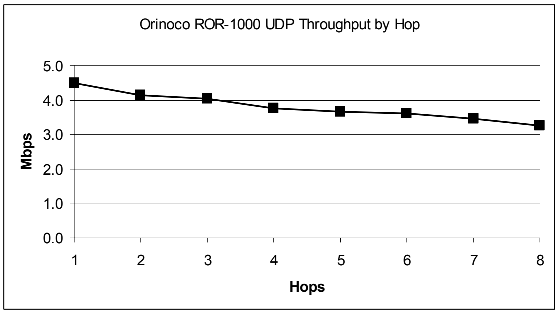

Figure 8 Average UDP throughputs at each hop illustrating throughput degradation

TCP data was gathered by placing laptops at each node and performing FTP transfers between laptops. As expected, UDP throughput is higher than TCP throughput due to the connectionless nature of UDP.

E. Analysis of other systems in 3 hop configurations

We have procured several other radios and set them up in 3 hop configurations in order to determine if they are suitable for a serial type of architectures. Some radios, such as the Tsunami Quick Bridge products would not operate in a serial configuration over multiple hops and are more suited for individual point to point or single link point to multipoint architectures. Currently we are testing the Proxim MP.11a 802.11a radio, the Proxim MP.11 802.11b radio that has replaced the Orinoco product line, and the Buffalo Tech 802.11g wireless bridge/AP radio.

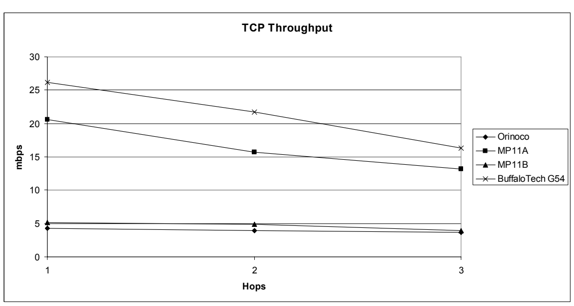

Figure 9 TCP throughput comparisons over 3 hops

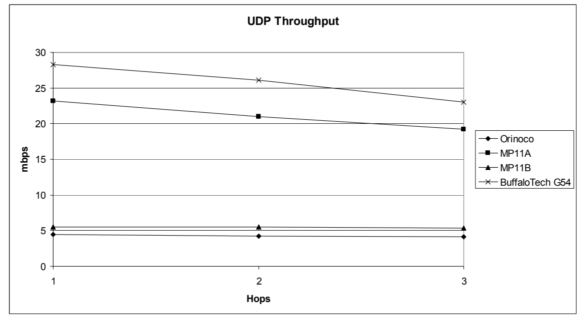

Figure 10 UDP throughput comparisons over 3 hops

IV. DESIGN METHODOLOGY FOR DOTS

The first steps required for designing a wireless LAN are to determine the quantity and type of devices that will be placed on it and that will be sharing the bandwidth. Cameras are by far, the most bandwidth-intensive devices that will most likely be used in the field. Therefore, they tend to be the driving force in defining the requirements of a WLAN.

Once the number of cameras is determined, the next step is to define what type of image is required and where it will be viewed. In other words, what kind of clarity, picture size, and streaming quality is required? Is a delay between when a PTZ command is issued and when the command is realized on screen acceptable? For example, in a security application where one must have the ability to pan and follow a specific vehicle or individual, a delay on the front-end compression or delay in transmission of a pan/tilt command might be unacceptable. However, this delay is perfectly acceptable in a strictly traffic monitoring application, where the defining questions are: Is traffic moving? If not, why?

Common digital video compression algorithms include MJPEG, MPEG1, MPEG2, and MPEG4. Each compression method will have a range of bit rates that the camera uses when streaming video. The chosen bit rate will affect the clarity of the picture, and depending on the specific compression method and manufacturer it may affect the frame rate. Larger pictures sizes will naturally require more bandwidth because they are sending more information.

All of these factors need to be taken into account to determine the optimal design of the WLAN. One suggestion is to make use of JPEG stills as opposed to streaming video for general monitoring applications where several cameras are sharing wireless bandwidth. For example, if a network has 9 cameras on it, it is more bandwidth efficient to grab 9 JPEG stills every 30 seconds than it is to stream video from all 9 cameras at the same time. In addition, an operator scanning multiple cameras can focus easier on a still image than multiple streaming small scale images. Cameras can be streamed continuously as needed for more detailed monitoring.

If the terrain allows it, creating point to point links between each camera and a central location is the equivalent of home run fibers to each camera.

V. Next steps and conclusion

There seems to be no slowdown for the wireless industry in the near future, and new products are being developed yearly. On the national-standards level, a new standard is currently in development called 802.16. This standard is specifically for backbone point- to-point applications. It will have its own dedicated spectrum and will be designed with higher throughputs and with the demands of long-distance point-to-point communications in mind. In addition, non-line-of-sight and near-line-of-sight systems will certainly come down in price, making them more available for large-scale deployments. In addition a DSRC (Dedicated Short Range Communications) standard is in development specifically for vehicle-to-vehicle and vehicle-to-roadside communications.

The time for accepting wireless as a viable alternative is here. The costs are well within the means to deploy systems on a permanent or temporary basis. The speed in which they can be installed means that the field device can be placed within months instead of years. While it is by no means and end-all solution, wireless is definitely a viable option for DOTs to extend their communications network.

1. F. Aziz, “Implementation and Analysis of Wireless Local Area Networks for High-Mobility Telematics,” Masters Thesis submitted to Virginia Tech University, p. 124, May 2003.