U.S. Department of Transportation

Federal Transit Administration

SharpRAIL: Evaluation of Mobile WiMAX and Intelligent Video for Enhanced Rail Transit Safety

Report Number FTA-MD-26-7132-08.1

June 2008

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
PB 2008-111189	June, 2008	Final Report, April 2007-January 2008

4. TITLE AND SUBTITLE
SharpRAIL: Evaluation of Mobile WiMAX and Intelligent Video for Enhanced Rail Transit Safety

5. FUNDING NUMBERS
MD-26-7132-00

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S Department of Transportation
Federal Transit Administration
Office of Research, Demonstration and Innovation,
Office of Technology, TRI-20
1200 New Jersey Ave, S.E., East Building, 4th Floor
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
FTA-MD-26-7132-08.1

11. SUPPLEMENTARY NOTES
This project was supported by a cooperative agreement with the Federal Transit Administration.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Available online at http://www.fta.dot.gov/research.html

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
U.S. rail transit operations have an excellent safety record with fatalities from rail accidents averaging fewer than forty per year. However, FTA continues to pursue a proactive approach in seeking new technologies that can help in identifying and anticipating safety hazards and preventing accidents. SharpRAIL represents a unique integration of high-speed mobile wireless technologies, advanced computer intelligence, and scalable video processing with versatile command and control to achieve automated detection of incidents and impending collisions. SharpRAIL seeks to exploit advances in 1) artificial intelligence software that can analyze video images in real-time to automatically catch pre-configured security/safety events, such as rail trespass, vehicles trapped on tracks, loitering, criminal activities, etc., and send instant wireless alerts to responsible rail personnel; 2) availability of high-speed mobile wireless technologies in conjunction with industry-wide standardization efforts through mobile/static WiMAX for high-bandwidth data transport, and 3) sophisticated DSP-based video encoders that can perform intensive image processing right at the "edges", where the cameras are located. The SharpRAIL project involved design of a prototype solution that achieves these capabilities using commercial, off-the-shelf (COTS) offerings and operational feasibility demonstration through a public-private partnership involving the industry, local government and a public transit agency.

14. SUBJECT TERMS
public transportation, rail transit, safety, security, intelligent video, image analysis, WiMAX, EV-DO Rev-A, automated real-time alerts, Wi-Fi, WiFi, broadband, communications

15. NUMBER OF PAGES
67

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

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List of Acronyms

24/7/365	24 hours per day, 7 days per week, 365 days per year
3G/EV-DO	Third generation Evolution-Data Optimized
4CIF	Four (4) times Common Intermediate Format (704x576 pixels of video resolution)
AI	Artificial Intelligence
AP	Access Point
CCTV	Closed Circuit Television
CDMA	Code Division Multiple Access
CIF (FCIF)	Common Intermediate Format (Full Common Intermediate Format) (352x288 pixels of video resolution)
COTS	commercial, off-the-shelf
DARPA	Defense Advanced Research Projects Agency
DFS	Dynamic Frequency Selection
DPD	Dead Peer Detection
DSP	Digital Signal Processing
DVR	Digital Video Recorder
EV-DO	Evolution-Data Optimized, or Evolution-Data only
EV-DO Rev-A	Evolution-Data Optimized, or Evolution-Data only; Revision A
FDD	Frequency Division Duplex
FIPS	Federal Information Processing Standard
FPS	Frames per Second
FTA	Federal Transit Administration
GRE	generic routing encapsulation
HSDPA	high speed downlink packet access
IDE	integrated drive electronics - describes a hard disk with integral disk controller
IEEE	Institute of Electrical and Electronic Engineers
IP	Internet protocol
IR	Infrared
IT	information technology
LAN	local area network
LoS	Line of Sight
MAC	Media Access Control
MAN	Metropolitan Area Network
Mbit/s	Mega bits per second
MIMO	Multiple-Input and Multiple-Output
M-JPEG	Motion – Joint Photographic Experts Group (file format)
MPEG	Motion Picture Editors Guild (Video Compression Standard, e.g. MPEG-4 (H.264))

MTBF	Mean Time between Failures
NLoS	Non-Line of Sight
NPV	Net Present Value
OFDM	Orthogonal Frequency-Division Multiplexing
OV	ObjectVideo
PCMCIA	Personal Computer Memory Card International Association
PHY	PHYsical layer (interface for transmission and reception of data packets transferred across a serial bus)
PMP	Point to Multi Point
PTZ	Pan-Tilt-Zoom
QCIF	Quarter – Common Intermediate Format (176x144 pixels of video resolution)
QoS	Quality of Service
RFI	Radio Frequency Interference
RSTP	Rapid Spanning Tree Format
SMS	Short Messaging Service (text messaging)
TDMA	Time Division Multiple Access
URL	Uniform Resource Locator
VRE	Virginia Railway Express
VPN	Virtual Private Network
WAP	Wireless Access Point
WEP	Wired Equivalent Privacy
Wi-Fi	Wireless [Fidelity]
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WMM	Wi-Fi Multi Media
WPA, WPA2	Wi-Fi Protected Access

1 Foreword

The primary purpose of this final report is to document the results of implementing an independent prototype system and associated research study, codenamed "SharpRAIL", on the effectiveness of a combination of mobile broadband wireless and intelligent video surveillance technologies in enhancing transit safety. The report includes i) an analysis of these technologies, including benefits and limitations when deployed in a real-life transit scenario, ii) details on a selected optimal integrated SharpRAIL system architecture, and iii) discussions on the research methodology and approach, and system evaluation process employed by the team during the course of the study. This study is intended for all interested readers but includes information particularly relevant to federal transportation officials, transit agency representatives, transit information technology staff, municipal staff and public safety officials.

1.1 Acknowledgement

The SharpRAIL team would like to acknowledge the significant contributions of Mr. Lou Woolner, Mr. John Duque, Mr. Nahom Debessay, Mr. Dale Zehner and Ms. April Maguigad from Virginia Railway Express (VRE) in helping us successfully complete the pilot evaluation phase of the project. We are thankful to VRE's senior management, in particular, Mr. Mark Roeber, for allowing us access to their infrastructural facilities and key staff members during the course of the study.

1.2 Executive Summary

The Rail Transit System moves more than 7 million passengers every day, and, according to Federal Transit Administration (FTA) statistics, accounts for less than 6 percent of all public transportation accidents, making it one of the safest forms of public transportation. Rail transit related fatalities have ranged from 26 to 57 per year, with an approximate average of 40 per year.

Although rail transit operations have an excellent safety record, FTA continues to pursue a proactive approach in seeking new technologies that can help in anticipating safety hazards and preventing accidents. Capturing accurate and real-time information is highly beneficial in proactively intervening and preventing safety incidents from evolving into serious accidents. Pursuing a goal of zero accidents is a shared responsibility of government and the industry. Hence, our approaches to this project focused on anticipating safety hazards and preventing accidents. VT Aepco's SharpRAIL demonstrated a significant advancement in this respect.

1.2.1 Objective

Over the past decade or so, rail transit systems have been introducing advanced technologies for a variety of onboard recording and monitoring functions. However, transit agencies are now seeking new technologies that can help in anticipating safety hazards and preventing accidents. Capturing accurate and real-time information is instrumental in proactively intervening and preventing safety incidents before they happen. SharpRAIL's objective was to demonstrate enhancements in rail transit safety with advanced capabilities in automatic incident detection of adverse events occurring along rail tracks that may affect costly assets or cause harm to people and personal property. The SharpRAIL concept utilizes an innovative combination of mobile WiMAX, 3G/EV-DO, and machine vision intelligence technologies.

1.2.2 Execution

The SharpRAIL project followed a classical systems engineering process approach that included: requirements gathering; technology definition and selection; prototype, design, development, and implementation; system testing and results; and conclusions with lessons learned.

The SharpRAIL team's first task was to find a rail transit partner that would allow physical access to their trains and station facilities and help define the types and amounts of system data that would demonstrate the project's effectiveness. The SharpRAIL team was introduced to the management at Virginia Rail Express (VRE). Together, a project partnership was formed that fostered the design, implementation, and testing of SharpRAIL at VRE's Franconia-Springfield railway station and aboard VRE's V02 train.

While working with VRE, the team researched and evaluated different venders that supplied the required SharpRAIL technologies, namely, pre-WiMAX Access Points (AP), 3G/EV-DO Rev-A broadband services and products, and intelligent video products. We decided on Proxim's MP-11 pre-WiMAX products, Sprint's EV-DO service, and Mango DSP's edge encoders with ObjectVideo's onboard analytics.

These products were integrated, configured, and tested at VT Aepco's in-house lab before deploying the system to VRE's Franconia-Springfield station and aboard their V02 locomotive.

SharpRAIL's evaluation prototype, Figure 1, included both static and mobile wireless nodes. Static nodes were located at the Franconia-Springfield station and on a wayside tall building along the tracks, carrying high-definition cameras and video encoders with embedded machine vision intelligence. Two mobile cameras, one inside the locomotive facing the tracks and another inside a passenger car, were installed to proactively monitor safety and security events on the track and inside the train, respectively. Each mobile camera was connected to a mobile wireless backbone, such as a WiMAX subscriber unit with an omnidirectional antenna or EV-DO high-bandwidth backhaul for reliably connecting nodes along the track. The machine vision intelligence enabled the passenger train camera to detect unusual events inside the passenger car and relay that information instantly through the mobile broadband infrastructure in real time to alert the operations center of a potential situation.

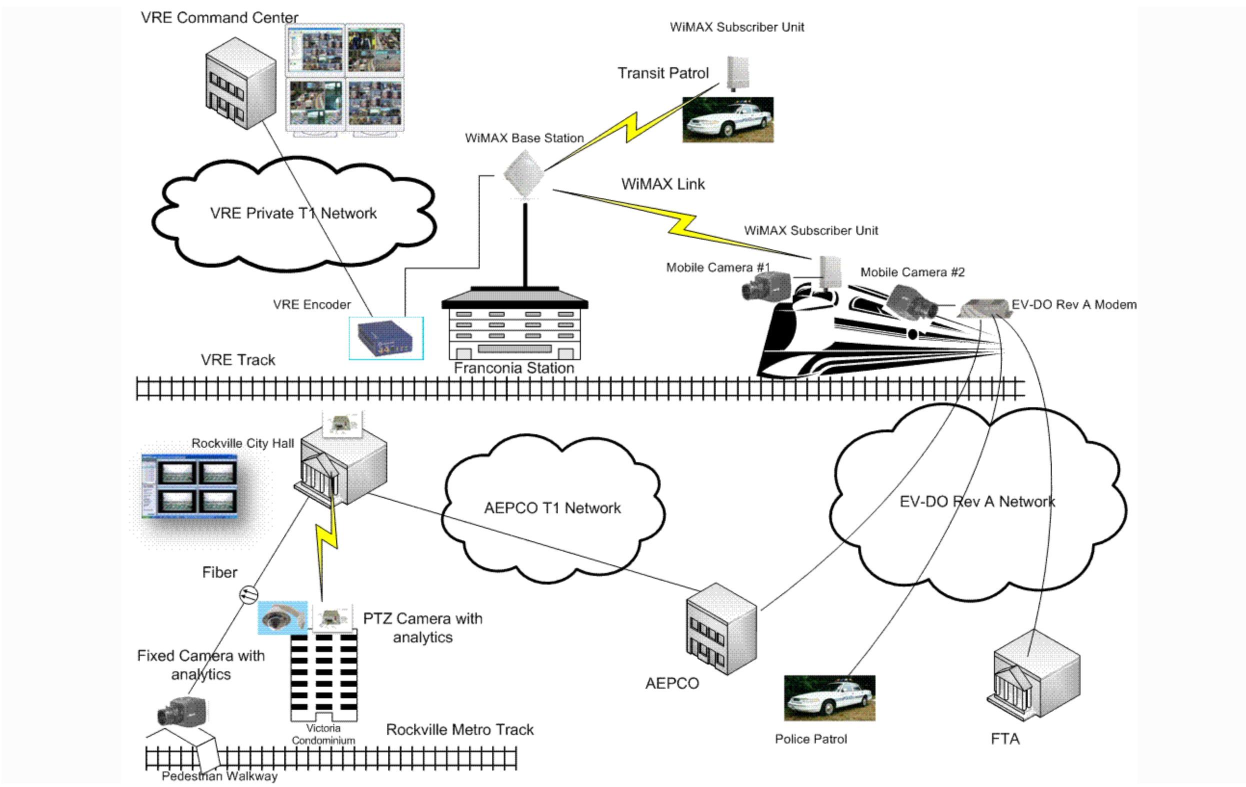


Figure 1: Final SharpRAIL Architecture

1.2.3 Results and Conclusion

SharpRAIL's field and laboratory studies conclusively proved the utility and feasibility of SharpRAIL technologies in enhancing situational awareness and emergency response times on rail transit. With the use of commercial off-the-shelf (COTS) wireless broadband and video technology and with services from Sprint, our study was able to demonstrate solid benefits using these integrated technologies. For example, VT Aepco's in-field intelligent video system resulted in less than 5% error rate as measured by

False Alarms and False Rejections. The error rate can be reduced further by using customized analytics rules and improvements in passenger car camera stability. Another key result was very good mobile video streaming performance using EV-DO Rev-A technology from Sprint with its support for higher upload rates. We did have difficulties with our results with mobile WiMAX technology due to poor LOS (Line of Sight) at the chosen location and wireless connectivity limitations due to the extremely short stopping time (~ 23 seconds) at the VRE Franconia-Springfield station location.

Overall, SharpRAIL proved that today's integrated advanced technologies can offer enhanced rail transit safety in a cost effective way.

1.3 Organization of Content

The main content of the SharpRAIL Final Report starts with the project's objective and scope in Section 2. Section 3, *Approach*, gives an overview of our systems engineering process approach to this project. After Section 3, the report delves into more specifics starting in Section 4, *Requirements Gathering*. In the next several sections, the report evolves from conceptual information to physical information. This starts in Section 5, *Technology Definition and Selection*, and continues with Section 6, *Prototype Design, Development, and Implementation*. *System Testing and Results* (Section 7), discusses the test plans, testing, and test results. Lastly, Section 8, *Conclusions and Lessons Learned*, presents the study's conclusions, a discussion on the cost-benefit implications, and lessons learned.

2 Objective

SharpRAIL represented a unique integration of high-speed mobile wireless technologies, advanced computer vision, and scalable video processing with versatile command and control. SharpRAIL's aim was to exploit i) advances in artificial intelligence software that can analyze video images in real-time to automatically catch pre-configured security/safety events, such as rail trespass, vehicles trapped on tracks, loitering, criminal activities, etc. and send instant wireless alerts to important rail personnel; ii) availability of high-speed mobile wireless technologies in conjunction with industry-wide standardization efforts through mobile and static WiMAX for high-bandwidth data transport; and iii) sophisticated DSP-based video encoders that can perform intensive processing right at the "edges", co-located with video sensors, to realize efficient and scalable distributed architectures.

The objective of SharpRAIL was to design and demonstrate a prototype solution that achieved these capabilities using COTS offerings and standardized technologies. SharpRAIL studied cost-benefit implications, training needs, operational challenges of introducing the system into public transit agencies.

2.1 Scope

The scope of the study includes an analysis of the following capabilities:

- Use of sophisticated artificial intelligence (AI) algorithms to automatically detect abnormal safety situations on video, captured using high-resolution cameras on railway stations or facilities along the railway track. Study of ability to record key video frames related to these incidents for forensic analysis.

- Real-time video feed transmission from a vehicular camera, mounted inside a high-speed mobile rail car to a command and control center, using a broadband wireless infrastructure. This ensures that both rail operators and station supervisors have access to a common operating picture of ground reality.

- Real-time, wireless video feed transmission from an infrastructure camera situated on a fixed facility (e.g., a tall building) near the railway track, to rail operators, mobile responders and station supervisors, for real-time situational awareness. With regard to rail operator access capability to these camera feeds, the challenge was to ensure a seamless connectivity and wireless coverage as the train moves at high speeds between successive stations.

- Instant wireless notifications and alerts to multiple stakeholder agencies in the event of a potential safety "event" to trigger intelligent operational responses and to facilitate rapid incident management.

3 Approach

In order to adequately conduct this analysis, VT Aepco divided the project into five distinct systems engineering phases, namely, Requirements Gathering; Technology Definition and Selection; Prototype Design, Development, and Implementation; System Testing and Results; and Conclusions and Lessons Learned.

3.1 Requirements Gathering

The objective of this phase was to clearly understand the problem domain through extensive secondary research, consultation with transit experts and practitioners to finalize the functional and logistical requirements of the SharpRAIL project. The major tasks accomplished in this phase:

- Discussed and finalized high-level project requirements with Stakeholders during a kick-off meeting; compiled an initial project plan based on this meeting;
- Aggregated and documented information on current technologies, systems and practices in the field through extensive secondary research on the web, consultation with domain experts as well as use of internal knowledge repositories;
- Modified and compiled functional requirements generated as a result of insights gathered through internal review and primary and secondary research; and
- Researched additional business development activities to identify a suitable transit partner for the pilot phase of the SharpRAIL project.

3.2 Technology Definition and Selection

The objective of this phase was to define the "to-be" system by translating functional requirements identified during the Requirements Gathering Phase to well-defined technical requirements. This phase included an analysis of technology and vendor alternatives to determine the optimum design for SharpRAIL. The major tasks accomplished in this phase were:

- Explored and analyzed technology choices that enabled the functional elements defined in the Requirements Gathering phase and the initial project proposal. This included technologies that were generally available as well as emerging alternatives expected to be released in limited quantities for prototype testing during the Development Phase (e.g., EV-DO Rev A).
- Initiated discussions with VRE technical team to understand their IT infrastructure as it applies to SharpRAIL. The Team conducted a preliminary analysis of VRE track maps and identified a station location (i.e., Franconia-Springfield) for the SharpRAIL pilot.
- Conducted detailed wireless site surveys at three VRE stations to select the best location for the tests. Franconia-Springfield was chosen as the final test site for SharpRAIL based on easy access to installation facilities (e.g., sky bridge) and clear line-of-sight (LOS) stretch for reasonable connectivity and video streaming tests.
- Performed a facilities survey with VRE stakeholders at Franconia-Springfield station to understand power cabling, video backhaul and communication requirements. Refined the existing SharpRAIL design to accommodate site constraints as well as VRE privacy issues.
- Assessed vendor capabilities and solutions appropriate for the SharpRAIL scenario, especially focusing on the challenges of implementing a video surveillance system in a highly mobile situation.

3.3 Prototype Design, Development, and Implementation

The objective of this phase was to design, develop, and implement a "proof-of-concept" pilot test for field evaluation of the "to-be" SharpRAIL system. The major tasks accomplished in this phase were:

- Designed and implemented a SharpRAIL Command Center at VT Aepco's office in Gaithersburg;
- Designed and developed a detailed installation and testing plan for a moving train (VRE Train 305 of Fredericksburg Line) and Franconia-Springfield station premises in Virginia; and
- Procured, integrated, configured, and installed the SharpRAIL pilot at VRE's Franconia-Springfield station and aboard VRE train V02's locomotive for use on Line 305 to Fredericksburg.

3.4 System Testing and Results

The objective of this phase was to deploy the prototype system designed, constructed, and tested in the previous phase and to collect and analyze the operational data. The major tasks accomplished in this phase were:

- Collected remote mobile-camera video-output data from VRE's Franconia-Springfield Station using EV-DO and pre-WiMAX,
- Tested remote monitoring of mobile camera output from VT Aepco's Office in Gaithersburg using EV-DO Rev A, and,
- Performed onboard ride tests, collected and analyzed WiFi-based web access and video quality data for ten (10) business days.

3.5 Conclusions and Lessons Learned

The objective of this phase was to analyze and evaluate the test results and formulate conclusions on the effectiveness of the SharpRAIL pilot system. The major tasks accomplished in this phase were:

- Developed the SharpRAIL Final Report.

4 Requirements Gathering

Based on section 2.1, Scope, the SharpRAIL team contacted several industry representatives and potential partners to gather information to create a set of functional and logistical requirements that would become the basis of an operational demonstrator. The results of our efforts are the following:

- The overall project requirements were defined around available current WiFi, WiMAX, and video analytic technologies that would:
  - allow for a real-life demonstration,
  - be cost effective, and,
  - be available for duplication if someone else wanted to pursue a production implementation.
- SharpRAIL team executed a partnership agreement with Virginia Railway Express (VRE) to conduct objective tests on an actual train along the Fredericksburg Line in Washington DC and Northern Virginia. With our VRE partner, the following requirements were defined:
  - Demonstrate sending live video from a train to a command center,
  - Demonstrate video analytic alerts from activity within a passenger car and sending the alerts to a command center,
  - Demonstrate WiMAX high-broadband connectivity between a moving and stationary train and a local train station, and,
  - Demonstrate passenger WiFi access onboard a train.

- The operational and technical requirements for SharpRAIL are:
    - Install, setup, and configure one (1) fixed WiMAX base unit at a local station,
    - Install, setup, and configure one (1) mobile WiMAX subscriber unit onboard a train,
    - Install , setup, and configure two (2) fixed video cameras onboard a train, one for passenger video analytics and one for a locomotive window, looking at the tracks, and
    - Install, setup, and configure one (1) EV-DO broadband router for public WiFi access.

5 Technology Definition and Selection

The following sections describe the core technologies in their current state that was researched for the SharpRAIL project. This includes, *Mobile Broadband Wireless Technology* (Section 5.1); and, *Intelligent Video Surveillance Technology* (Section 5.2). At the end of each technology section, there is a table that describes the challenges and benefits of each available product within the Wireless and Video technology groups (e.g. EV-DO versus WiMAX). After evaluating these two tables, we made the selection of the final products used for the SharpRAIL prototype. The final technology selection criteria and list of products selected for the project are presented in Section 5.3, *Technology Selection*.

5.1 Mobile Broadband Wireless Technology

5.1.1 Wi-Fi

Wi-Fi is a brand originally licensed by the Wi-Fi Alliance to describe the underlying technology of wireless local area networks (WLAN) based on the IEEE 802.11 specifications.

Standing for "wireless fidelity", it was developed to be used for mobile computing devices, such as laptops, in LANs, but is now increasingly used for more services, including Internet and VoIP phone access, gaming, and basic connectivity of consumer electronics, such as televisions and DVD players, or digital cameras. More standards are in development that will allow Wi-Fi to be used by cars in highways in support of an Intelligent Transportation System to increase safety, gather statistics, and enable mobile commerce. (IEEE 802.11p exclusively covers this aspect of technology.)

Wi-Fi and the Wi-Fi CERTIFIED logo are registered trademarks of the Wi-Fi Alliance, the trade organization that tests and certifies equipment compliance with the 802.11x standards.

Advantages of Wi-Fi

- Allows LANs to be deployed without cabling, typically reducing the costs of network deployment and expansion. Spaces where cables cannot be run, such as outdoor areas and historical buildings, can host wireless LANs.
- Built into all modern laptops. IDE cards are available for desktop machines and other PC devices to use the Wireless Communication.
- Wi-Fi chipset pricing continues to reduce, making Wi-Fi a very economical networking option and driving inclusion of Wi-Fi in an ever-widening array of devices.
- Wi-Fi products are widely available in the market. Different brands of access points and client network interfaces are interoperable at a basic level of service. Products designated as Wi-Fi CERTIFIED by the Wi-Fi Alliance are interoperable and include WPA2 security.
- Wi-Fi is a global set of standards. Unlike cellular carriers, the same Wi-Fi client works in different countries around the world.
- Widely available in a large number of public hot spots and millions of homes and corporate and university campuses. Wi-Fi is becoming popular and the numbers are increasing.
- As of 2006, Wi-Fi Protected Access (WPA and WPA2) encryption is not easily decrypted if strong passwords are used.

- New protocols for Quality of Service (like 802.11e for Wi-Fi Multimedia (WMM) standards) and power saving mechanisms (WMM Power Save) make Wi-Fi even more suitable for latency-sensitive applications (e.g. voice and video) and small form-factor.

Disadvantages of Wi-Fi

- Spectrum assignments and operational limitations are not consistent worldwide; most of Europe allows for an additional 2 channels beyond those permitted in the US (1-13 vs. 1-11); Japan has one more on top of that (1-14) - and some countries, like Spain, prohibit use of the lower-numbered channels.
- Wi-Fi networks can be monitored and used to read and copy data (including personal information) transmitted over the network unless encryption, such as WPA or VPN, is used.
- Wi-Fi Access Points typically default to an open (encryption-free) mode. Novice users benefit from a zero configuration device that works out of the box but might not intend to provide open wireless access to their LAN.
- Many 2.4 GHz 802.11b and 802.11g Access points default to the same channel, contributing to congestion on certain channels.
- Wi-Fi networks have limited range. A typical Wi-Fi home router using 802.11b or 802.11g with a stock antenna might have a range of 45 m (150 ft) indoors and 90 m (300 ft) outdoors. Wi-Fi in the 2.4 GHz frequency block has better range than Wi-Fi in the 5 GHz frequency block, and less range than the oldest Wi-Fi (and pre-Wi-Fi) 900 MHz block. Outdoor range with improved antennas can be several kilometers or more with unobstructed line-of-sight.
- It is also an issue when municipalities or other large entities, such as universities, seek to provide large area coverage. Everyone is considered equal when they use the band (except for amateur radio operators, who are the primary licensee). This openness is important to the success and widespread use of Wi-Fi, but makes it unsuitable for "must have" public service functions.
- IEEE Standards 802.11b and 802.11g use the 2.4 GHz band, and 802.11b and 802.11g equipment will suffer interference from microwave ovens, cordless telephones, Bluetooth devices, baby and security monitors, amateur radio and other appliances using this same frequency band.

Mesh variants of Wi-Fi technologies address some limitations of range and reliability by enabling bridging connectivity between adjacent wireless AP's. However, Wi-Fi mesh implementations continue to be proprietary in nature with different vendors claiming significantly different performance attributes.

5.1.2 3G/EV-DO

EV-DO stands for Evolution-Data Optimized or Evolution-Data only, and is a standard under 3GPP2d for high-speed wireless transmission. It uses multiplexing techniques, such as CDMA (Code Division Multiple Access) and FDD (Frequency Division Duplex) to optimize data throughput. EV-DO has been adopted by major cellular carriers like Verizon and Sprint in U.S.

Revision 0 (Rev. 0) of EV-DO provides access at over-the-air rates of up to 2.4 Mbps. This has increased to 3.1 Mbps in the enhanced Rev. A standard that was recently launched. Rev. A offers fast packet establishment on both the forward and reverse links along with air interface enhancements that reduce latency and improve data rates[1]. In addition to the increase in the maximum burst downlink rate from 2.45 Mbps to 3.1 Mbps, Rev. A also shows significant improvement in the maximum uplink data rate to a maximum uplink burst rate of 1.8 Mbps. The uplink enhancement is critical to the success of a SharpRAIL deployment to be able to transport video from the moving train to a remote dispatch center.

[1] http://en.wikipedia.org/wiki/Evolution-Data_Optimized

Security is another important facet of EV-DO technology. The security of 1x EV-DO offers authentication, integrity, and encryption capabilities. 1x EV-DO supports authentication of the access terminal (AT) to authorize access to the wireless network, as well as authentication of a subscription to authorize access to the Internet Protocol (IP) network. The system also provides session security via re-authenticating the AT during a session to prevent 1x EV-DO session hijacking and to protect integrity of the user packets.

5.1.3 WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless broadband technology, which supports point to multi-point (PMP) broadband wireless access. There are two main applications of WiMAX today: fixed WiMAX applications are point-to-multipoint enabling broadband access to homes and businesses, whereas mobile WiMAX offers the full mobility of cellular networks at true broadband speeds. Both fixed and mobile applications of WiMAX are engineered to help deliver ubiquitous, high-throughput broadband wireless services at a low cost. Figure 2 below shows four potential fixed and mobile WiMAX applications that include transporting IP data for Internet users, and phone, cable TV, and satellite communications.

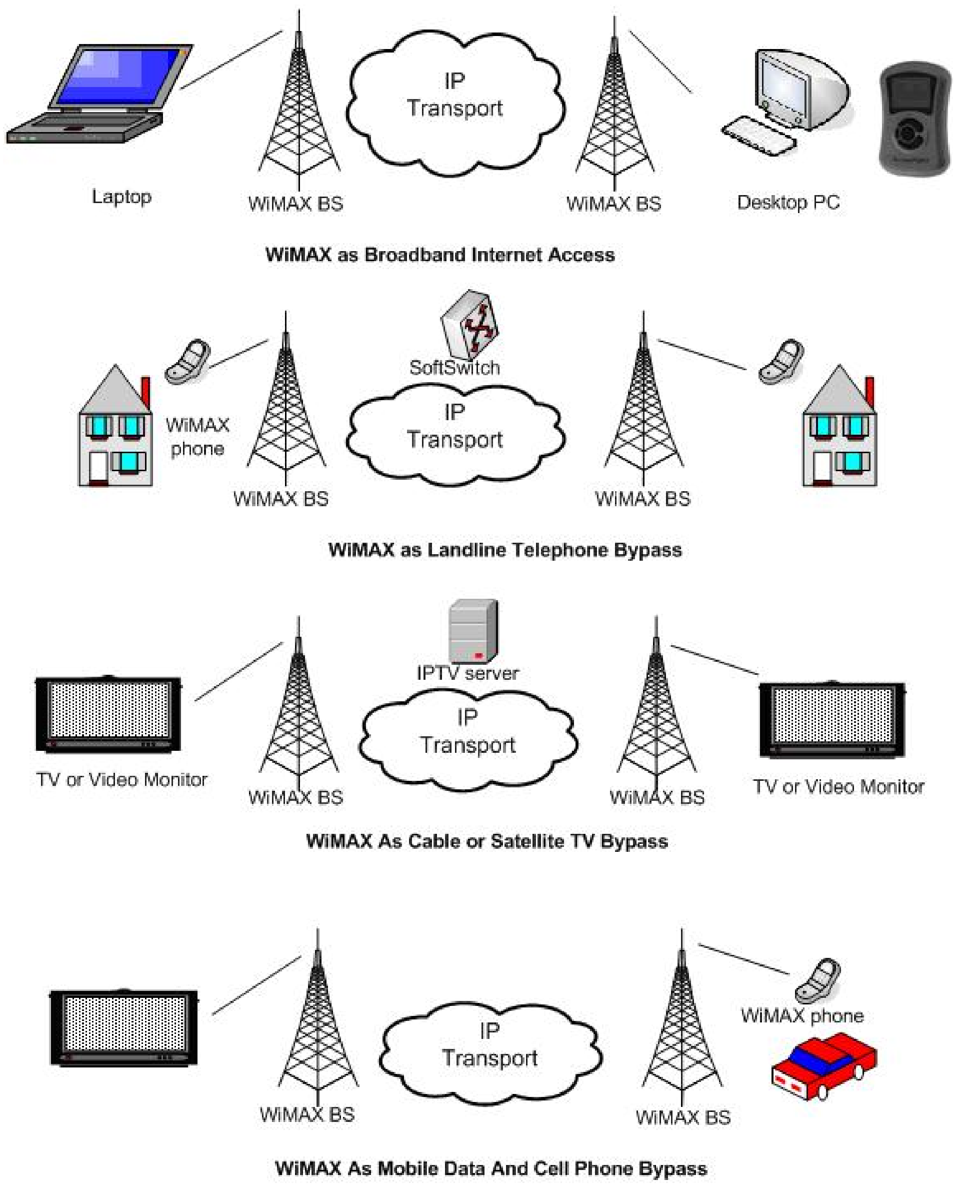


Figure 2: Applications of WiMAX technology

Fixed wireless is the basic concept for the metropolitan area networking (MAN), given in the IEEE 802.16 standard. In fixed wireless, a backbone of base stations is connected to a public network.

Each of these base stations supports many fixed subscriber stations, either public Wi-Fi hot spots or fire walled enterprise networks. These base stations use the media access control (MAC) layer, and allocate uplink and downlink bandwidth to subscribers as per their individual needs. This is basically on a real-time need basis.

Typically, a WiMAX system consists of two parts:

- **WiMAX Base Station:** The base station consists of indoor electronics and a WiMAX tower. Typically, a base station can cover up to 10 km radius (Theoretically, a base station can cover up to 50 kilo meter radius or 30 miles, however practical considerations limit it to about 10 km or 6 miles). Any wireless node within the coverage area would be able to access the Internet, and

- **WiMAX Receiver**: The receiver and antenna could be a stand-alone box or a PCMCIA card that sits in a laptop or computer. Access to WiMAX base station is similar to accessing a Wireless Access Point in a Wi-Fi network, but the coverage and speeds are greater.

Several base stations can be connected with one another by use of high-speed backhaul microwave links. This would allow for roaming by a WiMAX subscriber from one base station to another base station area, similar to roaming enabled by Cellular phone companies. Important Wireless MAN IEEE 802.16 (WiMAX) Specifications:

- Range - 30-mile (50-km) radius from base station.
- Speed - Up to 70 megabits per second.
- Non-Line-of-sight (NLoS) between user and base station.
- Frequency bands - 2 to 11 GHz and 10 to 66 GHz (licensed and unlicensed bands).

IEEE 802.16 standard defines both the MAC and Physical layers and allows multiple Physical-layer specifications. The subscriber stations might also be mounted on rooftops of the users. The MAC layer is a common interface that makes the networks interoperable. In the future, one can look forward to 802.11 hotspots, hosted by 802.16 MAN's. These would serve as wireless local area networks (LANs) and would serve the end users directly too.

WiMAX supporters are focusing on the broadband last mile in unwired areas, and on back-haul for Wi-Fi hotspots. WiMAX is expected to support mobile wireless technology, including wireless transmission directly to mobile end users. WiMAX changes the last-mile problem for broadband in the same way that Wi-Fi has changed the last one hundred feet of networking.

The IEEE approved the 802.16 standards in June 2004, and three working groups were formed to evaluate and rate the standards. The predecessors to IEEE 802.16 (like 802.11a) were not very accommodative of the European standards; the devices based on 802.11a had to undergo major modifications to work in Europe. European HiperLAN standard was issued to compete with the US-centric 802.11 series of standards. But the European HiperLAN standards failed to attain popularity as Wi-Fi exploded.

Today's WiMAX standard incorporates Europe's newer HiperMAN standard as well as the Korean WiBro, which is a version of what today is being called Mobile WiMAX or 802.16e. The IEEE wireless standard 802.16e has a range of up to 30 miles, and can deliver broadband at around 75 megabits per second. This is, theoretically, 20 times faster than a commercially available wireless broadband.

Unlike 3G systems, which have a fixed channel bandwidth, WiMAX defines a selectable channel bandwidth from 1.25MHz to 20MHz, which allows for a very flexible deployment. When deployed using the more likely 10MHz TDD (time division duplexing) channel, assuming a 3:1 downlink-to-uplink split and 2 x 2 MIMO, WiMAX offers 46Mbps peak downlink throughput and 7Mbps uplink. The reliance of Wi-

Fi and WiMAX on OFDM modulation, as opposed to CDMA as in 3G, allows them to support very high peak rates. The need for spreading makes very high data rates more difficult in CDMA systems.

From a capacity standpoint, the more pertinent measure of system performance is spectral efficiency. WiMAX can achieve spectral efficiencies higher than what is typically achieved in 3G systems. The fact that WiMAX specifications accommodated multiple antennas right from the start gives it a boost in spectral efficiency. In 3G systems, on the other hand, multiple-antenna support is being added in the form of revisions. Further, the OFDM physical layer used by WiMAX is more amenable to MIMO implementations than are CDMA systems from the standpoint of the required complexity for comparable gain. OFDM also makes it easier to exploit frequency diversity and multiuser diversity to improve capacity. Therefore, when compared to 3G, WiMAX offers higher peak data rates, greater flexibility, and higher average throughput and system capacity.

Another advantage of WiMAX is its ability to efficiently support more symmetric links—useful for fixed applications, such as T1 replacement—and support for flexible and dynamic adjustment of the downlink-to-uplink data rate ratios. Typically, 3G systems have a fixed asymmetric data rate ratio between downlink and uplink. The WiMAX media access control layer is built from the ground up to support a variety of traffic mixes, including real-time and non-real-time constant bit rate and variable bit rate traffic, prioritized data, and best-effort data. However, 3G solutions, such as HSDPA and 1x EV-DO were also designed for a variety of QoS levels.

5.1.4 Evolution of Mobile WiMAX

Mobile WiMAX is based on IEEE 802.16e-2005 and will initially operate in the 2.3 GHz, 2.5 GHz, 3.3 GHz, and 3.4-3.8 GHz spectrum bands. Support for additional bands will be added on the basis of market demand and new spectrum allocations. All mobile WiMAX products will support handoffs and power-saving mechanisms. More advanced mobile functionality will gradually be added through support for high-speed handoffs, roaming and multiple antenna technologies, such as MIMO and beam-forming, and be available in equipment in the second half of 2008. The advanced performance of mobile WiMAX is largely tied to its use of Orthogonal Frequency Division Multiple Access (OFDMA), a multiplexing technique well suited to multipath environments that gives network operators higher throughput and capacity, great flexibility in managing spectrum resources, and improved indoor coverage.

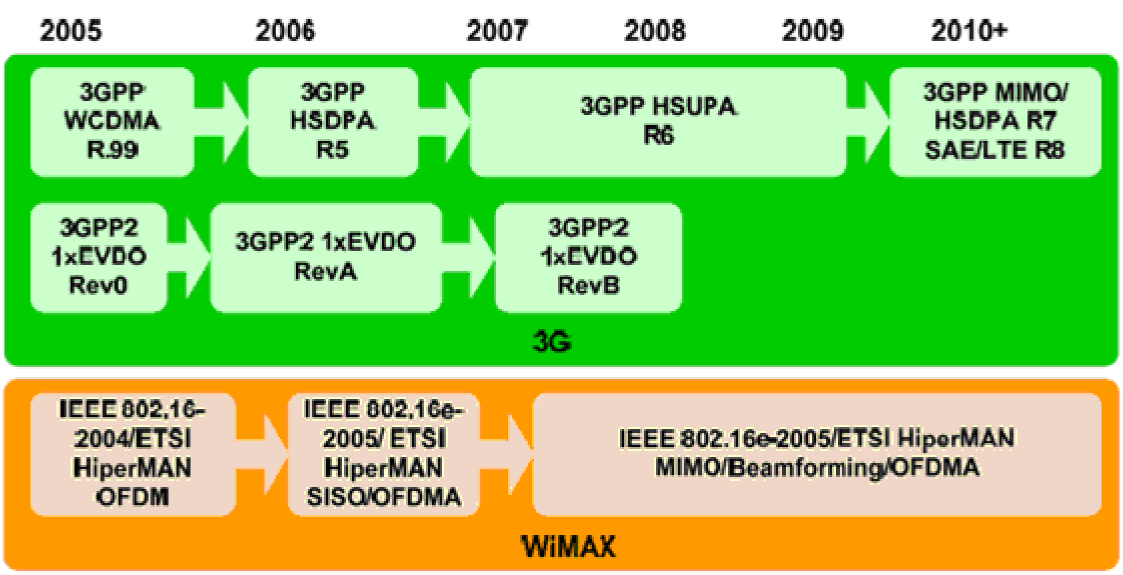


Figure 3: Evolution of 3G and WiMAX. Source: WiMAX Forum

5.1.5 Challenges and Trade-offs

Perhaps a key advantage for WiMAX and Wi-Fi (with IEEE 802.11n extensions) may be the potential for lower cost owing to its lightweight IP architecture. Using IP architecture simplifies the core network and reduces the capital and operating expenses. IP also puts WiMAX on a performance/price curve that is more in line with general-purpose processors, thereby providing greater capital and operational efficiencies. IP also allows for easier integration with third-party application developers and makes convergence with other networks and applications easier.

However, in terms of supporting roaming and high-speed vehicular mobility, WiMAX and WiFi capabilities continue to be unproven when compared to those of 3G. In 3G, mobility was an integral part of the design; WiMAX and WiFi were fundamentally designed for fixed systems, with mobility capabilities developed as an after-thought. Please refer to a detailed trade-off chart shown below.

Feature	3G/EV-DO Rev A	Wi-Fi Mesh	WiMAX
Cost	Moderate Monthly recurring expenses Low capital expenses	Expensive Costly infrastructure build-out (40 to 80 nodes per sq. mile) No recurring expenses	Expensive Less dense compared to Wi-Fi but more expensive units No recurring expenses
Coverage	Good to Excellent Location and ISP specific	Good 100% coverage possible with dense build-outs Potential interference	Good 100% coverage possible with dense build-outs Potential interference
Mobility	Excellent mobility support; evolution of cellular voice to data	Poor, since mobility is an afterthought; issues with hand-offs	Certified Mobile WiMAX products are still not available
Interoperability	Tied to a carrier (Verizon/Sprint)	Good for Wi-Fi standards (IEEE 802.11a/b/g); IEEE 802.11s for mesh is a work in progress	Good for static WiMAX but mobile WiMAX testing is still in progress
Bandwidth Scalability	Moderate to Low. Backbone network traffic related	Moderate to High; Hop count from nearest wired node	Moderate to High; Hop count from nearest wired node
Transmission rate	Practical upload rate of 400 Kbps	Practical upload rate of 1-2 Mbps	Practical upload rate of 1-2 Mbps with QoS
Security	128-bit AES encryption SHA-1 for authentication	NIST FIPS 140-2 compliant platforms are available (e.g., 3eTI)	128-bit AES encryption SHA-1 for authentication

TABLE 1: MOBILE BROADBAND TECHNOLOGIES – UNDERSTANDING THE TRADE-OFFS

5.2 Intelligent Video Surveillance Technology

Intelligent Video is an advanced solution that performs intelligent video analysis and fully automates video monitoring. It automatically tracks and identifies objects, analyzes motion and extracts video intelligence from analog or digital video streams. The system can output analysis and video data mining in real-time events or store them in a database. Companies in this market are focused on automating video analysis and security alerts, thus enabling real-time response while eliminating the need for manual labor and huge monitoring costs. It also increases productivity and efficiency of video surveillance systems and the people who monitor them. These solutions can be either deployed or customized to the meet specific customer security needs.

Traditional CCTV was the first generation of video surveillance. These CCTV systems utilized bundles of coax cable from every camera and connected them to a central security location. Monitors, controls and recording equipment were maintained in that central location. Cable schemes were proprietary and were used only for a single application. In addition, moving or installing additional cameras was very expensive and, in many cases, required entirely new cables. A lack of standards allowed either poorly designed or poorly installed networks, or both. The end-result was a sloppy video “architecture” that had poor quality and limited range. Volumes of data were produced, but very little was accomplished with respect to video information management and flexibility. Remote viewing capabilities were absent since the system could only scale to the central security office.

This was followed by the arrival of DVR. Though input and output remained analog, the DVR could store the data in a digital form. The monitoring system was digitized by using a PC and interfaced with the DVR through a modem interface.

IP-based video is the latest in this evolution. An IP surveillance environment is able to leverage a company's existing network and Internet technology to transmit images from analog cameras or IP cameras over public networks[2]. In this environment, everything goes digital. These systems allow live streaming video and still image transfer (both one-way and two-way) at an average of 30 frames per second into a standard, easy-to-use Web browser, so video can be viewed in real time from any remote viewing area, including police cars or homes. In conjunction with intelligent video applications, IP-based systems are leading a fundamental shift in video surveillance.

5.2.1 Centralized versus Edge Analytics Approach

There are three practical concerns with the deployment of video analytics in surveillance systems, namely-cost, scalability and bandwidth. Analytics requires ability to process video with software suites that require relatively expensive servers. As the number of cameras deployed runs into hundreds or even thousands for larger infrastructures, the size and processing capacity of these servers too have to scale manifold. In addition, it requires considerable bandwidth to transmit all of this video back to the servers, over wired or wireless transmission links. Over the past year, a number of camera manufacturers and video management software providers have therefore joined hands with a select few industry leaders in DSP to move analytics and processing to the edge of the network. The "edge" refers to the camera itself or even the digital encoder that is often co-located with an analog camera. By creating an "intelligent" edge, analytics offers new scalability and requires a fraction of the bandwidth to support and monitor complex deployments.

The trend of migrating analytics to the edge has been enabled by a rapid increase in digital processor speeds such that complicated software can now be run on some of these smaller camera and encoder systems, with only alerts or specific types of information (e.g., e-mail, images, SMS, video snaps, etc.) being sent back over the network. This transmission can happen either to a central fixed location or to a mobile first responder carrying a PDA or other portable device, where that information can be used in a variety of ways. Chip-makers like Texas Instruments and Cradle technologies have been very active in this area. Cradle Technologies has focused its multi-core digital signal processors exclusively on the surveillance market. Verint and Mango DSP are one of the early leaders in exploiting this trend to deliver more versatile and scalable video surveillance solutions. Axis, a leading IP camera manufacturer, too has recently entered the intelligent-camera and server market with a device equipped with the Texas Instruments chip that is pre-loaded with people counting software. The camera/server counts the people it detects and simply sends the number on a periodic basis back to the end user, drastically decreasing the bandwidth necessary to employ the function on a network.

[2] "The Security Killer App: Intelligent Video Surveillance," SGC 2007

5.2.2 Intelligent Video Commercial Offerings

Company	Description	Products	Comments
IntelliVision	Company founded in 2002 after the 9/11 incident. Products are deployed in Disneyworld, DHS/TSA, WMATA, Pentagon and other agencies.	Offers a suite of products ranging from Basic analytics to Advanced modules. These products are also integrated with video management systems from Genetec, Broadware.	IntelliVision has some innovative products for video stabilization, noise reduction and enhancement
Mango DSP	Privately held company that has been in operation for the last 10 years and has offices in USA and Israel. Provides an API framework for incorporating third-party analytics modules.	Offers ruggedized intelligent video servers called Raven that operate completely on the edge. ObjectVideo and IntelliVision analytics are licensed.	New product release also supports web-based analytic rule setting as well.
ObjectVideo	One of the largest software companies in the video analytics space. ObjectVideo grew out of DARPA in 1998. OEM partners include American Dynamics, Cisco, TI and Verint.	ObjectVideo currently focuses on embedding its analytical software on DSP chips within cameras, encoders, networking devices, etc.	Verint System and Mango DSP utilize ObjectVideo algorithms on their encoder/server appliances. VT Aepco utilized Mango DSP in its evaluation
iOmniScient	Founded in 2001, the company sells analytics software that works with several cameras and systems.	The company's IQ product specializes in algorithms to monitor crowded places for abandoned objects, theft and vandalism.	People counting, slip-and-fall detection and perimeter protection are also supported.
Verint Systems	Verint Systems sells products for monitoring both communications and video data.	Company focuses on end-to-end solutions that include video management software, cameras, encoders and analytics software that is either developed in-house or licensed from ObjectVideo	Verint's next-generation platform with analytics support is called Nextiva. Nextiva does analytical processing partially at the edge and partially on a centrally located appliance.

Table 2: Sample Intelligent Video Commercial Offerings

5.2.3 Benefits and Limitations of State-of-the-Art Systems

Benefits	Issues
Automate detection of objects left behind, suspicious behavior (loitering, etc.), access to restricted areas, monitor crowd patterns, monitor exit/entry lanes	Current solutions have limited processing capabilities with regard to supporting multiple analytic rules on the same video channel or camera. Processor load has to be carefully managed based on the scope of the application.
Leverage investment on existing cameras	Although substantially better than first-generation motion detection systems, current generation systems are still vulnerable to vibrations, shadows, snow, rain, etc. and require significant customization
Automate response to security events through instant alerts	Many of the solutions have limitations with regard to forensic search capabilities.
Improve safety and security by processing and analyzing significantly more data than humans possibly can due to information overload.	Web-based programmability of analytics rule configuration is limited for realizing a true "server-less" solution.
Improve operational efficiency and productivity	Advanced behavioral algorithms are in their infancy and are not commercially deployable.

Table 3: Intelligent Video Benefits and Limitations

5.3 Technology Selection

The following is a summary of the Final Design from all previous documents and analytical findings.

5.3.1 Vendor Selection Criteria

The choice of vendors and their respective product offerings was driven by the following requirements.

- Versatility and variety of advanced Intelligent Video modules as applicable to a transit scenario,
- Superior accuracy including low false alarm rates, high event detection rates, and third-party audit results/references provided by the vendor,
- Solid track record in Intelligent Video and Mobile Transport including a history of actual product deployments in the field for top-tier government agencies and commercial establishments,
- Length of experience of key personnel in mobile wireless, networking, video sensors and encoders,
- Reliability of proposed system with 24/7/365 continuous operation as observed in lab tests and customer references,
- Open, scalable, web-based architecture,
- Number of customers and OEM partners (especially third-party analytics vendors), and,
- Highest Value-Price ratio.

5.3.2 Selected Technology

SharpRAIL analyzed multiple feasible architectural options before finalizing on one design. The following table contains a description of each subsystem, vendor offerings selected along with the underlying technology/product strengths.

Subsystem	Vendor	Major Strengths
Intelligent Video	Mango DSP Rugged Server with embedded analytics	a. True "Serverless" Solution including Web-based Programmability b. Versatile and Open API Framework for interfacing with multiple analytic vendors, such as ObjectVideo and IntelliVision c. Attractive Value/Price Ratio d. Ease of Configuration and Upgrade path
Pre-WiMAX Mobile	Proxim pre-WiMAX offerings	a. Base station hand-offs at speeds up to 200 km/hr b. Certified Dynamic Frequency Selection c. Advanced QoS support d. Extended Range e. Mature Products with Wide Deployment in Government and Military
3G Mobile Wireless	Sprint EV-DO rev A cards with Junxion and AirLink wireless router/modem	a. Excellent Signal Strengths in Washington DC Area b. Optimal Upload and Download Throughput Rates for Real-time Streaming Video c. Superior Latency Results for Real-time Streaming Video d. Consistently Superior Performance in a variety of Static, Mobile and Highly Mobile Connectivity Scenarios
Video Management System	Mango DSP analytics console	a. Web-based Interface with Control over Network and System Configuration b. User-friendly Graphical Interface c. SDK support d. Implements Advanced Analytics from multiple partners (OV, IntelliVision, etc.) e. Easy to Deploy and Manage

Table 4: Major Subsystems of the SharpRAIL Architecture

A brief description of the major SharpRAIL product elements is given below. Please refer to **Appendix B** for details.

i) *pre-WiMAX Base Station and Client:* Tsunami MP.11 is Proxim Wireless' leading-edge point-to-multipoint pre-WiMAX product line. Advanced features include: WiMAX Quality of Service (QoS); roaming with seamless handoffs at speeds up to 200 km/hour; dynamic frequency selection (DFS), which has already received EN 301-893 v1.3.1 certification, and extended range. Available in outdoor and indoor models, the MP.11 series is capable of supporting converged voice, video and data transmission in fixed and mobile applications, bringing capabilities of the IEEE 802.16e (mobile WiMAX) standard to for license-free frequency bands in 2.4GHz and 5GHZ.

ii) Mobile EV-DO Router: Junxion EV-DO Router is a very popular platform that supports EV-DO Rev-A PC card modems from both Sprint and Verizon. The Junxion Box is ruggedized and has been tested for compliance with U.S. Military Standards (MIL-STD-810F) to simulate exposure to vibration, temperature and humidity. A licensed third-party laboratory performed these tests for Junxion. Key features supported include GRE tunneling, NAT traversal for IPSec termination, Dead Peer Detection (DPD) for IKE peer failover, enhanced boot time performance, and support for IEEE 802.11g on the latest models.

iii) Edge Analytic Appliance: Raven-M is a compact, 2 channel, and intelligent video server employing H.264 or MPEG-4 video compression and advanced video analytics from the leading vendors. As a standalone leading Edge Solution or part of a multi-blade rack mounted 19 inch 3U system, the Raven-M transforms standard analog video surveillance cameras into proactive sentinels that deliver reliable high performance video streaming and content analysis. This video server is equipped with PTZ control, TTL inputs and relay outputs, has an optional onboard storage Flash disk and WiFi module, and is available in two build configurations, industrial or commercial grade. In conjunction with Mango IVS framework, Raven supports seamless integration of third party video analytic software creating a truly intelligent edge device.

iv) IP Video Transmitters and Receivers: The IndigoVision transmitter/receiver supports one camera or one monitor. This next generation MPEG-4/H.264 technology offers analog levels of quality at a choice of resolutions for the most demanding applications, such as surveillance, identification and high speed movement. Standalone transmitters introduce high quality and high compression MPEG-4 or H.264 video and audio to CCTV applications. IndigoVision transmitters guarantee 25/30 frames per second at any resolution or bit rate including QCIF, CIF and 4CIF resolutions. They also support built-in firewalls for additional security.

v) Analytics Integration Framework: Mango IVS software allows full command and control of video parameters, such as resolution, bit rate, frame rate and the video analytics embedded into the server. Leading content analysis providers, such as ObjectVideo and IntelliVision have chosen to integrate their content analysis libraries with Mango IVS. This combination enables video security devices to analyze video streams and apply a large set of user definable rules. Among these rules are: motion detection, people/vehicles counting, loitering, congestion, video stabilization, slip-and-fall and video stitching.

6 Prototype Design, Development, and Implementation

6.1 Overview

In order to ensure a successful research outcome, the SharpRAIL team developed an actual proof-of-concept demonstration for testing the usability and efficacy of each of the technology elements chosen in Section 5.3.2 in a realistic operational setting on VRE's Train 305. The demonstration utilized both 3G/EV-DO and pre-WiMAX technologies to establish video connectivity from the moving train to the VRE station and the remote command center simulated at VT Aepco's headquarters in Gaithersburg, Maryland. It also included Mango DSP's rugged server with embedded video analytics and management console.

6.2 Prototype Design and Installation

The SharpRAIL team installed a Proxim WiMAX (MP.11) base station along with an omnidirectional antenna on the locomotive of VRE's Train 305. A Proxim WiMAX subscriber station was installed on the Sky Bridge at the Franconia-Springfield, Virginia station. This site was chosen because of the Line of Sight (LoS) between the base and subscriber devices as the train approached the station. Two fixed cameras were installed – one inside the locomotive looking out towards the rail tracks and another inside a passenger car to monitor the inside of the train. EV-DO broadband services by Sprint provided the connection between onboard video inside the passenger car to the remote command center through high-speed cellular technology. A backup EV-DO modem (AirLink) was used to provide Wi-Fi based internet access during the train journey. 3G/EV-DO has the advantage of non-Line of Sight capabilities and high-speed mobility which makes it ideal for a rail transit mobile application. 3G/EV-DO does not require Wi-Fi repeater nodes and allows for the flexibility of travel routes with a high throughput data connection. The high-speed variant of EV-DO, namely the Rev A version, was utilized to study the performance of 3G/EV-DO for broadband connectivity.

Figure 4, below, depicts the overall SharpRAIL architecture. It shows how the SharpRAIL project was built upon an earlier project with the City of Rockville, Maryland, as seen in the lower left portion of the diagram. The Rockville City project consisted of a partnership with the city's Information Technology and police departments to provide video surveillance with analytics and management control capabilities.

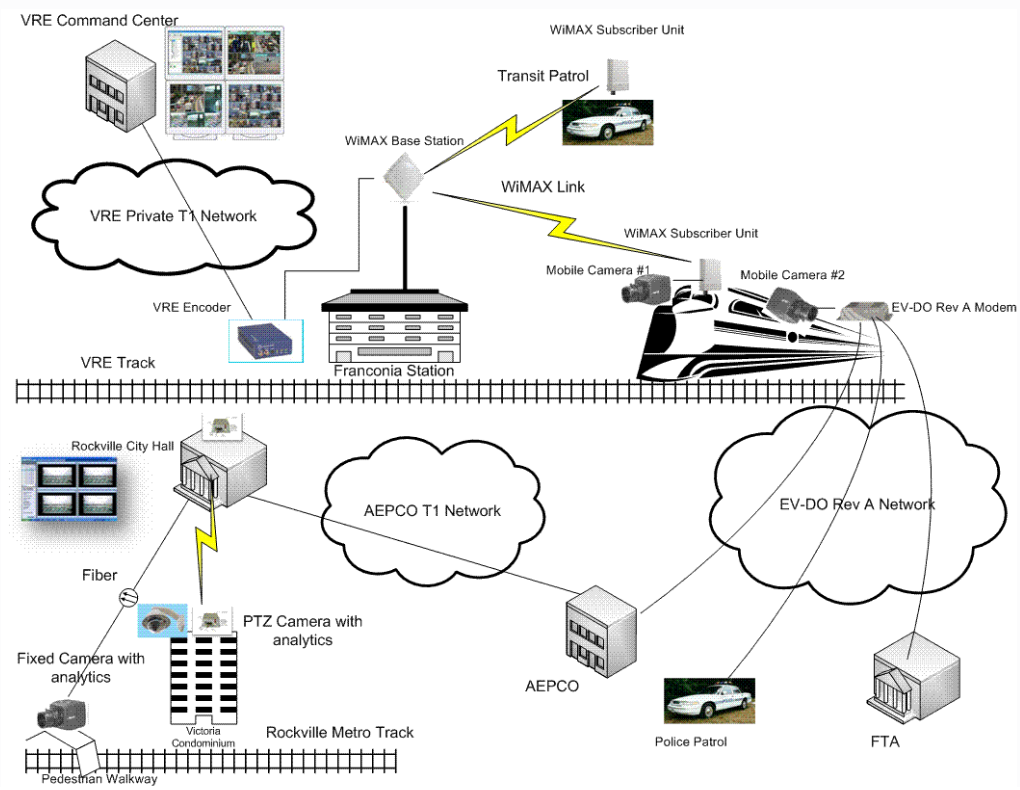


Figure 4: Final SharpRAIL Architecture

Figures 5 and 6, shows the camera and antenna installation on the locomotive, and broadband cellular router and camera installed in a passenger car, respectively.

Figure 5: Camera and Antenna – Locomotive

Figure 6: EV-DO Router and Camera – Passenger Car

Figure 7 shows a Proxim pre-WiMAX subscriber station and omnidirectional antenna attached to the sky bridge support at VRE's Franconia-Springfield, Virginia station. The central command center was established at VT Aepco's Gaithersburg, Maryland office. The SharpRAIL train linked to the command center over an EV-DO Rev A (Sprint) backhaul. (More installation pictures can be found in **Appendix C**).

Figure 7: SharpRAIL – Antenna and WAP - VRE's Franconia-Springfield, VA Station

Integration Summary

Item	Equipment Location	Wireless System	Public Access	Note
Public WiFi Internet	Quiet Car of Train 305	Designated Sprint EV-DO Rev-A	WPA Encrypted Internet through WiFi in 802.11 b/g	Maximum bandwidth of 1.2 Mbps for download and 400 kbps for upload
Camera for Quiet Car	Quiet Car of Train 305	Designated Sprint EV-DO Rev-A	Restricted	15 fps for Recording Video and 1 fps for Live Video all through EV-DO Rev-A
Camera for Locomotive V02	1. Locomotive V02 (Camera, Indigo Encoder and Pre-WiMAX Base Station AP) 2. VRE Franconia-Springfield Station (Pre-WiMAX Client AP)	Pre-WiMAX at 5.825 GHz	Restricted	Pre-WiMAX Tuned 802.11a 5.745 GHz for base station and subscriber AP

7 System Testing and Results

This section presents some key results from the SharpRAIL prototype evaluation on an actual mobile rail car traveling on VRE's Fredericksburg Line in MD-DC-VA Metro Area. The command center was located within VT Aepco's office.

7.1 Success Metrics

Broadly speaking, the success of the SharpRAIL research effort was assessed based on the following criteria:

- Demonstration of high probability of detection of anomalous events along commuter lines with commensurate low false alarm rates, characterized by i) the variety of relevant safety scenarios that can be effectively detected, such as passengers dropping things on rail tracks, large obstructions on tracks, such as broken cars, passengers getting up on their seats, illegal trespassing and the ii) robustness of the detection algorithms to environmental changes, while the train is moving, leading to changes in lighting, vibrations, etc.,
- Demonstration of improved performance for lower cost when compared to the status quo by using commercial off-the-shelf equipments and software; the cost comparison will be performed using standard financial metrics, such as Capital Expenses, Operational Expenses and Net Present Value (NPV) analyses, and
- Quantifiable reduction in operator workload in terms of faster response to incidents and better management of physical resources; The demonstrator should clearly show the potential for SharpRAIL to monitor and record all camera outputs, and wirelessly alert relevant personnel only when pre-specified events occur. The system should provide timely notification of safety incidents, demonstrate a robust archival, retrieval facility for post-incident analysis and deliver accurately marked-up alarm videos.

7.2 EV-DO Testing

As the backbone of SharpRAIL's data transmission, EV-DO broadband services provided the connection between onboard video and the command center through cellular technology. Due to its advantage of non-Line of Sight and high speed mobility, our tests included multiple locations based on different environments to evaluate the performance of EV-DO from both Sprint and Verizon.

All tests were conducted in real world environments within the region of the greater Washington, D.C. area which has the potential for significant Radio Frequency Interference (RFI). The following are some of the causes of RFI that could affect the throghput rate of EV-DO during our testing:

- Service Quality (Ratio of base stations to subscribers),
- Traveling Speed,
- Signal Strength,
- Conlicting Spectrum (EMT, Police, Fireman),
- Environemtal Effect, and
- Regional Base Station Specifications.

7.2.1 EV-DO Test Plan

Testing Procedures: In most tests that involve radio transmissions, it is ideal to evaluate its performance in locations that are as free as possible from interference. However, the SharpRAIL project was based on real world scenarios where Radio Frequency interference was present. Therefore, since tests were conducted in an uncontrolled environment, out in the real world, the results cannot be considered scientifically repeatable.

Test Environments: All four environments are within the region of greater Washington, D.C. area. The tests were designed to evaluate various aspects of a wireless Internet connection to ensure the connectivity of video through wireless. The testers performed a series of tests in several physical locations, specifically:

- Urban City Environment.
  - (Inside an office building or conference center, or a location surrounded by buildings).
- Transit Environment.
  - (On moving transit, such as in a moving car, bus, train, or ferry).
- Residential Environment.
  - (At home or indoors).
- Remote Environment.
  - (On moving transit, such as in a moving car, bus, train, or ferry).

Tests were performed in these locations to obtain a fuller picture of the quality of service under various normal conditions in which people might use the Sprint EV-DO Rev A and Verizon EV-DO Rev 0 services. When possible, testers repeated tests in the same locations at different times of the day, to determine whether peak usage affected the quality of their connection. Our final data reading reflects the average results for each test, based on all the results submitted by the testers.

Performance Testing: The following sections describe in detail each test covered. Each of the three tests below was performed at each location listed above.

1. **Ping Test**
   A ping test is a standard network diagnostic that determines the latency, in milliseconds, that elapses between when a single packet of data leaves the originating PC and when the originating PC receives an echo (response) back. We used the Windows command prompt to ping a public website, such as www.yahoo.com with 32 bytes of packet.

2. **File Uploads/Downloads Test**
   Testers used Toast.net Web page (http://performance.toast.net) and ran the download speed test on two different web hosts. The file size was near 755K bytes for all downloads and

uploads. Testers averaged out the download speed rates as throughput in units of kilo bits per second (kbps).

3. **Streaming Video Test**
Testers launched Windows Media Player and watched streamed video for up to a minute. They recorded details about video quality problems, such as static, skips, lost packets, lost video frames, a jagged image, or repeated or extended buffering. Once the video quality was determined as stable, testers ran video analytics through EV-DO and reviewed the video from the command center's SharpRAIL Review GUI.

*Test Data Collection***:** Once all EV-DO tests were completed, the average data was recorded. See Section 7.3.2, EV-DO Test Results. (Note: due to Verizon's incomplete Rev-A coverage, tests were performed on their Rev-0 network and compared to Sprint's Rev-A network which provided better coverage in our test environment.)

7.2.2 EV-DO Test Results

Verizon EV-DO Rev 0

Location	Signal Strength (estimated from signal bar)	Traveling Speed	Throughput	Live Video Tx/Rx Quality (optimal fps rate)
Urban	96% Full Signal	0 mph	150 kbps download 55 kbps upload	2 fps
Transit	80% Full Signal	80 mph	110 kbps download 35 kbps upload	5 fps
Residential	60% Full Signal	5 mph	120 kbps download 40 kbps upload	2 fps
Rural	40% Full Signal	70 mph	100 kbps download 25 kbps upload	1 fps

Sprint EV-DO Rev A

Location	Signal Strength (estimated from signal bar)	Traveling Speed	Throughput	Live Video Tx/Rx Quality (optimal fps rate)
Urban	98% Full Signal	0 mph	1.4 Mbps download 250 kbps upload	15 fps
Transit	90% Full Signal	90 mph	0.8 Mbps download 150 kbps upload	10 fps
Residential	80% Full Signal	8 mph	1.1 Mbps download 180 kbps upload	5 fps
Rural	50% Full Signal	75 mph	0.5 Mbps download 120 kbps upload	2 fps

Video Over EV-DO Rev-A

Video over EV-DO Rev-A demonstrates its advantages in mobility, velocity and non-Line of Sight (LOS) capability. LOS plays an important role in the railroad application due to lack of bridging hubs throughout the track. Depending on the specific locations and area of the tracks, VRE train has a maximum velocity of 79 MPH. Hence, EV-DO Rev A fully serves the need of remote video streaming of SharpRAIL.

For optimal user efficiency, all video viewing application and analytics alerts are achieved through remote clients. Once a notebook or PC is connected to the secured private network of SharpRAIL's EV-DO Rev-A network, remote clients will provide high resolution 640X480 live streaming video in Mpeg4 format through popular applications, such as Quick Time. The user can open up the URL of Video Analytics Encoder in an RSTP format to view live streaming video with an additional video analytics overlay. Video can also be recorded on the same application for future reference.

Video Over 5.745 GHz Pre-WiMAX

Regarding Proxim Pre-WiMAX, the SharpRAIL team was able to obtain RF and Ping connection between Franconia-Springfield Station and Train 305 after antenna adjustment. However, the total period of Train 305's at Franconia-Springfield Station is limited to 23 seconds; it was too short that video was not able to show up due to time for video processing and route through T3 of VRE. In conclusion, video is not suitable for mobile WiFi based technology, which will require line of sight and stability in packet transmission.

Public WiFi over EV-DO Rev-A

Our goal was to provide WiFi access points to be tested as a demo in conjunction with the cameras on the trains. We did not provide WiFi Internet access or the use of wireless Internet to everyone since we secured the connection with WPA encryption for Internet on the trains. WiFi signal strength from the router from the farthest seat on train 427 was observed to be 50%.

Following are the average EV-DO Rev-A WiFi signal quality throughout train 305 of VRE Fredericksburg Line between Fredericksburg, VA and Union Station DC:

Location	Quality of Service
Fredericksburg	65%
Between Brooke and Quantico	20%
From past Rippon to Woodbridge	10%
Lorton to Union Station	80%
Leeland Road until past Brooke	35%
From Quantico to until past Rippon	5%
Woodbridge to Lorton	20%

Security over Wireless

Regarding Public WiFi and Camera, there is no physical interconnection between them for security reasons. Each system is running under its own backhaul system, i.e., public WiFi is running on its own EV-DO Rev-A WAN, while the fixed camera in the quiet car is running through a separate EV-DO Rev-A, with access restricted to a pre-designated PC. Finally, the camera in the locomotive was connected through secure pre-WiMAX between the Locomotive V02 and the Franconia-Springfield station, and the only way to access is through the VRE network. All these systems are running independently such that no one will be able to access one system from the other, because it is designed to be hardware specific.

7.3 Video Analytics Testing

7.3.1 Video Analytics Test Plan

The goal of SharpRAIL is to apply video analytics technology to track unauthorized incidents in a transit scenario. Cameras with analytics encoders provide video analytics “on-the edge”, so the software will analyzes video surveillance at the point of capture, providing higher accuracy and fewer false positives. SharpRAIL edge devices eliminate the need to transmit all captured video to centralized servers for analysis, dramatically reducing servers required and optimizing network use.

Testers will focus on detecting incidents, such as obstructions on a rail track leading to potential collisions, loitering and trespassing in protected zones near critical transit assets, suspicious objects being dropped on railway tracks, etc. Once the incident is detected, an alert will be sent through text message or e-mail to the authorize personnel to complete the procedures. The evaluation will be based on the efficiency of these incidents and the analytics' success rate.

Video Analytics Site Survey Procedure: The first step prior to a detailed evaluation of video analytics implementation is a site survey to minimize the chances of poor design and installation of video sensors impacting optimal machine vision performance. The testers will survey the installation location to select ideal equipment locations, the ability for each location, planned camera angles and elevation to provide the intended video coverage, the presence of outside interference, such as weather conditions, lighting, camera vibrations and any other issues that could impact performance. The site survey considered the following factors:

- *Anticipated safety scenarios and detection rules for the customer including alert notification rules; it is important to determine which customer classes should be alerted for a detected analytic event.*

- *Detailed site map at the prospective locations, such as manmade/natural obstructions, seasonality of scenario changes, distance from area of interest and adequacy of coverage.*

- *Camera characteristics especially field of view, light sensitivity, resolution, frame rate, make.*

- *Camera environment including rapid lighting changes as the train is moving, activity levels, path of the sun, climate changes (rain, hail, snow, wind, hurricanes, etc.), flora (trees, bushes, tall grass) and fauna (birds, animals).*

After the survey is completed, a list of locations to be used is compiled and mapped. Plots showing the resulting proposed coverage are prepared. **A detailed site survey template is shown in Appendix A.**

Video Analytics Testing Procedures: SharpRAIL Intelligent Video Analytics Solutions is ideal for vast amounts of security video and data, automatically pinpointing potential breaches and significant events quickly and without the need for constant monitoring. These automatic alerts transform threat detection from a manual, resource-intensive operation to an efficient, accurate, and automated process. The video surveillance solution lets security staff focus on deterring and managing threats, rather than watching banks of monitors trying to detect events of importance.

Following four scenarios will be staged to determine the efficiency and success rate of video analytics, in order to increase passenger safety during transit:

Object Left Behind
An event in which a suspicious object is left behind anywhere within the camera's field of view for a certain time or more. This analytics will be applied to prevent after hour incidents, such as any unknown object that is being left on a track or within the train. The snapshot is marked with the Inside message to indicate that something has been left inside the camera's field of view:

Figure 8: Object Detection from Full View Camera

Figure 9: Object Detection from Partial View Camera

- After Hour Object Left Behind.
    - An event in which an object is left behind anywhere within the camera's field of view. Tester will apply the analytics by intentionally dropping an object within the moving train, and checking whether video analytics can detect the object left behind within a policy violation duration of one minute. Once the rule is violated, the video analytics will capture the object left behind and an alert will be sent to notify the authorized personnel.

Loitering Detection

Video analytics will capture an event in which an object remains within an area of interest for a user-specified period of time. Testers will simulate suspicious movement around transit assets to detect suspicious incidents. The blue polygon represents the area of interest and the snapshot is marked with the Loitering message:

- Passenger Loitering within a Train or on a Platform.
    - Tester will simulate passengers standing up within the train or moving around suspiciously, rather than being seated, while the rail car itself is moving. Testers will create an event in which the suspicious passenger remains within

an area of interest for a specified period of time of 20 seconds. Once the rule is violated, the video analytics will capture the moving incident, and an alert will be sent to notify the authorized personnel.

Figure 10: Loitering Detection from Full View Camera

Movement Detection: It is an event in which an object crosses two lines (tripwires) drawn within the camera's field of view within a user-specified period of time. The tripwires appear as red lines. The blue arrows are the direction the object is moving. The yellow arrows are the direction an object has to move for an event to be detected:

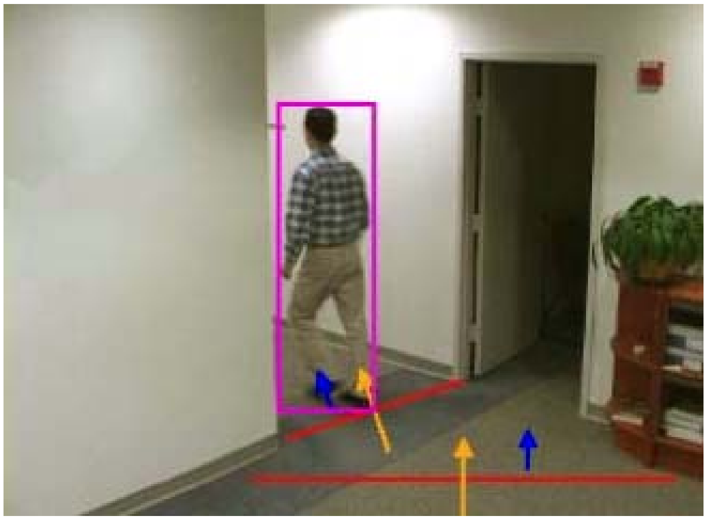


Figure 11: Double Trip Wire Detection from Partial View Camera

Figure 12: Single Trip Wire Detection from Partial View Camera

- Passenger Moving within the Train.
    - o Tester will simulate passengers walking or running movement as they are supposed to be seated while train itself is moving. Testers will create an event in which when a suspicious passenger crosses one or two lines (tripwires) drawn within the camera's field of view within a user-specified period of time of three seconds. Once the rule is violated, the video analytics will capture the moving incident, and an alert will be sent to notify the authorized personnel.

7.4 Sample SharpRAIL Pilot Screenshots

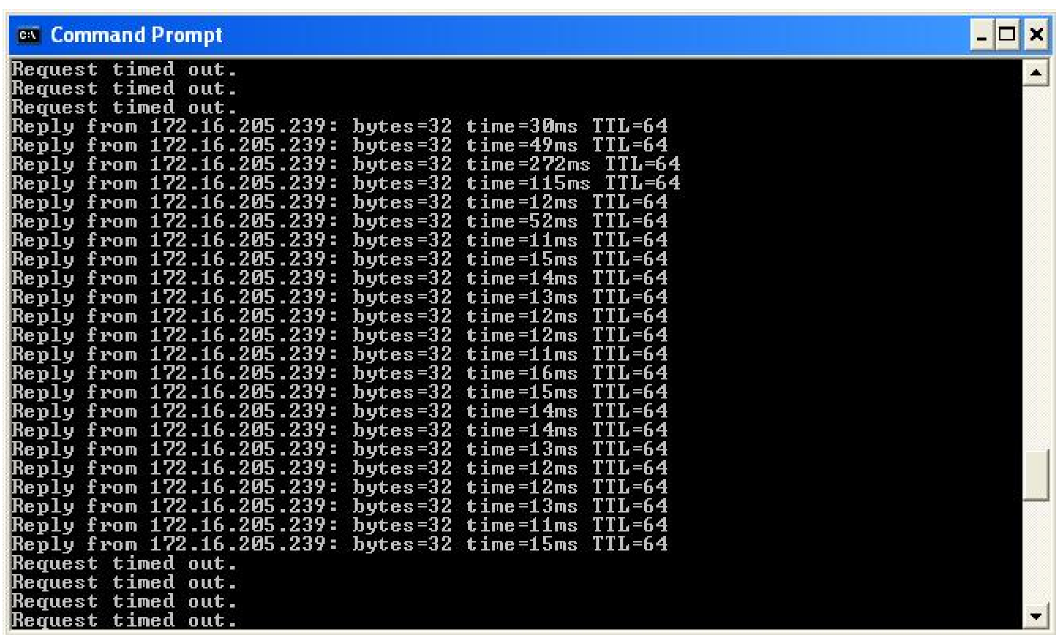


Figure 13: Pre-WiMAX connectivity from Train 305 to Franconia-Springfield Station

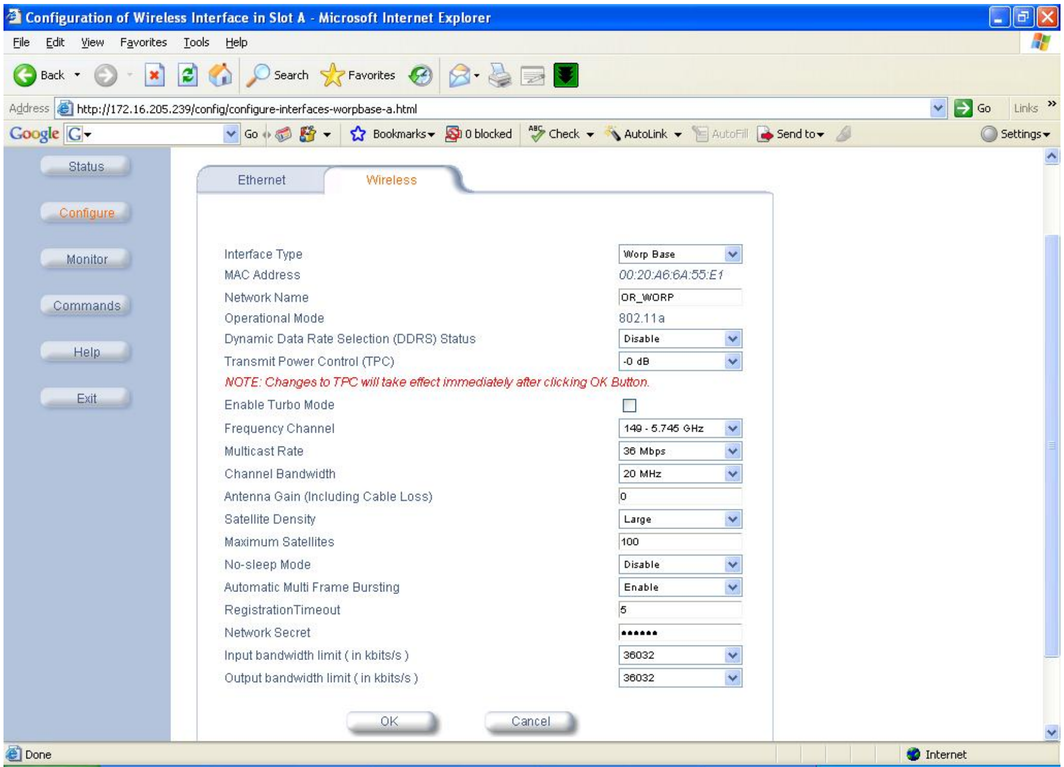


Figure 14: Proxim Pre-WiMAX Radio Configuration Screen

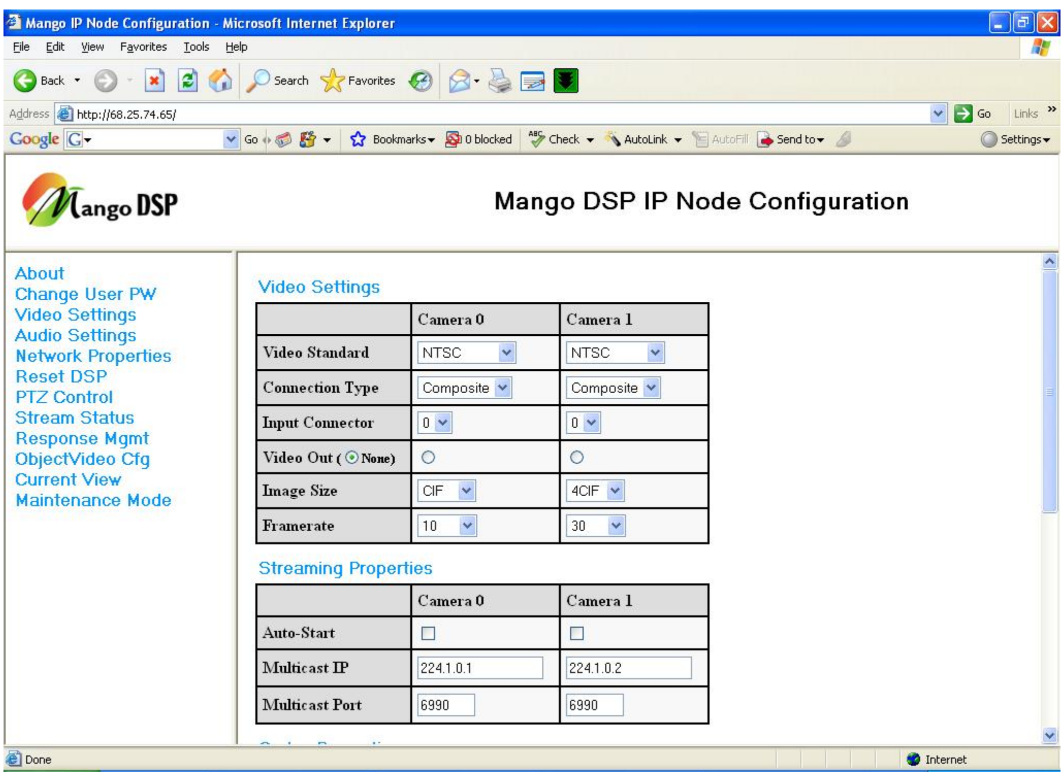


Figure 15: Mango DSP Video Analytics Configuration

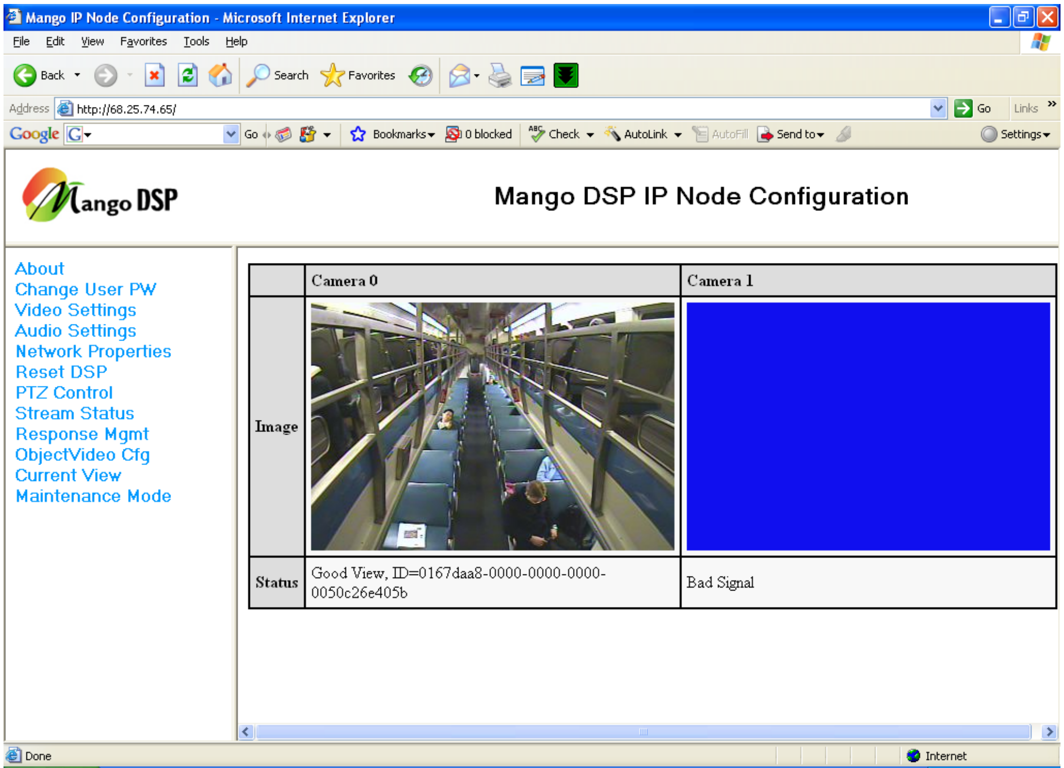


Figure 16: Live Video Interface Capture on VRE Train 305

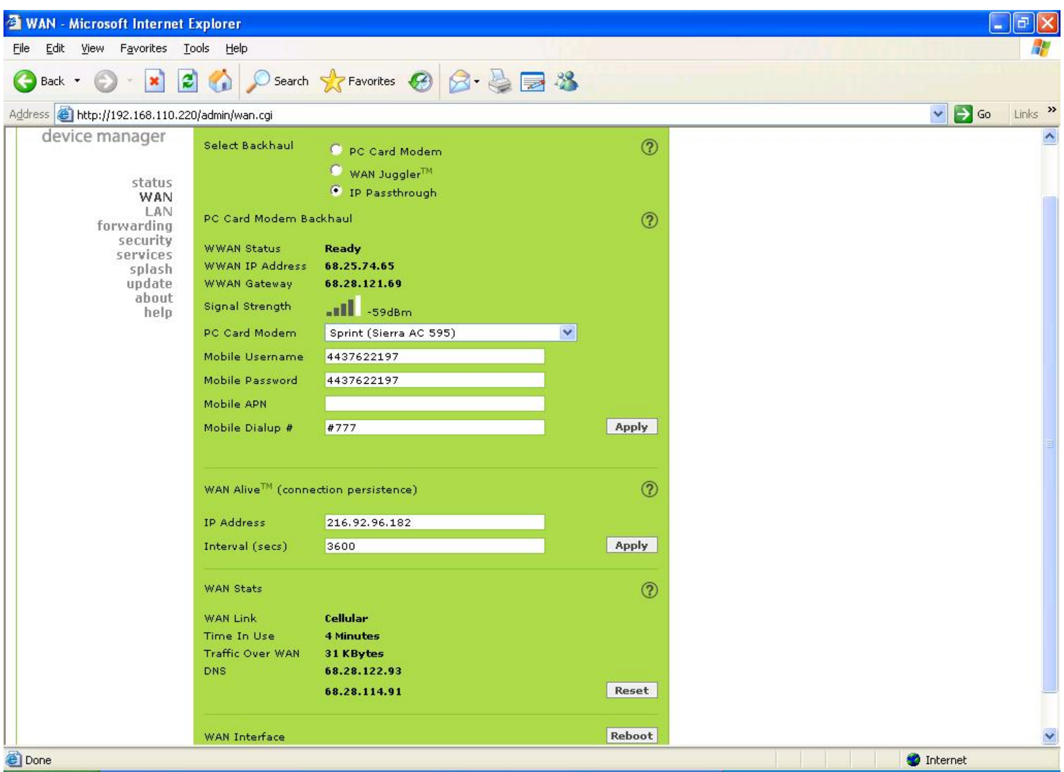


Figure 17: WAN interface of EV-DO Router for SharpRAIL

8 Conclusions and Lessons Learned

8.1 Summary

Some key results arising from this study are the following:

- The findings from this analysis indicate that the benefits from use of the SharpRAIL system are likely to outweigh the costs, even when taking into consideration the potential difficulties of retrofitting older trains.
- SharpRAIL can bring an integrated process to the capture, processing, and real-time management of incident data needed to enhance ride safety and streamline operations through networked video recording at a central operations center or a police dispatch location.
    - VT Aepco's live prototype study shows less than 5% error rate as measured by False Alarms and False Rejections. The error rate can be reduced further with customized analytics rules and through improvement of camera stability.
    - **A core technology enabler for this functionality is the availability of 3G/EV-DO Rev-A technology from major carriers like Sprint and Verizon.**
- Implementation of enhanced "analytic" solutions (capable of sending real-time alerts to response staff when a pre-defined bad incident occurs including short video) would be more cost-effective than basic video recording, since they are more likely to benefit in accident prevention and investigation costs.
    - **Advances in digital processing chipsets that enable extraction of this analytic intelligence right on the scene allows a cost-effective video transport solution.**
- A requirement to carry a SharpRAIL "edge" system on moving trains, while imposing an economic burden, would not be prohibitive, especially since a significant part of the cost can be offset against operational and administrative benefits. Even assuming a very modest productivity benefit, the cost burden would not be heavy for the more modern trains.
- While the immediate safety benefits may not be readily apparent, the SharpRAIL system will enable transit operators to capture valuable real-time data, allow proactive interventions before problems become serious, and will enable more effective incident investigation.
- SharpRAIL may also directly prevent security incidents happening within the passenger cars of a train. The system also has forensic tools to analyze recorded video when accidents or incidents occur, and performance trend data can be used to prevent future difficulties.

8.2 Cost Benefit Analysis

Normally decisions concerning new equipment or subsystems, such as the installation of the SharpRAIL sub-systems, involve the analysis of benefits and costs, some with quantifiable monetary values and some without. Ideally, decisions to proceed with implementation will be made only in those cases where quantifiable benefits outweigh projected costs, unless other considerations, such as public safety are predominant. For decisions with public safety implications, such as for SharpRAIL, it is extremely difficult to make a simple monetary analysis. Lack of exact data related to operations and maintenance costs, expected productivity and efficiency improvements, and quantification of potential benefits has also been an impediment to conclusive cost/benefit analysis. However, data from actual experience was used when available. In the course of preparing this report, the SharpRAIL team also spoke with a number of equipment suppliers (including strategic partners), rail transportation staff, public safety officers and local government staff to gather realistic data.

8.2.1 Relevant Costs

As with most acquisitions involving new technologies, costs can be organized into various project life cycle stages, such as Design/Specification Costs, Equipment Purchase, Installation, Operations and Maintenance. Each one of these is briefly discussed in the following paragraphs.

Design/Specification Costs: In the case of SharpRAIL, the first step is to decide which trains or routes are to have the new technology and how the installation will be implemented. If the system is to be part of a new procurement or part of a planned overhaul, this will reduce installation costs. Some usual questions that come up in the process could be the type of fleets to be retro-fitted, the system specifications, desired interface specifications, etc. The solutions could be different for different classes of trains in a fleet, depending on the extent of modifications that may have been made over the years. Once basic decisions have been made, technical specifications must be written. The procurement process follows specification development, resulting in bids for the hardware and related logistics support. Part of the effort will be to specify an appropriate maintenance concept since it will be a significant cost driver.

Equipment Costs: The SharpRAIL system offers many custom, value-added features, such as enterprise storage back-up, forensic analysis component, and support for additional viewing stations that allows more sophisticated management of incident information than the minimum requirements for enhanced ride safety and security. It is likely that many, if not most, buyers will opt for more than the specified minimum capability. The basic equipment costs associated with implementing the solution also depend upon various factors, such as the technology used to capture data and the number and types of video and other signals to be recorded. Sensor and wiring (both power and signal cabling) requirements will influence equipment costs.

Installation Costs: A key cost issue involves the installation of cameras, mobile recorders, wireless routers and sensors for retrofit installations. An installation in older trains, in which the design and construction includes no provisions for the physical installation of the video and wireless equipment, or displays, and where the installation of cables may be difficult is going to be more complex and costly. A large burden of labor and technical difficulty is associated with installing and routing new cables. However an installation in more recently built models or even those currently undergoing design and construction will be easier and involve lower installation costs.

Ongoing Costs: When a transportation department initially installs a real-time event monitoring and recording system on a train, it must also decide if the train will be allowed to remain in service without a fully functional SharpRAIL system. If so, the system will be added to the minimum required equipment list and very high system reliability and MTBF will be important attributes. If the equipment is not highly reliable, failures could serve to keep these rail cars out of service. Also, it is important that the accessory elements, such as wiring installed specifically to support local data transmission not be the source of failures not experienced otherwise. A new system inspection function will also need to be integrated into existing routines. Most agencies also have regular maintenance cycles for transit equipment that adds some labor. A typical inspection cycle may be three months, using a more extensive test procedure than an internal power-up self-test, but would ideally not take more than two hours. If repairs are necessary, the SharpRAIL sub-systems can be removed from the train relatively quickly and shipped to the manufacturer for factory repairs, in order to minimize tampering. This would offer the potential for manufacturers to provide reliability warranties, agreeing to provide all repairs at a firm fixed price for a defined period.

8.2.2 Assessment of Benefits

The primary benefits associated with the use of the SharpRAIL system include: i) investigation savings through better analysis of safety incidents, ii) reduction of operations and administrative costs for transit agencies, iii) improved productivity and revenue generation, iv) savings through a potential avoidance of serious incidents, such as litigation expenses, damage claims, post-incident administrative expenses, etc., and v) savings through a potential avoidance of serious accidents due to driver and staff distraction. While these benefits will be greatest for the enhanced "analytics" capable SharpRAIL system, even a basic SharpRAIL system with remote video pull-up facility will prove to be valuable.

*Enhanced Transit Safety for Passengers***:** SharpRAIL improves rail transit safety by proactively detecting potential safety incidents and alerting rail operators, station supervisors, transit police and local law enforcement. The system can automatically detect and warn against "unsafe" events that include trespassing, illegal crossing, track obstructions, collisions, etc. The system is designed to have negligible false alarm rates irrespective of snow, fog, reflections, wind, low light conditions.

Control Capital and Operational Costs of Transit Agencies: SharpRAIL is based on open technology standards, such as IEEE 802.11a/b/g (Wi-Fi), IEEE 802.16d/e (WiMAX), MJPEG for ease of inter-operability and reduced costs. SharpRAIL utilizes wireless technologies to significantly reduce the cost of cable installation and ongoing maintenance expenses. There is added flexibility in implementing network moves and changes.

Improve Productivity of Transit Officials and First Responders: SharpRAIL improves personnel efficiency by reducing operator errors and increasing on-scene coordination capabilities with station supervisors and first responders connecting wirelessly from a remote location. Also, the use of Machine Vision Intelligence technologies can provide a force-multiplier effect for efficient personnel deployment by supplementing existing labor-intensive systems with automated functions/features/systems.

Administrative Benefits of Live Tracking: Current transit systems are, to a large degree, complaint driven systems. Much of this time is consumed with tracking down the most accurate information they can find from drivers if an untoward incident happens. With accurate live video and on-board recording, many of the routine issues can be dealt with quickly. In addition, real-time information can be delivered via the Internet to further reduce staff time and saving administrative costs.

Revenue Generation: SharpRAIL on Mass Transit can serve as a potential source of revenue for the transit agencies. Rail occupants can be offered a mobile hotspot connection as a value added service. Even a 2% increase in commuter ridership as a result of this can serve as a significant revenue source. The system also has potential in capturing lost revenue through fare evasion in stations, damage claims for transit falling accidents, etc. Also, the estimated total of industry claims settlement cost for pedestrian falling accidents in stations is about $1.7 million annually.

Savings through Accident Avoidance: It is intuitive that a universal application of the SharpRAIL real-time alert system is likely to lead to a reduction of accidents. However, there are no reliable estimates that would quantify how much reduction in accident probability could be achieved. As per a U.S. Department of Transportation study, a human life equates to $2.7-3 million in its analyses of safety issues. While a potential dollar benefit could conceivably be developed for avoiding a hypothetical accident, no attempt has been made to do so in this analysis due to the inability to estimate how much the probability of accident occurrence would be reduced through the use of the SharpRAIL system.

8.3 Lessons Learned

This section tabulates some of the major technology gaps and operational challenges identified during the SharpRAIL project.

Issue	Area	Lesson learned
Structural vibrations in a moving train lead to occasional poor video quality	Technology	Use of special stabilization devices or software modules to neutralize video shake is necessary for stable video analytic input
Unlike fixed scenarios, the ambient scene in a moving train is continuously changing.	Technology	This leads to frequent lighting changes, shadows, etc. Salience filters and video noise reduction techniques to be used. Depending on camera locations, filter parameters like "object size", "minimum size", etc. are customized. Video Analytics for security applications within a moving train can be achieved in more controlled scenarios.
Train stopping time at Franconia-Springfield Station was not sufficient to test WiMAX video performance	Technology	Line-of-Sight is a critical issue for WiMAX compared to 3G/cellular option. Additional WiMAX repeater nodes along the wayside would have mitigated this effect to some extent. Drawback-Expensive.
Intermittent EV-DO wireless service in Washington, DC area	Operational	EV-DO being a third party wireless service is difficult to control. Geographic coverage is highly vendor dependent. VT Aepco recommends thorough upfront testing prior to service procurement using 30/60 day evaluation cards.
Limited wireless upload bandwidth to transport live train video to dispatch	Technology	VT Aepco recommends "analytics on the edge" with MPEG-4 compression to minimize bandwidth demands on wireless VT Aepco recommends EV-DO Rev-A (*not rev 1.0*), which shows an almost 6x increase in average upload rate
End-to-End security and privacy issues	Technology/ Operational	EV-DO Rev-A utilizes 128 byte AES encryption for confidentiality. FIPS-compliant Layer 3 VPN solutions are also available, if desired WiMAX also supports advanced AES security features compared to traditional Wi-Fi protocols. Intelligent Video limits intrusion by ensuring that operator intervention happens only in the event of an analytic alert

Issue	Area	Lesson learned
EV-DO service limits maximum download capacity per month. Dynamic IP addressing makes it harder to control mobile devices.	Operations	VT Aepco had to establish teaming relationships with Verizon and Sprint prior to evaluating their offerings and to overcome service constraints on the pilot

Table 5: Key Challenges and Lessons Learned from SharpRAIL Project

8.4 Accomplishments

The following Table lists key accomplishments of the SharpRAIL project.

Project Phase and Deliverables	Tasks and Achievements
Requirements Gathering - The objective of this phase is to clearly understand the problem domain through extensive secondary research, talking with stakeholders to finalize the functional and logistical requirements of the SharpRAIL project. **Key Deliverables:** **a.** Kick-off Meeting with FTA Program Manager and Team. **b.** Project Plan. **c.** Functional Requirements Document.	**i.** Kick-off Meeting with Stakeholders- **Completed** **ii.** SharpRAIL Project Plan – **Completed** **iii.** SharpRAIL Functional Requirements – **Completed** **iv.** iv. Business Development activities to identify a Transit Partner for SharpRAIL Pilot - **Completed**
Technology Definition and Selection - The objective of this phase is to define the "to-be" system by translating functional requirements identified during the Requirements Phase to well-defined technical requirements. This phase will include an analysis of technology and vendor alternatives to determine the optimum products for SharpRAIL. **Key Deliverable(s):** **a.** Stakeholder Site Visit to Franconia-Springfield Station and VRE Train 305. **b.** Revised Project Milestone Plan.	**i.** Seek and receive approval from VRE to partner with on SharpRAIL field pilot in the DC-MD-VA region - **Completed** **ii.** Initial discussion with VRE technical team to understand their IT infrastructure as it applies to SharpRAIL - **Completed** **iii.** Preliminary analysis of VRE track maps to identify potential station locations for the SharpRAIL pilot - **Completed** **iv.** Detailed wireless site survey at three VRE stations to select the best location for the tests - **Completed** **v.** Franconia-Springfield was chosen as the test site for SharpRAIL. Perform a facilities survey with VRE PM at Franconia-Springfield VRE station to understand power cabling, video backhaul and communication requirements - **Completed** **vi.** Refine the existing SharpRAIL design to accommodate site constraints as well as VRE privacy issues - **Completed**

Project Phase and Deliverables	Tasks and Achievements
Prototype Design, Development, and Implementation - The objective of this phase is to design, develop and implement a "proof-of-concept" pilot system for field testing and evaluation of the "to-be" SharpRAIL system. **Key Deliverables:** **a.** Revised SharpRAIL Design based on final pilot location. **b.** System prototype.	**i.** Procure SharpRAIL components – **Completed** **ii.** Integrate and lab-test SharpRAIL system components - **Completed** **iii.** Pre-WiMAX base station installation at VRE's Franconia-Springfield Station - **Completed** **iv.** Mobile Video Camera Installation in Passenger Car of Moving Train 305 along VRE's Fredericksburg Line – **Completed** **v.** Mobile Video Camera and Encoder Installation in Driver Car (V02) of Train 305 – **Completed** **vi.** Public Wi-Fi and EV-DO rev A devices' installation in Passenger Car of Train 305 – **Completed** **vii.** Pre-WiMAX Subscriber Station and Antenna installation on Driver Car of Train 305 - **Completed**
System Testing and Results- The objective of this phase is to pilot test and record SharpRAIL communications and video data. **Key Deliverables:** **a.** Stakeholder Visit VRE site for demonstration. **b.** Test Data Collection. **c.** Final Progress Report	**i.** Collect remote video data of mobile camera output from VRE Station using EV-DO and pre-WiMAX - **Completed** **ii.** Test remote monitoring of mobile camera output from VT Aepco's Office in Gaithersburg using EV-DO Rev A- **Completed** **iii.** Perform ride tests, collect and analyze WiFi-based web access and video quality data for ten (10) business days - **Completed**
Conclusions and Lessons Learned- The objective of this phase is to formulate conclusions and document lessons learned based on field test results. **Key Deliverables:** **a.** Prototype Evaluation **b.** Final Progress Report **c.** Final Technical Report	**i.** Final Report development – **Completed**

Table 6: SharpRAIL Project Phases, Deliverables, Tasks and Achievements

Appendix A - Video Analytics Site Survey Template

Determining Customer Requirements

1. Discuss anticipated threats and overall goals of installing the SharpRAIL Analytics system with the users.	Unauthorized railroad track crossing Unknown object left behind near the track
2. Discuss all anticipated threat scenarios with the user on a per-camera basis.	PTZ Train Station or Rooftop Camera will monitor object left behind on track and unauthorized railroad crossing Fixed indoor passenger car camera will monitor passenger movement to avoid any criminal incident Fixed indoor locomotive camera will monitor track for object found on track
3. Fully describe detection scenarios.	Person or vehicle crosses the railroad track through virtual video analytics lines Object left behind on railroad track for more than 2 min Object left behind within passenger train for more than 1 hour
4. Fully describe non-detection scenarios (i.e., inconsequential motion).	Continuously scene changes will cause unknown view for video analytics Background shadow changes will cause unknown view for video analytics
5. Describe notification scenarios on a per-alert basis. This includes determining which personnel should be notified of a detected event	Authorized personnel from VRE and VT AEPCO will be able to access alerts through alert console
6. Attempt to determine future needs and requirements that may impact early deployment decisions.	Stabilize background for all video analytics (background must stay constant for a period of 30 seconds) Do not apply "Appear" video analytics rule when it is indoor with shadow in the background, apply "Loitering" video analytics rule instead

Site Map

1. Placement of manmade and natural obstructions, and whether or not these obstructions are permanent or temporary	N/A (All tests are conducted in the real-world scenario without any environment placement)
2. Notes on obstructions that may change with seasons, such as visibility through trees with and without leaves	N/A (All video analytics tests are conducted without any obstruction due to change of seasons, such as visibility through trees with and without leafs)
3. Locations of roads and information about anticipated traffic, including: • Vehicular information, such	VRE Train can travel up to 75 mph No information for pedestrian as it is real world test with random passenger involvement

as vehicle size, number, average speed, and headlight path (for night operation). • Pedestrian information, including average speed, direction, and density.	
4. Detailed camera placement information, including: • The physical location of cameras. • Camera mount type (e.g., fixed or PTZ, housed or open, etc.). • Camera height, tilt, and focal length. • Whether the camera is indoor or outdoor. • The distance from the area of interest (i.e., the range). • A determination of adequate coverage to satisfy the detection goals of the system.	Outdoor Analog Pan Tilt Zoom Day and Night Camera - Sky Walk Bridge of VRE's Franconia-Springfield Station 35 feet above track (to view nearby railroad track) Outdoor Analog Pan Tilt Zoom Day and Night Camera – Condo rooftop camera 500 feet above track (to view far away railroad track) Indoor Analog Fixed Day and Night Camera 7 feet high Ceiling of Quiet Car Passenger Train with Locomotive V02 (to view passenger activity inside of quiet car) Indoor Analog Fixed Web Camera with 1.3 Mega Pixel located in driver window of VRE Locomotive V02 with 15 feet distance from the monitoring track (to view track when train is in motion or stationary)
5. The placement of all sources of illumination, such as incandescent, motion-activated, fixed or moving, infrared, etc.	N/A
6. The location of all reflective surfaces, including: • Mirrors or mirrored glass. • Windows. • Bodies of water (including pools). • Steel.	Windows in passenger trains and locomotive driver windshield
7. Photographs	Please see installation photographs

Per Camera Technology Information

1. Camera type (e.g., monochrome, color, integrated day/night, low-light, amplified light, Forward Looking Infrared [FLIR], etc.)	Analog Pan Tilt Zoom Day and Night Camera (VRE owned) Analog Pan Tilt Zoom Day and Night Camera (VT AEPCO owned) Analog Fixed Day and Night Camera Analog Fixed Web Camera with 1.3 Mega Pixel
2. Camera make	Bosch (VRE Owned), Pelco, Intel
3. Camera model	Bosch Dome PTZ Camera Pelco Spectra III

	Pelco CCC1390H-6 Intel Conference Pro
4. Light sensitivity rating (in lux)	0.08 lux at 1/2 sec (Color Mode) 0.3 lux at 1/60 sec shutter (B-W Mode)
5. Lens type and degrees of view	Optical Lenses F1.6 (f = 3.6~82.8 mm optical)
6. Years in service/maintenance issues	2 months for fixed indoor cameras 2 years for outdoor PTZ cameras
7. Output resolution in pixels	640 X 480 for all cameras
8. Frame rate	Up to 24 fps for all cameras
9. Required lighting (e.g., incandescent, infrared [IR] light emitting diode [LED], etc.)	Environmental Light Sources

Per Camera Signal Transmission Considerations

1. Length of cable run	
2. Number of splits	
3. Analog signal or IP feed	
4. Ease of malicious signal disruption	

Camera Environment

1. INDOOR • Lighting and anticipated lighting changes (e.g., camera exposure to sunlight through windows, etc.). • Anticipated traffic levels and types.	
2. OUTDOOR • Lighting/lighting changes. • Anticipated traffic/activity levels. • The path of the sun (blinding). • Climate phenomena and frequency, including: o Rain. o Freezing rain. o Hail. o Snow. o High wind.	

o Tornados. o Hurricanes. o Sand storms. • Flora. o Trees. o Bushes. o Tall grass. • Fauna. o Birds. o Small animals (both domestic and wild). o Large animals (both domestic and wild).	

Collection of Representative Footage

1. ~1 hour video footage captured from existing cameras at all installed and anticipated locations at different times of day and varying environmental conditions	

SharpRAIL Analytics Equipment Considerations

1. SharpRAIL Analytics platform requirements: • Placement and quantity. • Platform compatibility, including: • Windows 2003 or XP. • Sufficient RAM. • Sufficient drive space. • CD-ROM bay for software loading. • Type of edge device. • Server S-500 based. • Ethernet connectivity to SharpRAIL Edge devices.	
2. SharpRAIL Edge devices and Server environment : • Sensor proximity to camera feeds. • Rack space availability.	

• Correct temperature and humidity.
• Sufficient distance from operators, given fan noise.
• Grounding scheme AC power.
    • UPS or generator backup.
    • Sufficient service amperage.
• Physical placement.	

Appendix B - Equipment Specifications

i) Pre-WiMAX Base Station and Client: Tsunami MP.11 is Proxim Wireless' leading-edge point-to-multipoint pre-WiMAX product line. Advanced features include: WiMAX Quality of Service (QoS); roaming with seamless handoffs at speeds up to 200 km/hour; dynamic frequency selection (DFS), which has already received EN 301-893 v1.3.1 certification, and extended range. Available in outdoor and indoor models, the MP.11 series is capable of supporting converged voice, video and data transmission in fixed and mobile applications, bringing capabilities of the IEEE 802.16e (mobile WiMAX) standard to for license-free frequency bands in 2.4GHz and 5GHZ.

Pre-WiMAX Access Point Illustration

Wireless Radio Specifications

RF Modulation and over-the-air rates

Model 5054-R
OFDM (Orthogonal Frequency Division Multiplexing)

	20 MHz Channels	10 MHz Channels	5 MHz Channels
• BPSK	6 and 9 Mbps	3 and 4.5 Mbps	2.25 and 1.5 Mbps
• QPSK	12 and 18 Mbps	6 and 9 Mbps	3 and 4.5 Mbps
• 16-QAM	24 and 36 Mbps	12 and 18 Mbps	6 and 9 Mbps
• 64-QAM	48 and 54 Mbps	24 and 36 Mbps	12 and 18 Mbps
• Maximum Packet Size	1522 Bytes		

Wireless Protocol

- WORP (Wireless Outdoor Router Protocol)

Device Interface

Ethernet
- Auto-sensing 10/100BASE-TX Ethernet

Antenna Connector for BSU and SU with Type-N Connector
- Standard Type-N Female

Network Architecture Type

- Infrastructure

Receive Sensitivity

Model 5054-R-LR

Modulation	40 MHz Channels Turbo Mode	20 MHz Channels Standard Mode	10 MHz Channels Standard Mode	5 MHz Channels Standard Mode
64QAM ¾	-70dBm @108Mbps	-73 dBm @54Mbps	-73 dBm @36Mbps	-76 dBm @18Mbps
64QAM ½	-72dBm @96Mbps	-75 dBm @48Mbps	-76 dBm @24Mbps	-79 dBm @12Mbps
16QAM ¾	-74dBm @72Mbps	-84 dBm @36Mbps	-81 dBm @18Mbps	-83 dBm @9Mbps
16QAM ½	-78dBm @48Mbps	-85 dBm @24Mbps	-84 dBm @12Mbps	-86 dBm @6Mbps
QPSK ¾	-81dBm @36Mbps	-89 dBm @18Mbps	-87 dBm @9Mbps	-89 dBm @4.5Mbps
QPSK ½	-83 dBm @24Mbps	-90 dBm @12Mbps	-90 dBm @6Mbps	-92 dBm @3Mbps
BPSK ¾	-84 dBm @18Mbps	-93 dBm @9Mbps	-81 dBm @4.5Mbps	-93 dBm @2.25Mbps
BPSK ½	-85 dBm @12Mbps	-94 dBm @6Mbps	-91 dBm @3Mbps	-95 dBm @1.5Mbps

NOTE: All receiver sensitivities are +/- 2 dB

General and Electrical Specifications

Electrical	5054-R-LR POE Power Injector • Custom Power over Ethernet (802.3af compatible) • Input: Voltage 110 to 250 VAC (47-63Hz) • Output: 48V @ 420mA MAX (Injected into the Cat-5 Cable) • Pin for Remote reboot (reload) or reset to factory default 5054-R-LR Outdoor Radio Unit • Power Consumption: 7.5W typical. Up to 20 Watts across full operating temperature range. • Input: Voltage 42 to 60 VDC
Dimensions	Base Station and Subscriber Unit • Packaged: 14.57 in x 13.70 in x 8.19 in (370 mm x 348 mm x 208 mm) Base Station and Subscriber Unit with Type-N Connector • Unpackaged: 10.5 in x 10.5 in x 3.25 in (267 mm x 267 mm x 83 mm) Subscriber Unit with Integrated 23-dBi Antenna • Unpackaged: 12.60 in x 12.60 in x 3.50 in (320 mm x 320 mm x 89 mm)
Weight	Base Station and Subscriber Unit with Type-N Connector • Packaged weight: 9.2 lbs (4.2 kg) • Unpackaged weight: 5.5 lbs (2.49 kg) Unit-only, .45 lbs (.20 kg) for power supply Subscriber Unit with Integrated 23-dBi or 16-dBi Antenna • Packaged weight: 10.1 lbs (4.6 kg) • Unpackaged weight: 6.0 lbs (2.72 kg) Unit-only, .45 lbs (.20 kg) for power supply
Environmental	Operating • -33° to 60°C (-27.5° to 140° Fahrenheit) • 100% humidity • Wind loading: 125mph Storage • -55° to 80°C (-41° to 176° Fahrenheit) • 100% humidity
Packaging Contents	Base Station or Subscriber Unit • One Tsunami MP.11 Model 5054-R-LR Base Station or Subscriber Unit • One wall/ pole mounting bracket • One Power-Over-Ethernet injector for Model 5054-R-LR • One US power cord • One Ethernet cable weather-proof plug • One Documentation and Software CD-ROM
MTBF	• 100,000 hrs

Radio Power and Range Specification

Transmit Power Settings

Model 5054-R-LR

	6-24 Mbps @ 20 MHz 16QAM ½ QPSK ¾ QPSK ½ BPSK ¾ BPSK ½	36 Mbps @ 20 MHz 16QAM ¾	48 Mbps @ 20 MHz 64QAM ½	54 Mbps @ 20 MHz 64QAM ¾
•5.25-5.35 GHz	•20 dBm	•20 dBm	•20 dBm	•20 dBm
•5.725-5.850 GHz	•25 dBm	•23 dBm	•22 dBm	•20 dBm

Output Power Attenuation: 0 - 18dB, in 3dB steps
Output Power Values will have a tolerance of -1.5 dB

Range Information for 5054-R-LR

	54 Mbps	36 Mbps	6 Mbps
5.25-5.35 GHz (US)	5mi/8.05km	6mi/9.6km	5mi/8.05km
5.725-5.850 GHz (US)	5mi/8.05km	10mi/32km	20mi/32km

**Distance calculations assumes base station sector antenna with 16 dBi gain and 23 dBi client antenna Minimum fade margin; 99.995% or better availability; average terrain/climate; no unusual multipath; proper path clearance (0.6F1)*

System Processor and Memory

- 166 MHz Motorola 8241 processor
- 16 Mbytes RAM
- 8 Mbytes FLASH

ii) Mobile EV-DO WiFi Router: Junxion EV-DO Router is a very popular platform that supports EV-DO Rev A PC card modems from both Sprint and Verizon. The Junxion Box is ruggedized and has been tested for compliance with U.S. Military Standards (MIL-STD-810F) to simulate exposure to vibration, temperature and humidity. A licensed third-party laboratory performed these tests for Junxion. Key features supported include GRE tunneling, NAT traversal for IPSec termination, Dead Peer Detection (DPD) for IKE peer failover, enhanced boot time performance, and support for IEEE 802.11g on the latest models.

EV-DO Wireless Router Illustration

General Specifications

Part number	JB-120g **(JUNXION)**
Material	Aluminum with steel
Operating Temperature	0ºC to 50ºC
Weight	2.25 lb
Size	6.25 x 10.25 x 1.15 inches

Electrical Specifications

EV-DO Carrier	Sprint Nextel 3G Wireless Network
EV-DO Wireless Card	Sierra AC595 (1xEV-DO Rev. A/1xRTT)
VPN	VPN Pass-Though (ESP, AH protocol)
WiFi Protocol	802.11b/g
WiFi Security	WPA, WPA2, WEP 64/128b)

iii) Edge Analytic Appliance: Raven-M is a compact, 2 channel, and intelligent video server employing H.264 or MPEG-4 video compression and advanced video analytics from the leading vendors. As a standalone leading Edge Solution or part of a multi-blade rack mounted 19 inch 3U system, the Raven-M transforms standard analog video surveillance cameras into proactive sentinels that deliver reliable high performance video streaming and content analysis. This video server is equipped with PTZ control, TTL inputs and relay outputs, has an optional onboard storage Flash disk and WiFi module, and is available in two build configurations, industrial or commercial grade. In conjunction with Mango IVS framework, Raven supports seamless integration of third party video analytic software creating a truly intelligent edge device.

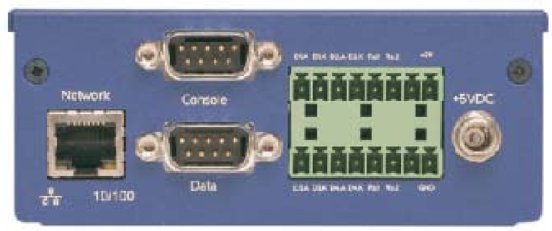
Mango DSP Raven-M Video Server Illustration

General and Electrical Specifications

Characteristics	Specifications
Board Form Factor	Standard 3U (6.299 inch by 3.937 inch)
DSP	One TI TMS320DM642 @ 600MHz or 720 MHz
Boot FLASH	Up to 16 MByte
Storage FLASH	Up to 2 GByte
SDRAM	Up to 128 MByte
Video Input	Two Composite or Two S-Video Inputs
Video Output	One Composite or One S-Video Outputs
Audio Input	One Stereo or Two Mono Inputs
Audio Output	One Stereo or Two Mono Output
UART	One RS232 and One RS485/422
Ethernet	One Fast Ethernet RJ-45 Connectors
Wi-Fi (802.11b)	One On-Board 802.11b Wireless LAN communication link.
On-board relays	Four DPDT Type relays (up to 1Amp @ 30 VDC Load)
Alarm /sensor inputs	Four TTL inputs.
LEDs	Four General Purpose LEDs.
Power requirements (Max.)	Wide Range +5DC@TBD Amp up to +12DC@TBD Amp
Operating Temperature	0ºC - 50ºC (available also in Industrial Temperature Range)
Storage Temperature	-40ºC to 85ºC
Relative Humidity	5% to 90% (non-condensing)
Dimensions: Length Width	6.299 inches [160 mm] 3.937 inches [100 mm]

iv) IP Video Transmitters and Receivers: The IndigoVision transmitter/receiver supports one camera or one monitor. This next generation MPEG-4/H.26 4 technology offers analog levels of quality at a choice of resolutions for the most demanding applications, such as surveillance, identification and high speed movement. Standalone transmitters introduce high quality and high compression MPEG-4 or H.264 video and audio to CCTV applications. IndigoVision transmitters guarantee 25/30 frames per second at any resolution or bit rate including CIF, 2CIF and 4CIF resolutions. They also support built-in firewalls for additional security.

Indigo Video Receiver Illustration



General Specifications

Part number	Stand Alone Receiver **(INDIGO VISION)**
Material	Aluminum with steel
Operating Temperature	32ºF to 122ºF (0ºC to 50ºC)
Weight	0.6 Kg
Size	167 x 110 x 45 mm

Electrical Specifications

Binary Input/Output	4 opto isolated input; 2 solid state relay outputs
Input Voltage	24 AC/DC
Input Power	5 Watts
Video Input	1 composite, 1 Vpp into 75 ohms (NTSC/PAL)
Video Connector	BNC female; S-Video
Compression	MPEG-4 SP
Frame Rate	1-30 fps programmable (full motion)
Bandwidth	RS232/RS422/RS485 up to 115.2 kbps

v) Analytics Integration Framework: Mango IVS software allows full command and control of video parameters, such as resolution, bit rate, frame rate and the video analytics embedded into the server. Leading content analysis providers, such as ObjectVideo and IntelliVision have chosen to integrate their content analysis libraries with Mango IVS. This combination enables video security devices to analyze video streams and apply a large set of user definable rules. Among these rules are: motion detection, people/vehicles counting, loitering, congestion, video stabilization, slip-and-fall and video stitching.

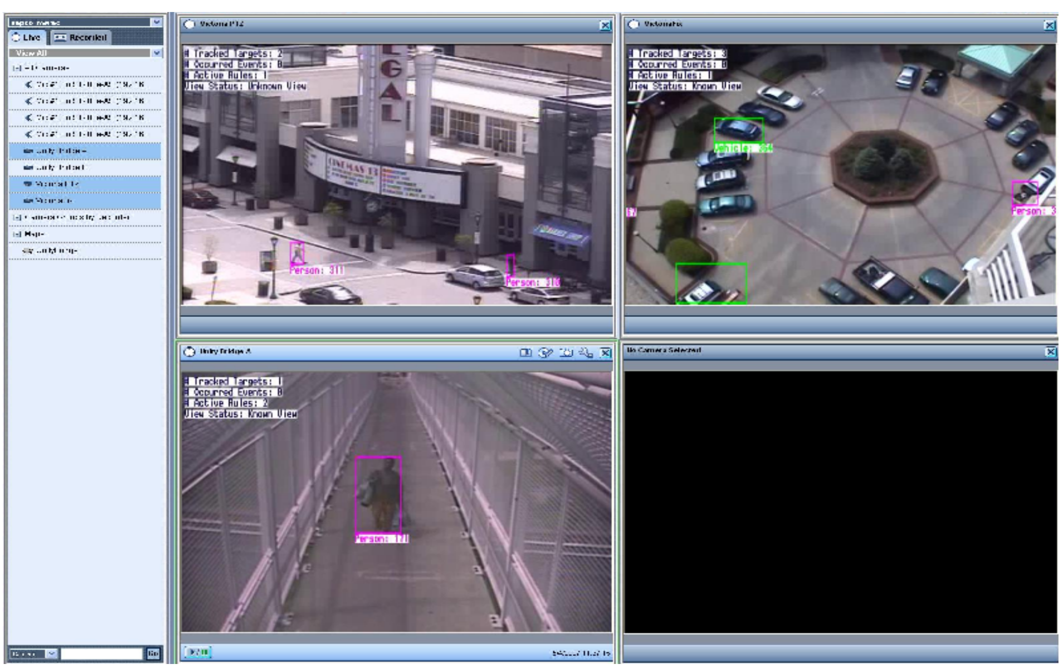
<u>Video Specifications</u>

Part number	Object Video Analytics
Optimal Resolution	7.5 fps to 30 fps
Video Format	MPEC4
Video Size	200 kbps
Analytics Rules	Loitering, Cross Trip, Double Trip Wire, Object Left Behind, Object Taken Away, Parameter Monitoring
Alert Messaging	E-Mail, Test Message, Nextiva GUI and Web Review, Decoder through Monitor

<u>System Requirement Specifications</u>

Operating System	Windows 2003 SP1, Windows XP SP2, Windows 2000
Operating System Processor	Intel Pentium 4 or Pentium D or Pentium Xeon, 2.8 GHz Hyper-Thread enabled
Minimum RAM Memory	1 GB
Network Interface	Network 10/100/1000Base-T

<u>Object Video Analytics and Management GUI Illustration</u>



Mango DSP Live Video through URL GUI Illustration

Mango DSP Analytics and Management Video Recorder GUI Illustration

Mango DSP Analytics GUI Illustration

vi) PELCO CCC1390H Series Day/Night Compact High Resolution Camera has been integrated for passenger quiet car video surveillance during the SharpRAIL project. The CCC1390 Series camera is a compact, wide dynamic range (WDR), day/night camera. Its WDR technology provides up to 60 dB of dynamic range and produces superior images over a wide range of lighting conditions, including extreme backlight conditions. The camera also uses a removable infrared (IR) cut filter to switch between color and black-white (B-W) modes as environmental lighting conditions change. It also provides a dual resolution of 530 TVL (B-W) and 480 TVL (color).

The CCC1390 Series camera has a standard CS-mount and can be used with fixed, manual, or DC-drive auto iris lenses. The auto iris is controlled through a standard four-pin square connector that is included with all Pelco auto iris lenses as following.

Compact Camera Illustration

General Specifications

Part number	CCC1390H-6 **(PELCO)**
Picture Elements	768 (H) x 494 (V) (Approx. 440K)
Operating Temperature	Absolute maximum; 122°F (50°C) Absolute minimum; minimal icing at sustained minimum of 14°F (-10°C);
Weight	0.44 lb (0.2 kg)
Size	2.69" D x 2.09" W x 2.19" H

Electrical Specifications

Input Voltage	24 VAC (±15%), 12 DC (±15%), 60Hz
Input Power	Less than 3.5 Watts
Video Connector	BNC
Power Connector	3-pin terminal strip, push-in type BNC
Control Connector	7-pin micro (1.25 mm) connector Data I/O (Pelco P or Pelco D)

Appendix C - Installation Pictures

Figure 18: Proxim Pre-WiMAX base station and antenna installed at Franconia-Springfield Station

Figure 19: Proxim Pre-WiMAX base station antenna installation – Close-up view

Figure 20: Proxim Pre-WiMAX base station antenna installation – Side view

Figure 21: VRE Locomotive V02

Figure 22: Proxim pre-WiMAX Station in Locomotive V02

Figure 23: Video Camera Pointing Outside of Locomotive

Figure 24: Power Source in Locomotive for Equipment

Figure 25: IndigoVision Video Encoder installation in Locomotive V02

Figure 26: Antenna Installation on Locomotive V02

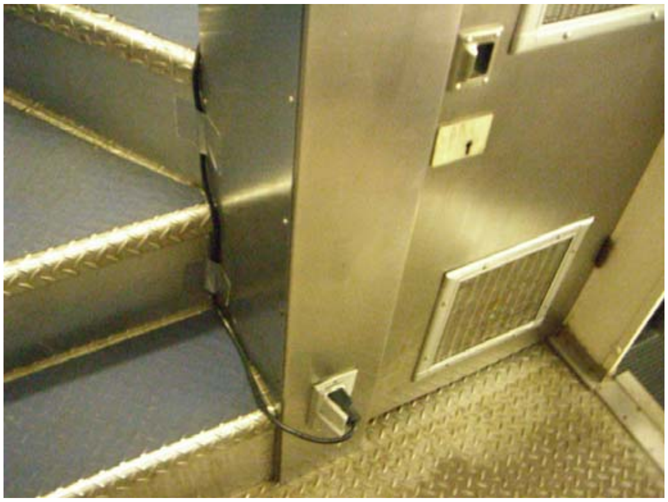


Figure 27: Temporary Power for Pelco Camera

Figure 28: Fixed Pelco Camera in Passenger Car

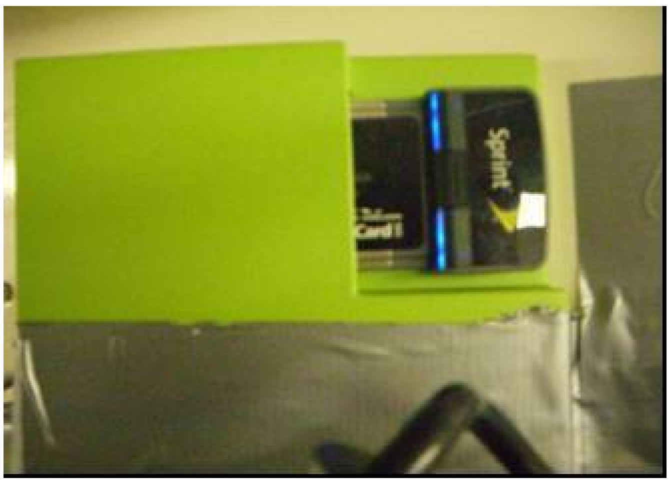


Figure 29: Junxion EV-DO Router for Pelco Camera

Figure 30: DLink Public WiFi Router

Figure 31: AirLink EV-DO Modem in Passenger Car

Figure 32: Camera View Inside Passenger Car

Figure 33: Verint Video Management System with Object Video Analytics

Figure 34: Object Video Based Mango DSP Analytics System Live Broadcast Screens

Appendix D - Glossary

CIF (FCIF)

Common Intermediate Format (Full Common Intermediate Format) is a format used to standardize the horizontal and vertical resolutions in pixels of YCbCr sequences in video signals, commonly used in video teleconferencing systems. It was first proposed in the H.261 standard.

CIF was designed to be easy to convert to PAL or NTSC standards.[citation needed] CIF defines a video sequence with a resolution of 352×288 like PAL Source Input Format, a frame rate of 30000/1001 (roughly 29.97) fps like NTSC, with color encoded using YCbCr 4:2:0. (Wikipedia)

EV-DO

Evolution-Data Optimized or Evolution-Data only, abbreviated as EV-DO or EV-DO and often EV, is a telecommunications standard for the wireless transmission of data through radio signals, typically for broadband Internet access. It uses multiplexing techniques including Code division multiple access (CDMA) as well as Time division multiple access (TDMA) to maximize both individual user's throughput and the overall system throughput.

WiMAX

Worldwide Interoperability for Microwave Access is a telecommunications technology aimed at providing wireless data over long distances in a variety of ways, from point-to-point links to full mobile cellular type access. It is based on the IEEE 802.16 standard, which is also called Wireless-MAN. The name WiMAX was created by the WiMAX Forum, which was formed in June 2001 to promote conformance and interoperability of the standard. The forum describes WiMAX as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL.

MIMO

Multiple-Input and Multiple-Output, is the use of multiple antennas at both the transmitter and receiver to improve communication performance. It is one of several forms of smart antenna (SA), and the state of the art of SA technology. (Wikipedia)

Omnidirectional Antenna

is an antenna system which radiates power uniformly in one plane with a directive pattern shape in a perpendicular plane. This pattern is often described as "donut shaped"

OFDM

Orthogonal Frequency-Division Multiplexing is a digital multi-carrier modulation scheme, which uses a large number of closely-spaced orthogonal sub-carriers to carry data.

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Report Number FTA-MD-26-7132-08.1