October 4, 2007

UTA-USU River of RF Project

Evaluation of the technological options available for providing broadband wireless service on commuter rails in Utah

Executive Summary

This report assesses the technological options available to provide wireless broadband service on the commuter rail in Utah. Technologies are identified and evaluated for realizable wireless architecture capable of handling large volumes of voice, video and data communications in a highly mobile setting. Several existing WiFi deployments are examined and compared in terms of in-train WiFi service and the train-to-ground backhaul. Newly emerged technologies are also considered and evaluated.

WiMAX backhaul is found to be the most attractive for the following reasons:

- Higher Network Bandwidth,
- Lower Network Latency,
- Low Cost of maintenance, and
- Proven track record.

Satellite communication is found to be desirable for backup and emergency operations.

The scope of this report is focused on technologies for the physical wireless data link, but also recommends inclusion of a long-term service manager to ensure quality, stability and security of the public WiFi service. Ideally this should be done by a service provider with experience managing open, public internet access points.

Some vendors offer complete turnkey service for deploying WiFi on rail systems, including service management. Turnkey solutions are given a separate assessment in this report.

Our final vendor assessments in each technology area are given as tables of numerical scores which can be found in Appendix 1.

This work was done within the Utah Transportation Center at Utah State University (USU), utilizing funding made available through the University Transportation Centers Program. The primary author is Dr. Chris Winstead.

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Chapter One: INTRODUCTION

1.1 Background

Wireless Internet on commuter rails requires robust networks capable of withstanding harsh outdoor environments. Furthermore, the network needs to be consistent, reliable and capable of providing high bandwidth to numerous passengers. Several different methods have been proposed and prototyped for use in providing wireless connectivity to mobile clients on trains.

1.2 Assessment Approach

This assessment identifies and evaluates five key technological needs.

1. The RF Layer for the Backhaul connection,
2. The physical layer communication link,
3. The network layer that bridges the backhaul to the in-train Wi-Fi service,
4. The Wi-Fi service within the train cars, and
5. Satellite backup service in the event of a fiber outage.

Products and vendors are evaluated based on the following criteria.

A. Technical Merit and product maturity.

B. Adequacy for future needs.
   - Bandwidth expansion,
   - Homeland security issues, and
   - Future communications standards.

C. Serviceability and Reliability
   - Portability of the devices,
   - Diagnostic and management capabilities, and
   - Seamless integration of all technological products (on-board and way-side solutions).

D. Balance between longevity and stability of the product vendor.

E. Compatibility between UTA's rail vehicle and rail corridor operation.

1.3 Structure of the Report

The structure of the report is as follows:

Chapter 2 examines the various existing and proposed Wi-Fi systems.

Chapter 3 describes backhaul solutions available for providing network connectivity to mobile clients. It also enumerates on the advantages and disadvantages, of each of these solutions

Chapter 4 gives a comprehensive description of the various products and vendors identified. Further, it evaluates these products and proposes several different options of realizable wireless architectures.

Chapter 5 summarizes our recommendations.

Chapter Two: OVERVIEW OF WiFi RAIL SERVICES

Wireless mobile internet technology is relatively new for public commercial use, especially on trains. It is a quickly evolving industry in which technology standards have not yet stabilized. This chapter examines a number of existing and proposed wireless systems with varying levels of product maturity and performance.

2.1 Existing Wi-Fi Services on Trains

Existing rail internet services are summarized in Table 1. Further details are given in the subsections that follow. Most of these systems use a satellite downlink with a cellular uplink. Cellular uplink systems require contracting with cellular service providers for network usage. The cellular systems do not provide free service to commuters, and suffer from low uplink data rates, but avoid the cost of installing and maintaining a trackside wireless infrastructure.

The WiMAX system used by Trinity Rail is able to supply superior network performance, but requires maintaining a network of base-stations that use relatively new (and potentially risky) technology. At present, several rail systems are being deployed with WiMAX-like hardware, and this seems to be the best solution for UTA given that trackside fiber is already available. Of the existing WiMAX deployments, Trinity Rail appears to be the only system with significant operating experience, and is discussed at the end of this section. The upcoming WiMAX systems are examined in Sec. 2.2.

EXISTING SYSTEMS	*COMPANIES INVOLVED*	*BACKHAUL SOLUTION*	*SPEED*
GNER *UK*	**ICOMERA**	**Satellite Downlink** **Cellular uplink**	**500 Kbps** **Max. of 64 kbps**
LINX *SWEDEN-DENMARK*	**ICOMERA**	**Satellite Downlink** **GPRS Uplink**	**400 Kbps**
VIA RAIL *CANADA*	**BELL CANADA, INTEL, POINTSHOT WIRELESS**	**Satellite Downlink** **Cellular Uplink**	**400Kbps** **Max. of 64 kbps**
ALTAMOUNT COMMUTER EXPRESS *NORTHERN CALIFORNIA*	**POINTSHOT WIRELESS**	**Satellite Downlink** **Cellular Uplink**	**1-2Mbps** **Max. of 64 kbps**
TRINITY RAIL EXPRESS *TEXAS*	**NORTEL, COLUBRIS, 4G-METRO**	**WiMAX**	**1Mbps**

Table 1: Existing Wi-Fi Systems.

GNER – UK

Icomera AB was chosen to operate the on-train wireless system on the Great North-Eastern Railway (GNER) in the UK. The Icomera system uses satellite download and cellular upload architecture. Users download at approximately 500Kbps, with a slower upload rate.

Linx – Sweden, Denmark

Icomera AB operates a wireless system on the Linx trains operating in Sweden and Denmark. The system uses a satellite downlink and a GPRS uplink. It achieves a maximum speed of about 400Kbps for downlinks.

VIA Rail – Canada

A joint venture by Bell Canada, Intel and PointShot Wireless deployed wireless internet on VIA trains between Montreal and Toronto. The VIA system uses Bell's ExpressVu satellite system for download and Bell's wireless network for upload. The downlink speeds achieved are about 400Kbps with slower uplink speeds.

The received satellite downlink signals are fed into an onboard server provided by PointShot Wireless. The server then feeds the satellite signal to Wi-Fi access points in the cars that users can access from laptop or handheld computers. The return signals from user laptops are fed from the access points to the server and then routed over Bell's terrestrial Code Division Multiple Access 1xRTT network, which has an average data rate of 70-80Kbps.

Altamount Commuter Express – Northern California

PointShot Wireless' Railpoint system was installed in the ACE trains, which run from Stockton to San Jose in California. Similar to the VIA Rail systems, the ACE installation uses a satellite downlink with a cellular upllink. This system achieves a maximum of 1-2 Mbps for downloads and serves about 45-60 users per day.

Trinity Rail Express – Texas

4G-Metro, a Dallas-area ISP and mesh wireless operator, developed and maintains the Wi-Fi network provided on the Trinity Rail Express linking Dallas, Fort Worth and the DFW airport

Numerous Nortel WiFi access points are mounted on track-side poles and connected to the Internet by wireless mesh, WiMAX and optical fiber links, which communicate with Colubris client bridges aboard each car. The combination delivers 10 Mbps of data throughput per car, with individual users able to get up to 1 Mbps.

The Trinity Rail system corresponds closely to the planned commuter rail installation in Utah. The Trinity Rail architecture offers a proven template for providing reliable mobile wireless service. It is worth noting that Nortel and Colubris hardware provided satisfactory backhaul and in-train connectivity solutions in this case.

2.2 Wi-Fi services on Trains under Development

This section examines wireless systems that are either recently deployed or still under development. The emerging technology of choice is the WiMAX approach. Nomad Digital and Redline Communications play an aggressive role in this market,

LOCATIONS	***COMPANIES INVOLVED***	***BACKHAUL SOLUTION***
SJ RAIL *SCANDINAVIA*	**ICOMERA**	**Satellite Downlink** **GSM/UMTS/HSPDA Uplink**
SOUTHERN RAIL *UK*	**NOMAD DIGITAL,** **REDLINE COMMUNICATIONS,** **T-MOBILE**	**WiMAX**
CALTRAIN *CALIFORNIA*	**NOMAD DIGITAL,** **REDLINE COMMUNICATIONS,** **SENSORIA CORPORATION,** **INTEL**	**WiMAX**

Table 2: Wi-Fi Systems under development.

SJ Rail – Scandinavia

Icomera AB installed a 3G/satellite system on 85 trains for SJ, the leading Scandanavian train operator. Icomera provides end-to-end, turnkey service for the train operator. Icomera's solution includes hardware, software and communication channels using different wireless technologies, i.e. satellite and redundant GSM/UMTS/HSDPA links for improved reliability.

Southern Rail – UK

Nomad Digital, with help from Redline Communications, developed a WiMAX mobile Internet solution on Southern's London to Brighton line. The 90 kilometer line has WiMAX equipment running along the track every three kilometers. On-board Wi-Fi access points communicate with the WiMAX devices and allow users to connect to the Internet via their laptop Wi-Fi network cards. The providers are expecting the system to provide a bandwidth up to 32 Mbps. The system should allow service at all times during the trip, including when the train is in tunnels. Users will be required to signup with T-Mobile to gain access.

CALTRAIN – California

Nomad Digital, Intel, Sensoria and Redline Communications worked with Caltrain to deploy a trial wireless architecture, which was demonstrated at speeds of up to 79 mph. The test included simultaneous laptop use with streaming video, email, large file downloads, and Web browsing. Nomad's system uses a series of fixed WiMAX base stations**.** Sensoria's mesh nodes connect and distribute Wi-Fi service over each train car. Redline's WiMAX gear provides the backhaul.

Chapter Three: MOBILE NETWORK TECHNOLOGIES

There are three possible independent methods for providing connectivity to the train:

1. Satellite Communication
2. Existing Cellular Networks
3. Wi-Fi / WiMAX Bridge Network

These approaches are illustrated in Figure 1.

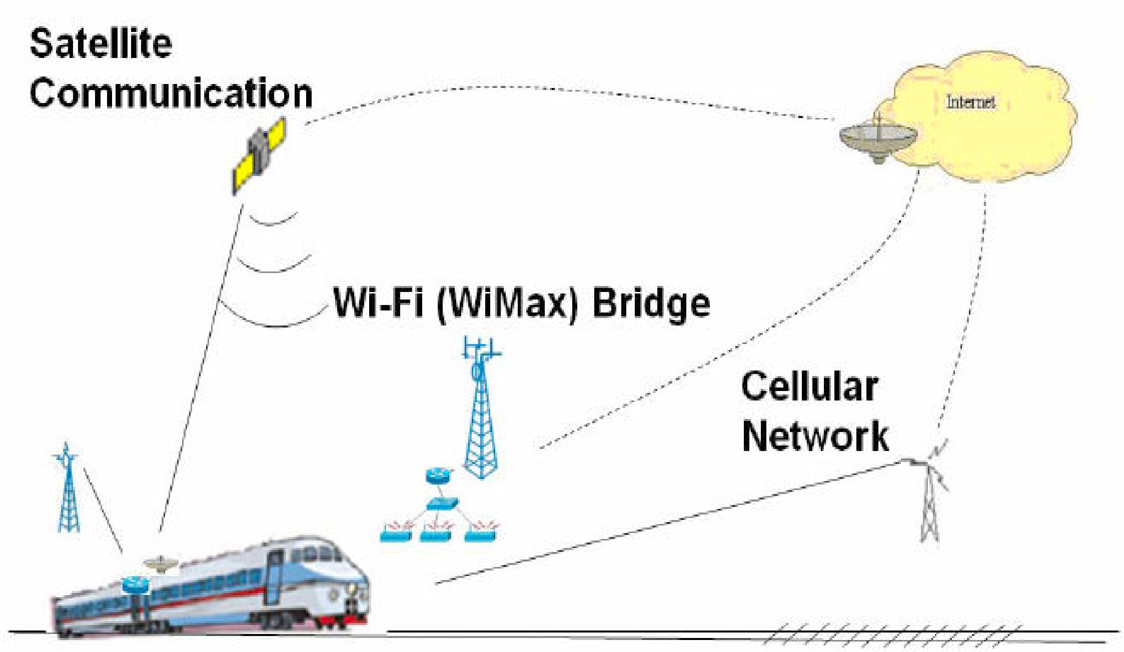

Figure 1: Connectivity to the train.

Figure 2 describes the pros and cons of using the different methods to provide backhaul connectivity to the train. The Wi-Fi / WiMAX bridge network is found to be the most appropriate solution given UTA's needs and existing fiber infrastructure.

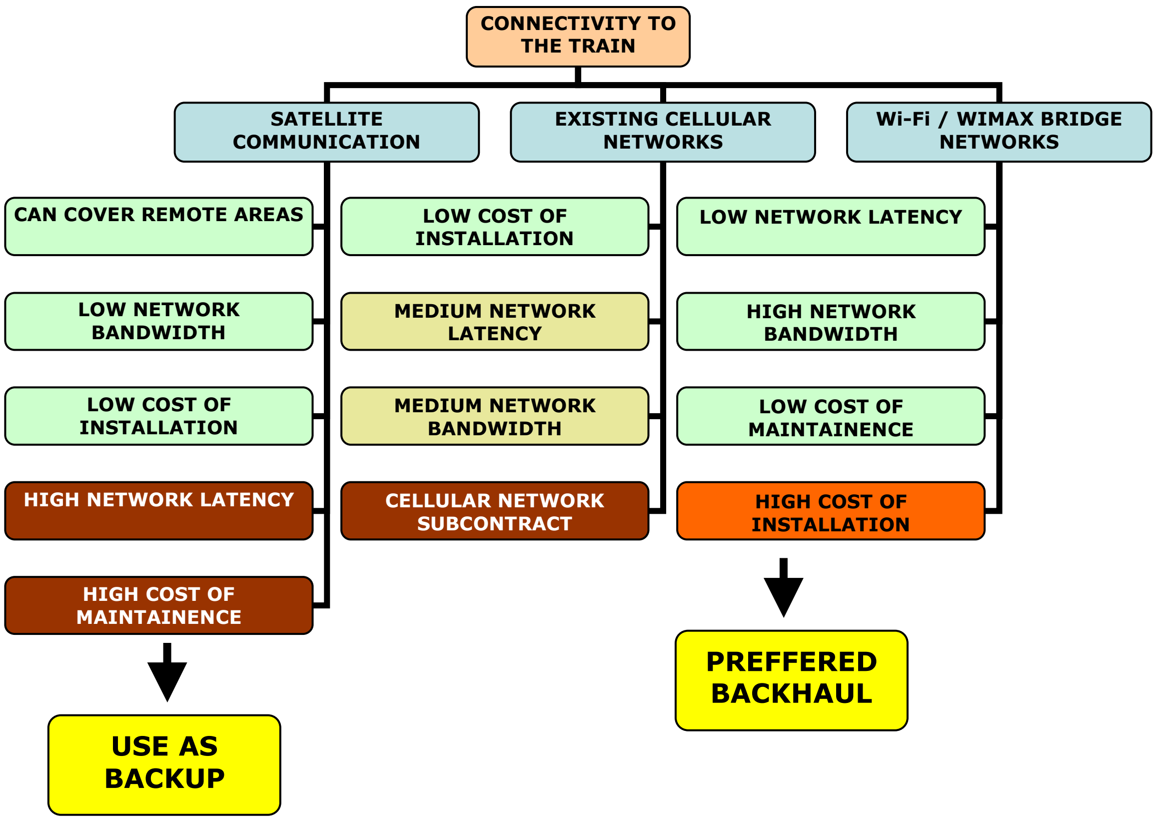

Figure 2: Pros and cons of employing different bridge networks.

3.1 Satellite Communications

The primary reason for considering satellite backhaul is to provide a backup mechanism if the trackside infrastructure fails. The usual attraction of satellite communication is that it can cover remote areas where trackside fiber and cellular infrastructure are unavailable. In UTA's case, satellite backup may be desirable in the event of a fiber network outage (which could occur for a variety of reasons), or in the event that the security of the fiber network is compromised.

The likelihood of these events must be weighed against the cost of a satellite backup. Satellite solutions also provide lower bandwidth and considerably higher latency than

WiMAX, and usually only provide a downlink solution. Additional agreements with local cellular operators would usually be needed to provide the uplink. We are aware of one instance in which a satellite uplink has been demonstrated on a rail platform, as detailed below.

A typical satellite downlink system consists of:

- On-Roof Antenna system
- Antenna Controller
- Satellite Modem
- In-Train Wi-Fi Distribution system

Recently 21Net, a company based in Spain, deployed a satellite uplink and downlink solution to support a high-speed wireless internet service. During trial testing, four laptops on a train were reported to be connected at 700 Kbps each. 21Net reports a faster uplink to the Internet using satellite connection than GPRS or 3G to send data from the train to the Internet.

Satellite backup may be of interest for homeland security and emergency management needs. A major accident, natural disaster or security incident could bring down the fiber network (and perhaps also halt the train). In such an event, a satellite system would provide a valuable alternative means of communicating with the personnel and passengers onboard the train. A satellite uplink would also be of value if cellular networks are impacted by the same event that disrupts the fiber connection.

3.2 Cellular Internet

Cellular networks have recently evolved to become a mainstream form of wireless Internet service. By connecting a cellular modem to a router in the train, a mobile wireless hotspot is easily created to supply internet service within any area under existing cell tower coverage.

Older cellular communication protocols allowed for only very low speed networking. Newer 3G cell technologies like EV-DO and UMTS promise to deliver network speeds competitive with those of DSL and other wired networks.

3.3 Wi-Fi / WiMAX Bridge

Trackside Infrastructure has the potential of providing high connectivity via WiFi (or WiMAX) which allow higher throughputs. Wireless broadband networks that involve point-to-point or point-to-multipoint networks with individual network links that can provide last mile connectivity in metropolitan environments or can span distances of up to 30 miles are often referenced as Wireless Metropolitan Area Networks (WMANs). Devices deployed in these networks are manufactured in accordance with the IEEE 802.16 family of standards. The IEEE 802.16 standard, first developed in 2001 for fixed wireless systems (*e.g.*, backhaul) operating in the 11-16 GHz frequency range of licensed “upper” bands, continues to evolve. In 2003, IEEE 802.16a – commonly referred to as Wi-Max – was developed for operations in lower frequencies in the 2-11 GHz range, including licensed bands as well as bands that permit use of unlicensed wireless devices. More recently, the IEEE 802.16a standard has been extended to include 802.16d, which is also for fixed wireless broadband applications. In addition, the IEEE currently is working to finalize the 802.16e standard, a mobile wireless extension. In sum, the evolving 802.16 standard holds great promise for future developments in wireless broadband because it can be used for applications in both licensed and unlicensed spectrum, allows communications without the need for line-of-site connections, enables interoperability with different equipment using the same standard, and, in the near future, will encompass both fixed and mobile wireless applications.

3.4 Network Architecture Components

The main network architecture components are as follows:

- In-Train Architecture components – components on-train supporting the mobile Internet service.

- Train to Back-Haul Architecture component
- Trackside communication system connecting all the trackside wireless infrastructures to the data gateway on which the data is routed to different service centers.

The In-Train Access would require at least the following components:

- On Roof Antenna System
- Antenna Controller
- Satellite / Wi-Fi / Wi-Max / Cellular Modems and Routers
- Wi-Fi in-train distribution system
- Onboard Server
- WLAN access points

The high level architectural overview of the network is shown in Figure 3.

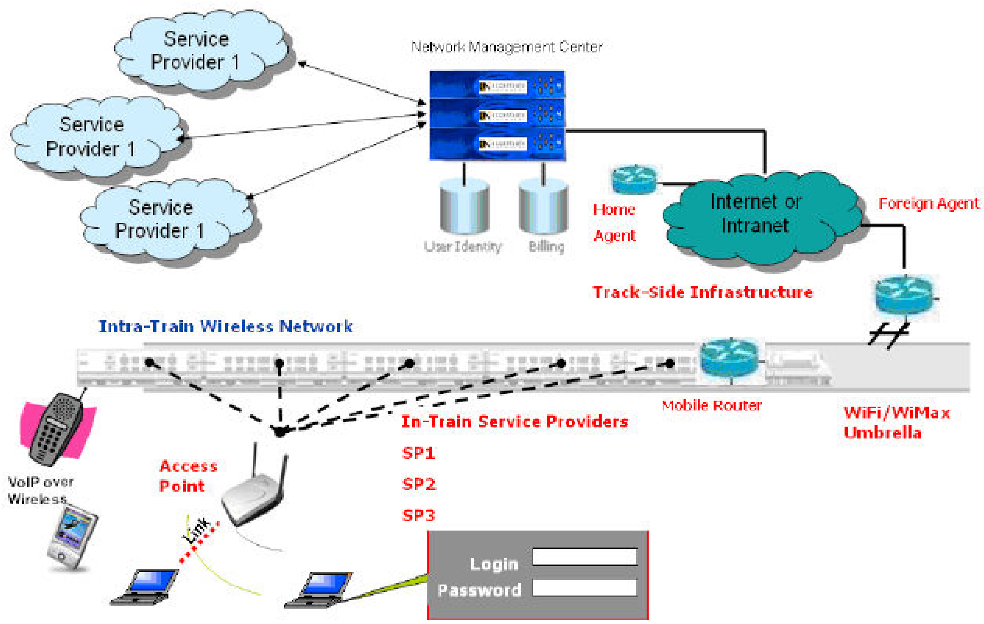

Figure 3: High Level Network Architecture (Courtesy Cisco Systems).

CHAPTER FOUR: VENDORS

The vendors can be broadly classified as vendors who provide the In-train architectural components, the train to trackside communication (backhaul) and those who offer a complete wireless solution as depicted in Figure 4. This chapter provides a comprehensive description of the various vendors and the products offered by them.

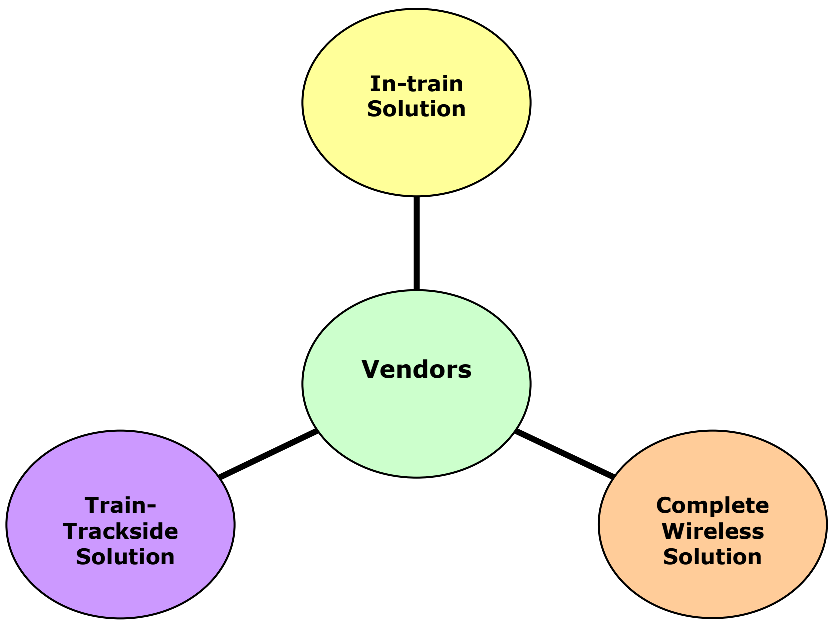

Figure 4: Vendor Classification.

4.1 In-Train Solution providers

The main in-train solution providers are shown in Figure 5. This section describes the existing solutions provided by these vendors in-detail. It also enumerates the key factors to be considered while choosing a particular solution.

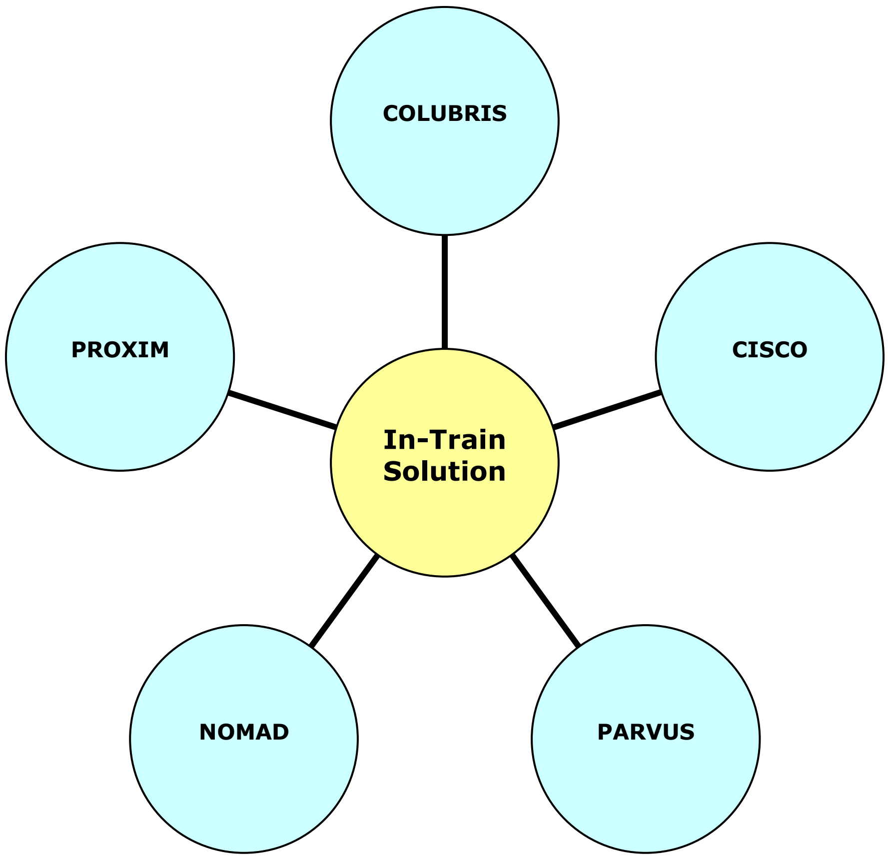

Figure 5: In-Train solution providers.

COLUBRIS NETWORKS

Colubris network provides In-Train and In-station solutions. The Colubris MAP-330 is a dual radio, access point (AP) capable of being used as a carriage link or an AP. In addition, MAP320, the single radio AP can be used to provide the carriage link while MAP-330R, a dual radio outdoor AP, can be used for In-station Wi-Fi access.

These access points are rugged and fulfill both railway rolling stock apparatus as well as shock and vibration compliances (EN 50121-3-2 and IEC 61373). Figure 6 depicts how MAP 320 and330 are used to provide Wi-Fi within the trains. MAP 320 and Radio 2 of MAP 330 provide the Inter-carriage link while Radio 1 of MAP 330 provides the passenger internet access.

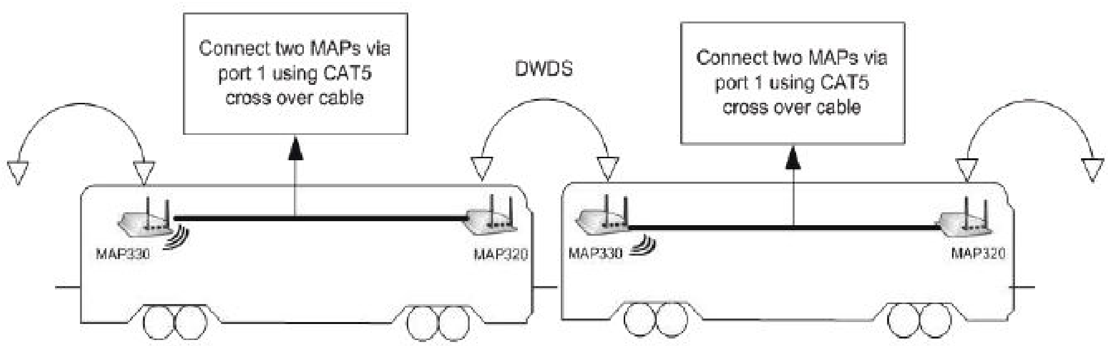

Figure 6: Inter-Carriage link (Courtesy Colubris Networks).

Some of the other features offered by Colubris are

- The AP allows hotspot operators to simultaneously enable UMA and 802.1x access.
- The APs prevent peer-to-peer traffic between Wi-Fi clients.
- The Colubris Multiservice Controller provides web-base authentication.
- The Colubris RF Manager can be used to detect and prevent attacks from rogue AP devices.

Colubris Networks was founded in 2000 and has several train deployment experiences as listed below:

- Icomera - GNER, United Kingdom.

- Icomera - SJ, Sweden.
- 4G Metro - TRE, Dallas, Texas.
- Dockland Light Railway – United Kingdom.

NOMAD DIGITAL

Nomad is a world leader in providing data communication services to train operators. Nomad installs small, low-power base stations (called pico-cells) on the train. Information is then routed to the outside world through the Nomad IP network. Nomad also provides a mobility layer that enables seamless switching between base stations and the various networks available (for e.g. WiMAX, 3G). The mobility layer dynamically identifies the strongest network signal available, and switches the backhaul connection accordingly.

Nomad's trackside solution consists of a series of low-impact base stations placed along the track. The trains communicate with these base stations in a sequence as they move along the track. The antennas on the Nomad base station are highly focused along the track creating a corridor of high speed coverage for the train. The base stations operate at low signal power and hence do not require massive mast structures.

Nomad along with its partners provides numerous other services including:

- On-board screens for automated live minute-by-minute updates on the journey,
- Live video monitoring of security on trains,
- Automated driver performance monitoring,
- On-train payment card processing,
- Passenger counting,
- Recorded video downloading, and
- Game applications.

Nomad has extensive train network installation experience and has provided their expertise at:

- Southern Trains – London to Brighton,
- Virgin Trains – UK,
- NS – Holland, and
- Caltrain –USA.

CISCO SYSTEMS

Cisco provides In-Train access points. Figure 7 depicts the various Cisco components that can be used for providing wireless access to passengers in the train.

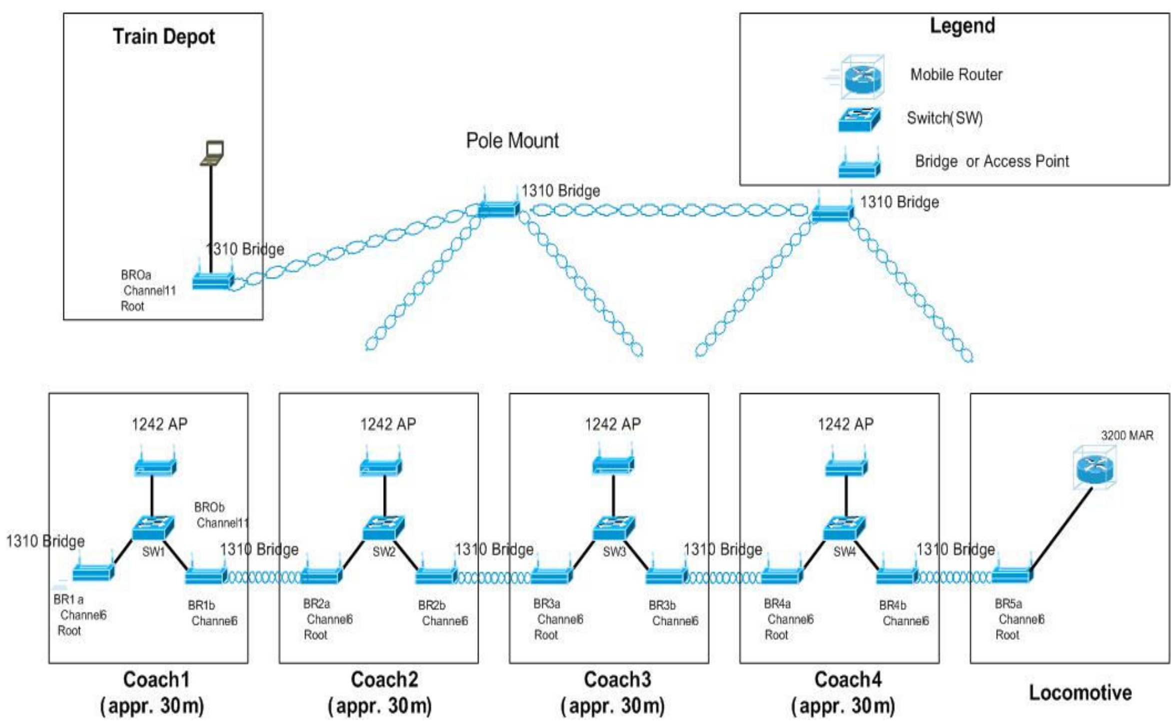

Figure 7: Cisco components required for providing Wi-Fi (Courtesy Cisco Systems).

The major components of the Cisco network are:

- The Cisco 3200 Mobile Router (MAR) comprises of multiple mobile interface cards that comply with industry-standards and support a wide variety of networks (GPRS, EVDO, HSPDA, satellite and 802.11 a/b/g).
- The Cisco Aironet 1242, 802.11 a/b/g access points are designed for challenging RF environments. They provide security, ease of deployment and manageability available in wired networks to wireless LAN.
- The Cisco Aironet 1310 access points can be used as a bridge between carriages. It supports the 802.11g standard, providing 54Mbps data rates with a secure technology while maintaining full backward compatibility with 802.11b devices.

Cisco has some experience with train deployments. Cisco technology has been used by Deustsche Bahn along to provide T-Mobile internet service on trains in Germany.

PARVUS

The Parvus RiderNet Rail is built on Cisco system's Mobile-IP router platform. The key features of this system includes a mobile router, high-speed EvDO cellular modem, 802.11 access point, 12-channel GPS receiver and hot spot server capabilities. Mesh networking, GSM/GPRS wireless, and satellite connectivity is optionally supported. This is a relatively new product and PARVUS has no prior train deployment experience.

PROXIM WIRELESS

The Ornico AP-4000 Access Point is Proxim's line of access points, supporting enterprise voice and video applications. Some of the features of these access points are:

- Enables mesh backhaul and Wi-Fi coverage on the same radio, while a second radio is used exclusively for Wi-Fi coverage,
- Automatic, universal Wi-Fi client interoperability,
- Supports 802.11b/g and 802.11a standards,
- External antenna connector for increased transmit distance,
- IEEE 802.11e quality of service support for latency-sensitive applications,
- Robust radius accounting and authorization interfaces, and
- Enhanced security with AES encryption.

This product is to be deployed on New Mexico's Rail Runner Express.

Summary of In-Train Vendors

In conclusion, some key points to consider while choosing a vendor for the In-train solution,

- Experience: Nomad and Colubris have extensive train deployment experience.
- Additional services provided: Nomad, in addition to providing access points, provides a mobility layer that allows seamless switching between the base station and the network. Further, they provide numerous data communication services to train operators.
- Security: Cisco Access points offer award-winning security.

4.2 Train-Trackside Solution

The backhaul is the infrastructure used to enable communication between the on-train data traffic and the track-side fiber network. The key mobile backhaul vendors, classified by the type of backhaul they offer are shown in Figure 8.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Figure 8: Key mobile backhaul vendors.

The Wi-Fi / WiMAX bridge networks are the recommended backhaul technology, as they offer high network bandwidth and low latency, and offer the best compatibility with UTA's existing fiber infrastructure. An in-depth discussion of vendors who offer this technology is provided in this section.

NORTEL

Nortel's Municipal wireless solution includes wireless mesh, WiMAX and optical network products. Nortel's mesh technology offers secure, seamless roaming in areas that do not support wired backhaul. Nortel's wireless mesh is formed by using multiple Nortel wireless access points (7220). This product includes two radio subsystems. One is the access radio for the mobile node interface and the other is the radio backhaul providing a communication link between other wireless APs and the wired network. The wireless access points perform traffic collection and distribution functions as well as incorporate:

- routing and wireless transit functions,
- security functions for validating connections to other Wireless APs, and
- low-cost advanced antenna designs.

Nortel also offers an end-to-end solution for WiMAX 802.16e that includes the base stations (BTS), core network, and network management. The base station consists of two primary building blocks: a digital module (DM) and a radio module (RM). The digital module provides:

- OFDMA baseband processing,
- WiMAX MAC processing,
- Radio interface, and
- Network timing and synchronization.

The radio module contains six transmitters, six receivers, RF filters and provides the digital baseband processing. Some key features of the WiMAX base station 5000 family include:

- MIMO base stations: 2x2 MIMO delivers up to 70 Mbps peak rate and 50Mbps capacity with an upgrade path to 4x4 MIMO,
- One to six sector BTS,
- 28 W of transmit power per sector.

Colubris' Wireless Client Bridge along with Nortel's wireless access points have been successfully used to provide seamless connectivity on the Trinity Rail express in Dallas at speeds up to 63 miles per hour.

REDLINE COMMUNICATIONS

The AN-80i broadband wireless system is Redline's latest backhaul and bridging solution. It operates at the license-exempt 5.8GHz band, using OFDM technology. Some key features of the AN-80i are:

- Offers long range operation of more than 50 miles in clear line-of-sight conditions, as well as robust non-line-of-sight conditions,
- Low end-to-end latency,
- Dynamic time division duplex (TDD) transmission, and
- Bi-directional adaptive modulation.

Redline communications has prior train deployment experience. It has been used to provide the backhaul technology for Southern trains in U.K as well as Caltrain in California. Redline communications partnered with Nomad Digital for both of these projects.

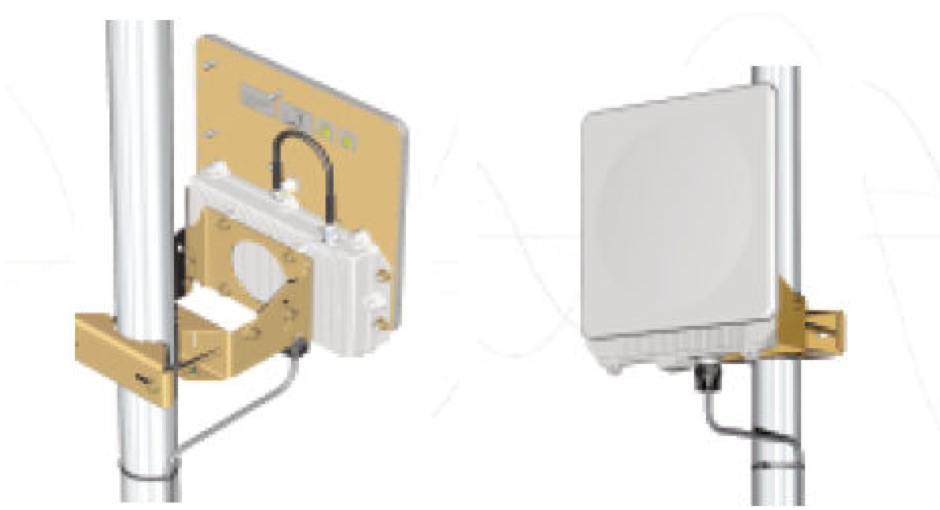

Figure 9: AN-80i broadband wireless system (Courtesy Redline).

MESH CITY

Mesh City provides a reliable structured mesh wireless architecture for metropolitan mobile-access networks. Mesh city's mesh net multi-radio backhaul ensure deterministic latency and jitter by eliminating the effects of single radio backhauls and involuntary contention. Figure 10 shows the various frequencies at which
Mesh City operates.

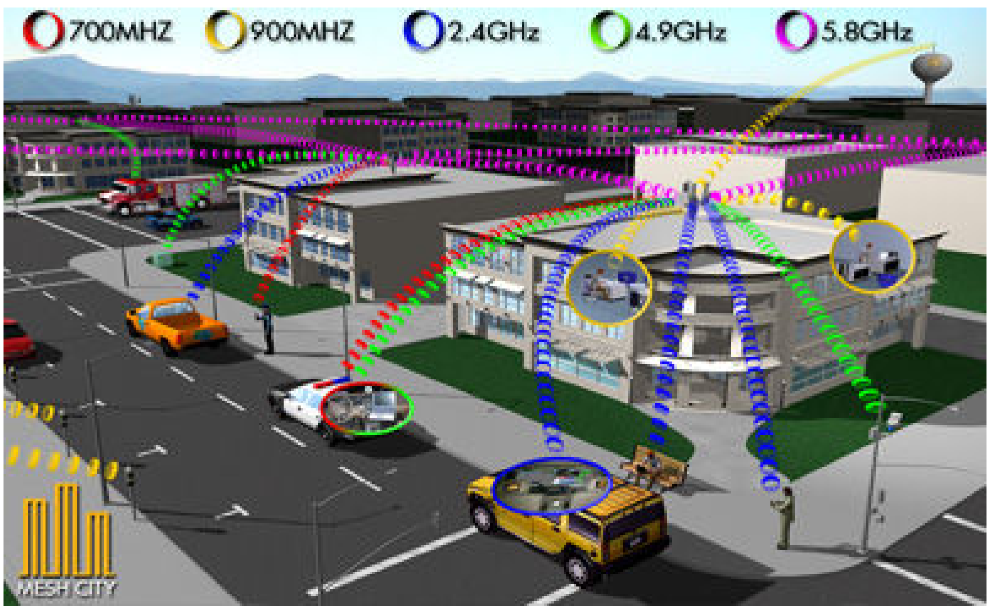

Figure 10: Mesh city's frequencies of operation (Courtesy Mesh City).

Mesh city's multi-radio backhauls can send and receive at the same time. These backhauls have two 5.8 GHz radios for uplink/downlink and a third 2.4GHz service radio. The backhaul uplink and downlink talk on different channels, thereby eliminating the bandwidth degradation effects associated with single radio backhauls. They have no prior train deployment experience.

PROXIM WIRELESS

Proxim's Tsunami MP.11 product family offers fixed and mobile WiMAX capabilities to distribute wireless broadband access supporting video, voice and data applications. Some of the features of the MP.11 family are:

- Supports 900 MHz, 2.4 GHz, 5.3 GHz, 5.4 GHz and 5.8 GHz unlicensed frequency bands and 4.9 GHz frequency licensed band,
- Enables quadruple-play applications - video, voice, data and mobility with low latency and IEEE 802.16 quality of service,
- Advanced security with AES encryption, and
- Mobile roaming with fast handoff speeds up to 120 mph.

Proxim's WiMAX backhaul is to be deployed on New Mexico's Road Runner Express.

4.3 COMPLETE WIRELESS SOLUTIONS

Some vendors provide turnkey solutions that include the design, hardware, software, installation and testing of the solution, and maintenance. Figure 11 shows some key vendors who provide a complete wireless solution. This section provides a detailed description of these vendors and the services provided by them.

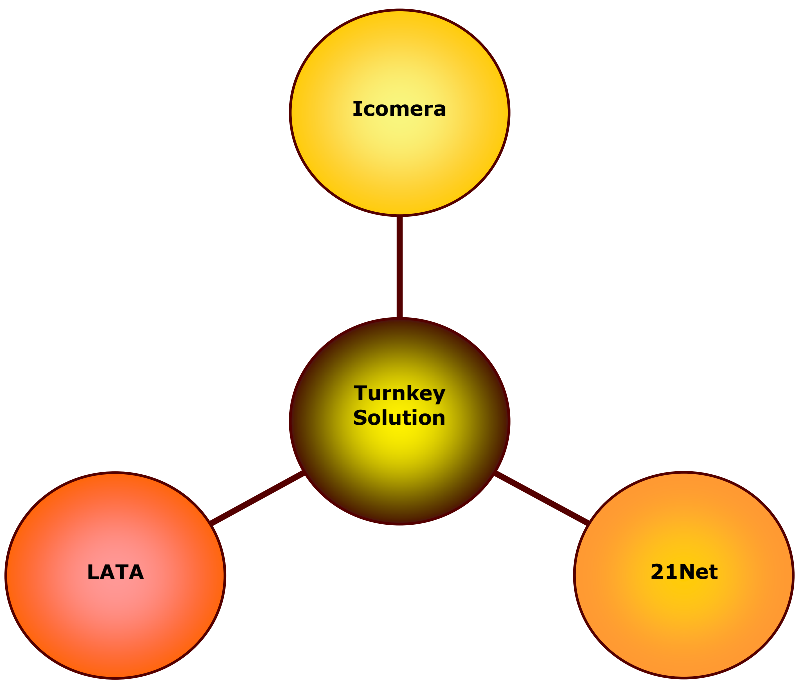

Figure 11: Main turnkey wireless solution providers.

ICOMERA

Icomera's complete wireless train solution is marketed under the name of "Wireless Onboard Internet". This end-to-end solution uses different wireless technologies like satellite and Wi-Fi for broadband capacity and multiple GSM/UMTS/HSDPA links in parallel for reliability. The main components of the Icomera's mobile system are:

- **Antenna Unit:** These include GSM, GPS, 3G, WLAN and satellite capabilities. A single antenna mounted on the roof is sufficient despite there being multiple modems.

Figure 12 : Icomera's Antenna unit (Courtesy Icomera).

- **High Voltage Protection Unit:** This unit is used to provide protection against high voltage when satellite antennas are used.

Figure 13: High Voltage protection unit (Courtesy Icomera).

- **Mobile System Rack:** This central unit comes equipped with a CPU, wireless communication cards, network switches, GPS receiver and optional satellite receiver or transceiver card. It also includes core software that supports communication link optimizations.
- **Onboard Wireless Network (OWN):** The OWN is installed in every coach and has two functions. It provides the in-train Wi-Fi access as well as provides a bridge network for connecting coaches together.

Figure 14: Onboard wireless Network(Courtesy Icomera).

Icomera pioneered the wireless onboard internet industry and has extensive train deployment experience. Since 2003, their systems have been successfully used at GNER-UK, SJ-Scandanavia and LINX-Sweden-Denmark.

21NET

21Net's "Broadband to trains" is the first to provide bi-directional satellite Wi-Fi to high speed trains. Passengers connect to the 21Net system, using their own Wi-Fi enabled laptops to link in to the on-train server. The train has a two-way satellite antenna installed on its roof which communicates with the Wi-Fi network on-board. Data is then transmitted from the train to the satellite, which in turn relays it to the satellite ground station. This system is managed by a network operations center which controls and monitors the entire network. Figure 15 depicts 21Net's Wi-Fi system.

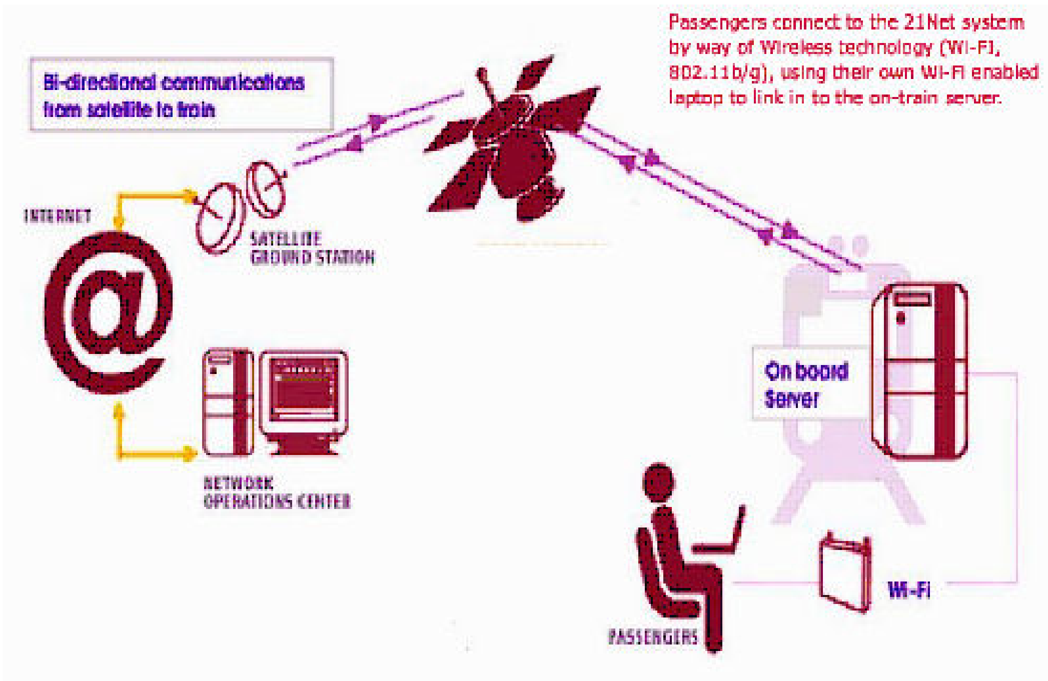

Figure 15: System Architecture(Courtesy 21Net).

21Net offers a fully managed internet broadband service to trains based on:

- Railway grade Wi-Fi installations,
- Network Operations Centre and Remote Management system,
- Telecommunication licenses and satellite operator approvals in place
- High performance antennas, and
- Mobile IP and fast switch-over technology for combining terrestrial wireless with bi-directional satellite for "gap filling" in tunnels, and stations.

21Net has successfully demonstrated trails in 2004, onboard the AVE train from the Spanish operator Renfe at 186mph. This demonstration of Ku-band bi-directional satellite communications to and from a train delivered uninterrupted broadband access at speeds of 4 Mbps.

LATA – Los Alamos Technical Associates, Inc.

LATA has considerable experience in providing complete wireless solutions. LATA proposes on using 802.11b/g Proxim access points for the in-train/in-station solution and the Proxim Tsunami for the train to trackside communication. Station to train interconnectivity is maintained using the 802.11a access points. When the train moves from the station, the network connection is handed off from the in-station 802.11a access points to the 5.8GHz Tsunami Backhaul. Local caching is provided for storing common internet content. Based on their current understanding of the Front Runner's initial configuration, they have come up with an equipment configuration for Wi-Fi on the train and on the platforms as follows:

- Internet access in stations and on trains with contiguous sessions throughout the line,
- Seamless mesh and backhaul,
- Omni-directional antenna system along right of way,
- 12 rack mount industrial cache server PC's,
- 12 US Robotics 8 port rack mounted hubs,
- 24 Proxim Orinoco AP4000 access point interfaces on train,
- 9 Proxim Orinoco AP4000 access point interfaces on stations,
- 58 Proxim Tsunami 5054AP antenna access points on route for seamless integration,
- Wireless network management software,
- Installation, integration, and implementation project management and engineering support with an optional three year equipment warranty.

LATA has been awarded all technology insertion on the Railrunner in New Mexico to date for phase 1 (9 stations between Belen and Sandoval County).

CHAPTER FIVE: CONCLUSION

In this report, various viable wireless technologies and key solution providers have been identified and evaluated. The solution ranges from using vendors who provide a turnkey solution to using separate entities for setting up the complete wireless system. The WiMAX mesh was found to be the preferred backhaul while satellite link could be used as a backup. Cellular backhaul has been waning in popularity due to slower uplink rates and has been used mainly in Europe. Further, classification of vendors based on experience and prior partnerships have also been identified.

Appendix 1 provides evaluation matrices of the different vendors based on our assessment approach.

APPENDIX 1: VENDOR EVALUATION MATRICES

The vendors are evaluated based on the following criteria:

- Criteria A: Technical merit and Product Maturity.
- Criteria B: Adequacy for future needs.
- Criteria C: Serviceability and reliability.
- Criteria D: Balance between longevity and stability of the product vendor.
- Criteria E: Compatibility between UTA's rail vehicle and rail corridor operation.

Evaluation Scale: high = 5; medium =3; low=1.

In-Train Solution Providers

EVALUATION CRITERIA	COLUBRIS	NOMAD	CISCO	PARVUS	PROXIM
(A) Technical Merit	4	5	5	1	2
(B) Future needs	3	5	4	1	4
(C) Serviceability	2	5	3	1	4
(D) Stability	3	4	5	1	2
(E) Compatibility	4	5	4	1	4

Train-Trackside or Backhaul Solution Providers

EVALUATION CRITERIA	ICOMERA	21NET	NORTEL	REDLINE	MESH CITY
(A) Technical Merit	4	1	4	5	4
(B) Future needs	2	3	4	5	3
(C) Serviceability	4	4	3	5	4
(D) Stability	5	3	3	4	2
(E) Compatibility	2	2	4	5	4

Complete Wireless Solution Providers

EVALUATION CRITERIA	ICOMERA	21NET	LATA
(A) Technical Merit	**4**	**3**	**5**
(B) Future needs	**2**	**3**	**5**
(C) Serviceability	**5**	**4**	**3**
(D) Stability	**5**	**4**	**3**
(E) Compatibility	**2**	**3**	**5**