Illinois Department of Transportation

Broadband Access Plan for Passenger Rail

Public Act 95-0009 – Broadband Access on Passenger Rail

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Executive Summary

Broadband Access Plan for Passenger Rail
Presented By: Illinois Department of Transportation

Public Act 95-0009 – Broadband Access on Passenger Rail
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Issue Background

This Executive Summary outlines a general plan by the Illinois Department of Transportation (IDOT) as required by Public Act 95-0009, the Broadband Access on Passenger Rail Act. This act requires IDOT to present a plan by Dec. 31, 2007, to the Governor and General Assembly on a way to provide future wireless network access on passenger trains in Illinois at a fair and reasonable cost.

Following enactment of PA 95-0009 in July 2007, IDOT commissioned a study by the University of Illinois on current technological possibilities that could meet the intent of the legislation. The study found that providing wireless access is a viable goal using current technologies and could indeed have positive impacts on traffic congestion, traffic safety, the economy, and other aspects of the quality of life Illinoisans enjoy.

Primary Program Goal:

Provide wireless network service to entice commuters and business travelers who rely on network connectivity to choose rail for Illinois travel, and increase ridership and revenues. Such services are now provided in London, Paris, Seattle, San Francisco, Tokyo, and Chennai, India.

Secondary Goals/Advantages:

- Improved management of highway traffic congestion.
- Increased revenues from additional ridership and service offerings.
- Potential related business opportunities and job creation.
- Better responsiveness rider needs and service expectations.

Short-Term Considerations

In the short term, state provision of wireless access on passenger trains could influence more travelers to utilize Illinois passenger rail options including Metra commuting services and Amtrak inter-city rail services.

By encouraging rail travel, we can:

- Discourage unnecessary roadway traffic, and improve safety and travel times,
- Decrease congestion and improve our ability to manage traffic more effectively,
- Support additional opportunities for job creation as small businesses are asked to provide necessary related services and supplies to users and vendors.

Long-Term Considerations

In the long run, a more accessible wireless network entails adding to the information technology infrastructure of the state, which in turn:

- Supports the statewide goal of accessible broadband network services to users,
- Creates more telecommuting options for workers, further decreasing vehicle traffic and unnecessary congestion on roadways,
- Leads to more effective technology for active traffic management to reduce the frequency and severity of roadway congestion.

Two Viable Service Options Identified through Study: *Cellular 3G & Wi-Fi*

Cellular 3G: Commercial Service Available by Fee From Large Telecom Vendors

- Requires a monthly data package subscription ranging from $40 to $80 a month.
- Requires no investment by the State but is cost prohibitive to many users.
- No one vendor has coverage or capacity to meet the legislative intent or user needs.

Wi-Fi: Same Service Offered Now in Many Coffee Shops, Hotels, Businesses

- Most computers now can access for little or no additional cost.
- Requires wireless infrastructure to be developed for broad access to the network.
- Network development and ongoing maintenance costs: $12,000 to $15,000 per rail mile. Overall cost could be phased in by specific rail line over time.
- Provides adequate bandwidth capacity to meet legislative intent and user needs.

Cost Considerations

Such benefits from Wi-Fi could be attained at a small fraction of the cost of rebuilding or adding lanes to heavily used commuter highways. The estimated wireless network cost of $12,000 to $15,000 per rail mile in Illinois would yield a projected full implementation cost of about $20 million on the nearly 1,600 miles of rail line in use for passenger service (Metra and Amtrak) in Illinois, including all Metra routes in the Chicago area and all in-state Amtrak routes (Chicago to St. Louis, Carbondale, Quincy, and the Wisconsin border bound for Milwaukee). This total cost compares favorably with the cost of freeway or roadway reconstruction to reduce congestion in urban areas, where construction costs start at several million dollars per roadway mile.

Cost Recovery Options

- The State could opt to provide the service to riders with no fees or cost recovery provisions attached in order to encourage ridership.
- Cost recovery options for development and ongoing maintenance:
    - Added ticket charges or other fees to all riders
    - Service available by subscription or on a per-use basis

Wireless Internet Service on Trains

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Summary

The Illinois legislature passed a Bill (Public Act # 095-0009) requiring the Illinois Department of Transportation to prepare a plan for ensuring high speed data transmission services on all passenger rail systems in Illinois at fair and reasonable prices no later than December 31, 2007. As an aid to the preparation of this plan, this report explores the following technologies:

1. *WiFi* (IEEE 802.11),
2. *WiMax* (IEEE 802.16) and
3. *Cellular 3G*

for providing Internet Access to passengers on trains. The report also outlines the infrastructural support required for these technologies to deliver an acceptable quality-of-service to a passenger using simplifying assumptions and results from the experiments conducted at the UPN-line on December 7, 2007 and December 10, 2007.

The required access can either be provided by the State of Illinois, the Railroad industry, or by a third-party. In either of these options there are additional non-technical issues that have to be considered if the vision of universal access on trains is to be translated into reality.

Introduction

The Illinois Legislature passed the "*Broadband Access on Passenger Rail Law*[1]" that requires the Illinois Department of Transportation (IDOT) to develop a plan for ensuring high-speed data access in all passenger rail systems in Illinois at fair and reasonable prices. IDOT approached the *Illinois Center for Transportation* (ICT) at the University of Illinois at Urbana-Champaign to investigate competing technologies that can bring the vision of providing internet access to passengers on trains closer to reality. To this end, the services of *HierComm, Inc.* were used to conduct experiments in a 34 mile stretch of the UPN line in the Greater Chicago area. The results of these experiments, reviewed in this report, and presented in detail in different report to IDOT, establish the technical feasibility of providing internet access at a reasonable infrastructural cost. However, there non-technical issues that need to be considered before this vision can gain acceptance in the market place. The remainder of this report is essentially an elaboration of these conclusions.

We looked into three candidate enabling technologies:

1. WiFi (IEEE 802.11),
2. WiMax (IEEE 802.16), and
3. Cellular 3G

For WiFi technologies, with the help of the services of *HierComm, Inc*., we have reasonable, base-line estimates of the infrastructural costs (measured in dollars-per-mile-of-track) for a collection of viable architectures. It was not possible to arrive at similar figures for the WiMax and Cellular 3G technologies as these services and their supporting vendor-base are not at the level of maturity as WiFi.

We also present an incomplete set of non-technical/semi-technical issues that could influence the feasibility of providing broadband access to passengers in trains in the state of Illinois. These could range from ownership of the right-of-way, logistic issues involving infrastructure, level of consumer-support required to justify different levels of capital-investment on behalf of the service provider, technologies with a broader scope of use as incentive to the service provider, etc. It is hoped that this report will be of use to IDOT in forming its recommendations to the Illinois Legislature.

Enabling Technologies

Wireless devices are constrained to operate in a certain frequency band in the spectrum. Each band has its associated bandwidth, which can be viewed as the space that is occupied by a device in the frequency band. Higher-bandwidth translates to larger data-transfer rates but this requires appropriate signal-processing. The use of the radio spectrum is regulated by the *Federal Communications Commission* (FCC). The FCC has allocated the 5GHz frequency band to devices that adhere to the IEEE 802.11a standard. These devices can provide data-transfer speeds up to 54 Mbps. Devices that conform to

[1] (cf. http://www.ilga.gov/legislation/publicacts/95/PDF/095-0009.pdf)

the IEEE 802.11g standard can also provide data-transfer speeds up to 54 Mbps, but these devices use the 2.4GHz frequency band.

There are wireless technologies in addition to the IEEE 802 family. For instance, *Bluetooth* is a standard that can be used to build small networks. A common example is the "network" between a Bluetooth-enabled cell-phone and its associated ear-piece. In its present form, Bluetooth is not a serious contender for providing wireless access on trains.

Third-generation (3G) mobile telephony networks can theoretically provide data-transfer speeds in the Mbps-range. Several sources seem to suggest that the rollout of commercial 3G services have experienced a serious push back. The preliminary experiments conducted by *HierComm Inc*. using cellular-cards on laptops seem to have poor data-transfer speeds to provide a level of service that is appropriate to the passengers. It is possible that sometime in the future, the promised 3G functionalities would be available to the consumers at large, and when this happens 3G mobile telephony networks can be serious contenders to providing internet access on trains.

WiFi (IEEE 802.11)

We present a short description of the terminology before we describe the capabilities and limitations of WiFi networks for the specific application we have in mind (cf. figure 1). An *access point* is a device that bridges the wired and wireless parts of the network. Any wireless device that is within the *Basic Service Area* of an access point can "talk" to it. The IEEE 802.11 standard allows for networks of arbitrarily large size by overlapping basic service areas to form a larger *Extended Service Area*. The presence of the wired backbone is essential. Customers within the extended service area can communicate with each other; this is in addition to access to the internet.

Communication between the access points in WiFi networks is done through a process known as the *Inter-access Point Protocol* (IAPP) and to the best of our knowledge there is no standardization of this protocol and vendors use proprietary technologies that perform this functionality.

When a customer turns her WiFi-enabled device on, her device would be *associated* with an access point after the appropriate *registration* process is completed. When the train she is traveling in moves out of range of one access point and into the range of the next one, her device would initiate a *re-association* with the new access point, and a *disassociation* with the previous access point. While this functionality should be standard by now, there can be customers with legacy WiFi equipment that are not equipped to perform this hand-off process. Users with such legacy equipment will not be able to surf the internet while traveling.

WiFi networks also provide privacy of transacted communications through a service called the *Wired Equivalent Privacy* (WEP). It is commonly accepted that WEP does not provide the level of security that it was originally intended for. It is not uncommon for

WEP-protected systems from being broken into. This said, several businesses use WEP keys as a means to authenticate legitimate users on their network.

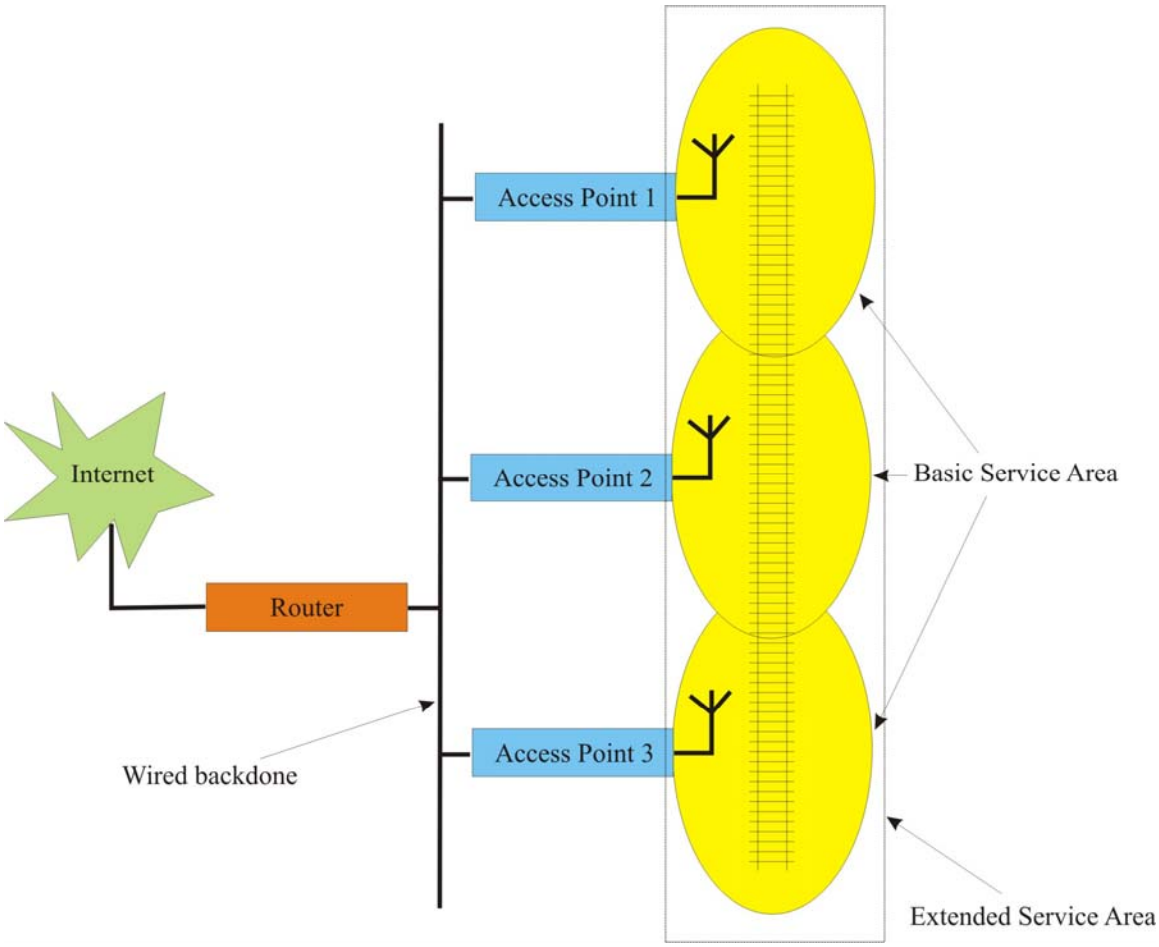

Figure 1: *Extended Service Area* with overlapping *Basic Service Areas* in WiFi networks.

At the physical-layer there are two things that are important to WiFi (and every other wireless technology): *Antennas* and *Amplifiers*. Anyone who owns a cell-phone knows the purpose of the antenna on a receiver is to improve the quality of the incoming or outgoing signal. A similar functionality is served by antennae on the access points. An *Omni-directional* antenna sends and receives signals from any direction, while a *Directional* antenna have preferred directions along which they can communicate better. For customers traveling on trains with WiFi-enabled devices their (directional) location relative to the access points is known. Since a directional antennae have longer reach than omni-directional ones along their preferred directions, a properly oriented directional antenna will permit larger spacing between access points.

Amplifiers increase the signal strength of the radio signals. The increase in signal strength is usually measured in *Decibels* (dB). If an amplifier doubles the power of a signal it is said to produce a 3-dB increase. A 1-dB increase corresponds to a 1.25-fold increase in power. The power of a signal is measured in terms of *dB above one milliwatt*

(dBm). A signal strength of -80dBm at the receiver was considered to be acceptable in the experiments conducted by *HierComm, Inc*. This threshold value of the received power pre-supposes a specific infrastructure involving access points with additional radio-frequency amplification. The relevant background and details are spelled out in the following paragraphs.

Directional antennae with appropriate amplification at each access point can permit the replacement of the wired-backbone in figure 1, with the wireless-backbone of figure 2. Roughly speaking, the quality of a directional antenna is measured in terms of the signal that needs to be generated by an omni-directional antenna to equal the power generated by the directional antenna along the preferred direction. This is measured in unit called *Decibel-Isotropic* (dBi). It is commonly acknowledged that a 3dBi improvement at the antenna translates to a noticeable improvement at the receivers.

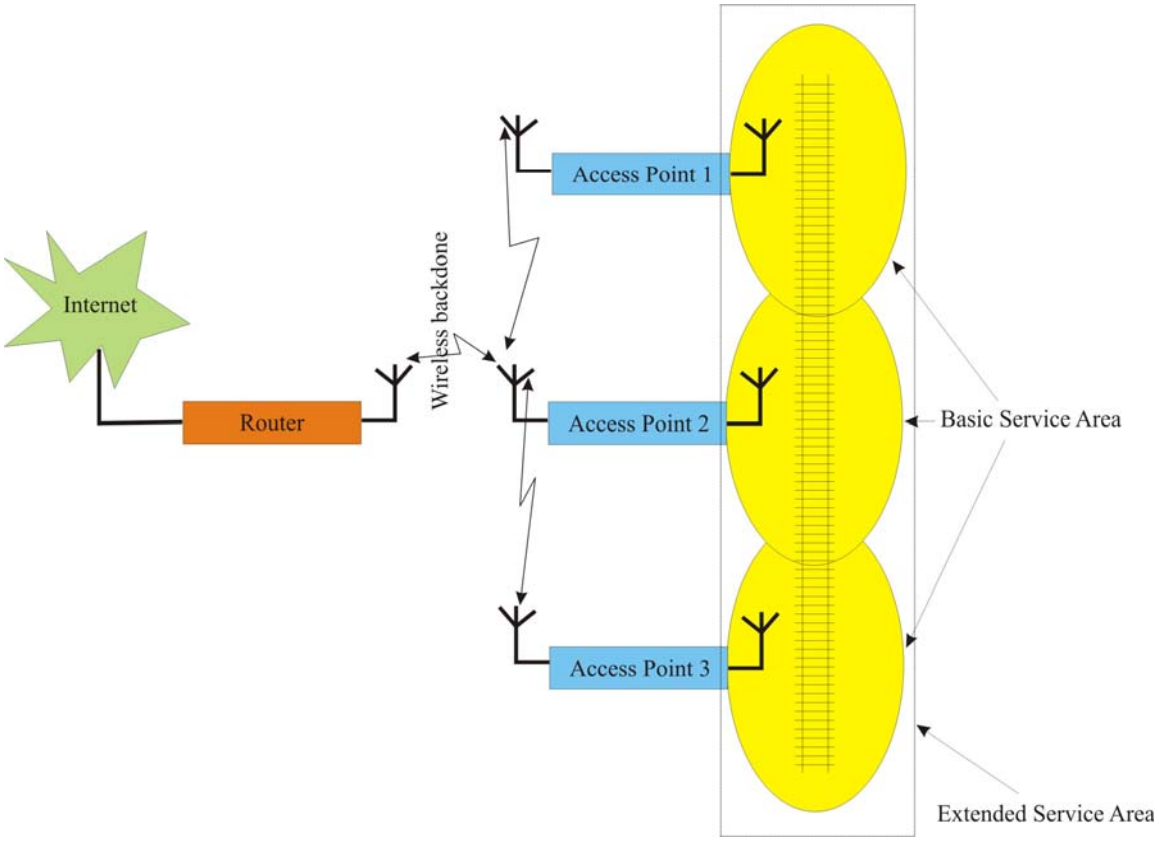

Figure 2: Replacement of the wired backbone of Figure 1 with a wireless backbone involving directional antennae, amplifiers and multi-spectrum radios.

The tests conducted by *HierComm, Inc*. suggest that the scenario outlined in figure 2 is indeed viable. The access points and routers used in this experiment can communicate along the 2.4GHz and 5.8GHz frequency bands. The preliminary design involved the access points communicating with users on the train along the 2.4 GHz band with directional antennae and radio-frequency amplification. The inter-access point communications and access point to router communication was presumed to use the

5.8GHz band, without the help of directional antennae. In course of the experiments alternate scenarios emerged which were more economical. These scenarios are discussed in subsequent portions of this report.

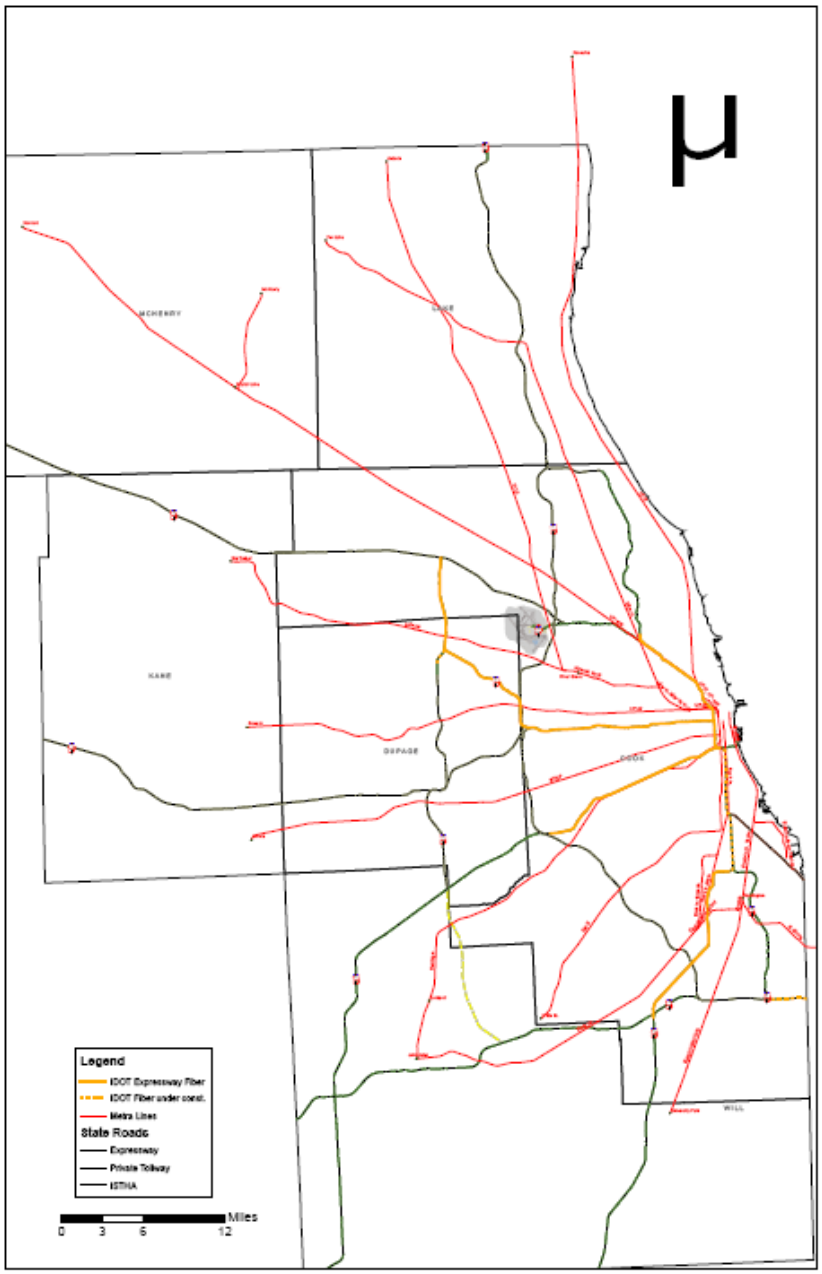

Figure 3: Current and future locations of IDOT's fiber-optic networks.

The routers would be placed at locations in close proximity to train tracks with access to wired network. Figure 3 shows the location of current and planned IDOT fiber-optic cabling. There are several spots along the tracks where the routers can be placed. The placement of the routers in the solution proposed in figure 2 is very critical. These routers can be viewed as spots where the internet-traffic is off-loaded on the wired-

network. If the routers are few and far between, it is likely that data-transfer rates (and consequently, performance) available to the users will worsen significantly. This is an issue that needs to be looked at when it comes to providing access to travelers who are not in the vicinity of Greater Chicago area where tracks and fiber optic cables are in close proximity at many locations.

There are two scenarios in which WiFi-enabled devices could be connected to the access points. The first, shown in figure 4, involves the direct communication between the WiFi-enabled devices and the track-side access points. The field experiments conducted in sections of the UPN Metra line suggest that this scenario would require an access point approximately every 0.5 miles along the track. As per prices quoted by *HierComm, Inc*., the 34 mile length of the UPN track would cost about $900,000. While there are terrain variations that need to be taken into account before pricing other locations, the rough estimate for this option would be in the $27,000-$30,000 range for each mile of track.

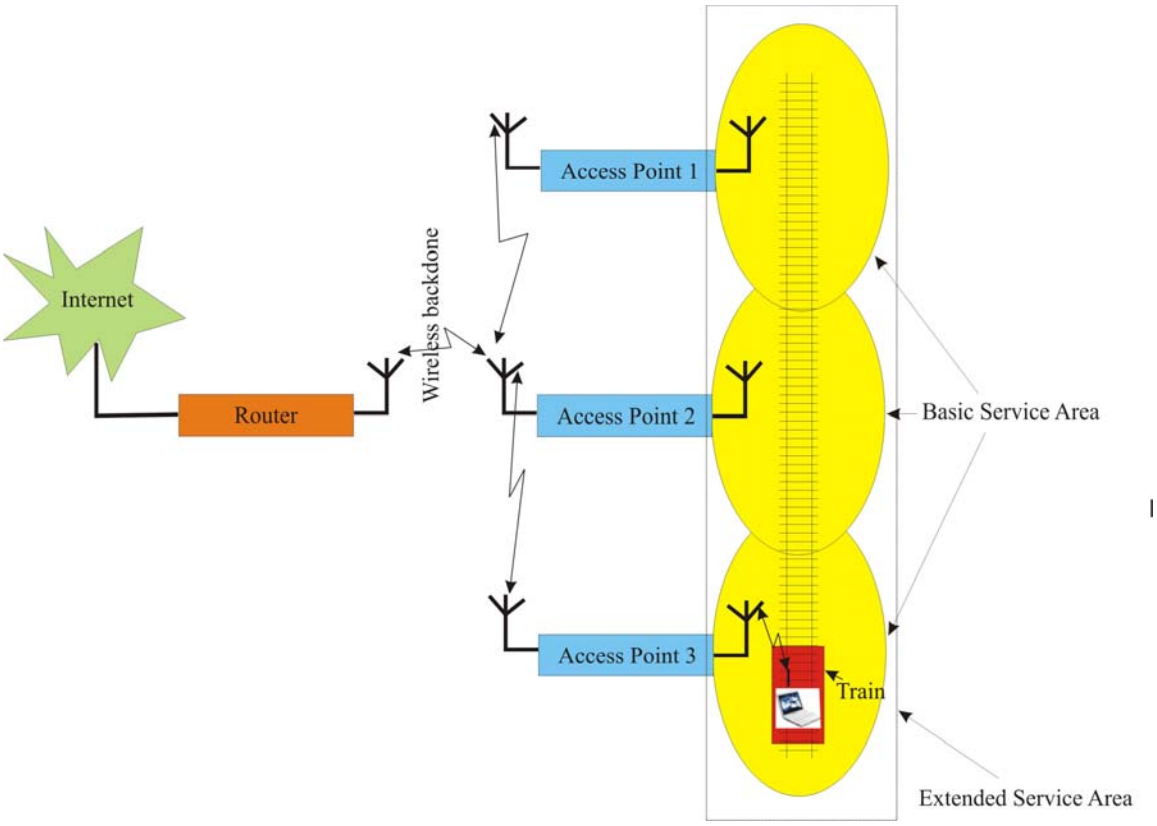

Figure 4: Direct connection between the Access Points and the customer equipment.

Alternately, one could adopt two variations on the scenario depicted in figure 5, where the WiFi-enabled device of the customer communicates to a transceiver that is either fixed to the train, or, is on a portable form-factor that can be easily off-loaded from the train if necessary. There will be a slight difference in the performance of these two systems as the train-mounted transceiver would have it antenna on the exterior of the train providing a stronger signal. The portable form-factor would have a slightly weaker signal sent out to the access point due to the fact that the relevant equipment stays on the

interior of the train. Tests conducted by *HierComm, Inc*. suggest that the train-mounted option would require an access point every 1.88 miles, while the portable option would require an access point every 1.54 miles. The cost estimate for the train-mounted option for the 34 mile stretch of the UPN line is about $250,000, while the portable option was priced at approximately $300,000. As mentioned before, there are terrain-variations that need to be considered before a precise estimate of cost can be obtained, but a ball-park estimate for the train-mounted option would be in the $7,500-$8,000 range per mile of track. The portable option would price approximately at $9,000-$10,000 range per mile of track.

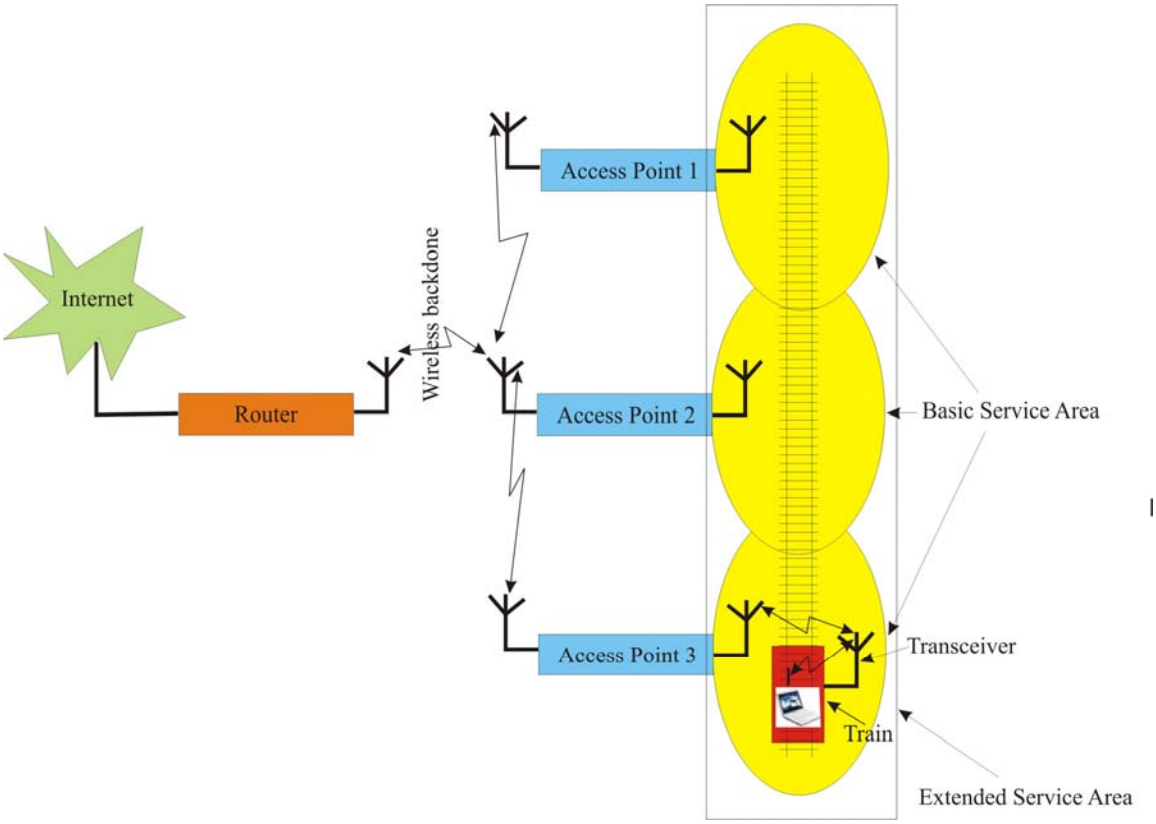

Figure 5: Connection between the Access Points and the customer equipment achieved through a Transceiver in the Train.

The experiments conducted by *HierComm, Inc*. also included a test where the WiFi devices communicated over the 5.8 GHz frequency band, instead of the 2.4 Ghz frequency band. The 5.8 GHz band has 12 channels of 20 MHz width, and consequently can provide better signal quality than the 2.4 GHz band. There are other devices like microwaves, cordless phones, etc. that use the 2.4 GHz band, and could create a significant amount of interference (with subsequent loss of signal quality) in this band. It is highly unlikely that these sources of interference are present in significant numbers in the train environment we are considering. The main issue with the use of 5.8 GHz frequency bands is that only those WiFi-devices that are IEEE 802.11a compatible will be able to use it. Devices that are IEEE 802.11b/g compatible only use the 2.4GHz frequency band and will require additional equipment on board for complete connectivity.

The quotes from *HierComm, Inc*. price this option at $240,000 for a 34 mile UPN segment. The interoperability issues with the common IEEE 802.11b/g devices would make this, albeit cheaper option, less desirable.

In summary, ad-hoc wireless mesh architectures like the one shown in figure 5, can provide reliable, good quality internet access (measured in terms of a signal strength of at least -80 dBm) to customers on train at a cost of approximately $10,000 per mile of track. This can serve as the base line for alternate scenarios described below.

WiMax (IEEE 802.16a)

WiMax, which stands for *Worldwide Interoperability for Microwave Access*, is a term that is used to refer to the IEEE 802.16a standard. This standard uses the 2 GHz to 66 GHz frequency band and provides (theoretically) a data-transfer rate of about 75 Mbps. Frequency bands above 11 GHz require a line-of-sight connection between communicating hosts. The 2 GHz to 11 GHz bands permit non-line-of-sight communication.

This technology is compatible with WiFi technologies described earlier. A typical scenario would involve WiFi-enabled devices at the customers premise to connect to IEEE 802.11 compliant access points, which are connected to a non-line-of-sight, point-to-multipoint IEEE 802.16a compatible access point. The 802.16a compliant access point can communicate directly to an out-of-sight tower. These 802.16a compliant towers are then backhauled through a series of IEEE 802.16 compliant, line-of-sight towers to the internet, or, the local telephone company.

As of today, this technology is not available in its entirety. The infrastructural modalities for the wide-deployment of this technology are quite involved in the context of providing internet access to passengers on trains. In a sense, one could adopt the scenario in figure 5 for this technology too. The access points in this figure have to be replaced by IEEE 802.16a compliant towers that are spaced about 4 to 5 miles apart along the length of the track. At locations where the tracks are close to the fiber optic networks (cf. figure 3), a line-of-sight backhaul can be provided between the track-side IEEE 802.16a compliant towers and the internet. Alternately, we can “mix-and-match” WiFi and WiMax technologies to arrive at a technology-mix that is more economical. That is, portions of the track can be served by WiFi-compliant access-points, others can be served by WiMax-compliant non-line-of-sight access points, and this mixture of access-points could be backhauled to the wired network using WiFi- or WiMax-compliant devices. While this is a little bit of an over-simplification, the reason for the product-mix could be that WiFi devices are cheaper, but have smaller range; WiMax devices are not cheap, but have larger range.

Our preliminary search for vendors seem to suggest that this technology is not as widely deployed as WiFi, and the standards are not completely adhered to by commercial vendors. This is a promising, but not yet mature, technology that can be a viable option for providing internet access to trains.

Cellular 3G

The *First Generation Cellular* (1G) systems were originally introduced in the early 1980's and the service was entirely analog. The *Second Generation* (2G) systems introduced in the mid-1990's were digital. These two systems used what is known as *circuit switching*, where a *virtual circuit* is established between the communication parties. The virtual circuit can be thought of as a pair of wires that connected the two parties involved in the conversation. At the end of the conversation these pair of wires are disconnected, and made available to others who need them. The first aspect where the *Third Generation* (3G) cellular systems diverged from the previous ones is that 3G systems involved *packet switching* as opposed to circuit switching. Here the voice communication between two parties are enclosed into packets that are routed through the network and re-assembled in the order they were sent before it is relayed to the party at the other end. There are several "intermediate generation" systems between 2G and 3G. The most common version of 2G systems is the *Global System Mobile* (GSM) system. This system when combined with what is known as the *General Packet Radio Service* (GPRS) is commonly referred to as the 2.5G cellular system. The 2.75G system is a GSM system combined with something called the *Enhanced Data Rate for GSM Evolution* (EDGE).

Reference[2] contains a comprehensive tutorial on the state-of-art on 3G cellular telephony. This reference also indicates the current roadblocks to the deployment of 3G services within the cellular service industry, which are not repeated here in the interest of space. The following quote from Sam May, US Bancorp Piper Jaffray, taken from this reference says it all:

> "*We believe the shelf life of 2.5G and 2.75G will be significantly longer than most pundits have predicted. Operators need to gain valuable experience in how to market packet data services before pushing forward with the construction of new 3G networks*."

According the cited reference, if cellular 3G systems are indeed widely deployed in the future a customer with a 3G-enabled device on the trains can see data transfer rates of 384 Kbps while moving (which is sufficient for internet access), assuming the providers have sufficient infrastructure to cover the areas where the train tracks are located. It is not exactly clear if and when wide-scale 3G deployment would be seen in the market place. It is important to note that although cellular coverage maps (cf. **http://www.cellphone.homestead.com/coveragemaps_deadcellzones.html**) seem to indicate a strong coverage in almost all regions in the state of Illinois, these coverage maps are for voice calls and not for data-transfer (which will require persistent and stronger signals).

In conclusion, if and when there is widely deployed 3G cellular coverage in the state of Illinois, it can be a strong contender for providing internet access to passengers on trains. The time-line for this deployment is not exactly clear. Experiments conducted using

[2] http://www.nmscommunications.com/file/3G_Tutorial.pdf

wireless cards from commercial cellular service providers by *HierComm, Inc*. suggest that this is not a viable option in the 34 mile segment of the UPN line. It is most likely that a similar experiment conducted down-state (as opposed to the Greater Chicago area) would yield less encouraging results.

Non-Technical Issues

The previous discussions have all centered around establishing the technical feasibility of providing internet access to passengers on trains. We now turn our attention to a few non-technical issues that can be significant roadblocks to deployment.

Security and Authentication

It is important to secure access to network irrespective of the chosen technology. This discussion on security and management assumes WiFi technologies are chosen for deployment. These points are equally valid, with appropriate modifications, to the WiMax option as well. However this discussion is moot as far as cellular systems are concerned as they have stronger authentication, security and billing procedures.

Network access can be secured through WEP key-management. This will require the personnel on board the train to distribute and manage (i.e. change the keys on a regular basis) the WEP keys. One could draw a parallel between this and what is usually done in commercial eateries that provide free internet access as a value-added service to their customers. The employers of these premises are required to distribute, and change the WEP keys. This will require buy-in from the train service providers.

An alternative to consider would be to re-direct any access to a common gateway where the users are authenticated (as paying customers). This is a common procedure among hotels that provide internet access to their clientele. This will require additional back-office support and billing-infrastructure to be handled by the service provider and could add to the cost.

Track- and Train-Side Infrastructure

Access points for the WiFi or WiMax options would require the installation of approximately *2' x 1' x 1'* form-factor that houses the relevant equipment and an external (possibly, directional) antenna. These would have to be mounted on a pole that is at least 20 feet off the ground in the right-of-way. The service providers might be required to pay a rental fee for these installations to the owners of the right-of-way. This recurring expenditure would have to be offset by revenues generated for any option to be viable.

The fixed-train solution (cf. figure 5) would require buy-in from the train service providers. For example, the train-cars of a train service provider could be in the state of Illinois on a particular day and a different state the next. In effect the provider would have to either modify all train-cars, or, manage the train-car assignments, so that internet

service can be guaranteed to all its customers in the state of Illinois. If the train service provider is also the internet service provider there could be a strong incentive for these modifications. This would depend on the estimated revenue generated by internet service.

Fair-Estimates of Consumer Interest

The vision of providing internet access to passengers on trains is technically feasible. But the issues raised above require a "business-side" analysis before it can be translated into reality. It is important to estimate the revenue that such a venture can generate for a service provider. It is important to know if there is lack of consumer-support for any reasonable price-structure that can provide appropriate pay-back. A thorough approach, which will require more time, would involve conducting consumer surveys on different segments to gauge support. This could be left to the service providers, but if there is a very strong support, it might make more sense for the State of Illinois to take on the role of a service provider (through an appropriate channel). In this case appropriate incentive schemes have to be devised to keep the train-service providers interest in the project.

"Dual-Use" Incentives

WiMax and Cellular 3G require significant capital investment from the providers. We view these solutions as "dual use" solutions. For instance, a provider of internet service on trains through these technologies can also provide multi-media access to remote areas in the state of Illinois. Assuming there no significant regulated-monopoly barriers, this could be a better option for the citizens of Illinois. The larger consumer-base that such "dual-use" can provide may be enough of an incentive for these service providers to enter the market. Having said that, it is important to keep in mind that today these technologies are no where close to what they promise.

Conclusion

The vision of providing internet access to passengers on trains is certainly technically feasible. The experiments conducted by *HeirComm, Inc.*, using WiFi technology suggest that the infrastructural cost would be in the vicinity of $10,000 per mile of track. WiMax and Cellular 3G technologies are strong contenders under ideal circumstances. However, these technologies have suffered from pushback and are not available in their promised-form in the market to date.

There are several non-technical issues that can become roadblocks to the vision proposed by the Illinois Legislature. It is not hard to see that investment decisions will be based on the estimate of the customer-base for internet service on trains. We recommend a marketing survey of passengers as an important next step.

Biography of the Author

Professor Ramavarapu "RS" Sreenivas is an Associate Professor of *Industrial and Enterprise Systems Engineering* (http://www.iese.uiuc.edu/) at the *University of Illinois at Urbana-Champaign*. He is also a Research Associate Professor at the *Coordinated Sciences Laboratory* (http://www.csl.uiuc.edu/) and the *Information Trust Institute* (http://www.iti.uiuc.edu/) at the University. He received his Bachelors degree in *Electrical Engineering* from the *Indian Institute of Technology* (IIT) at Madras, India in 1985. He then obtained his M.S. and Ph.D. degrees from *Carnegie Mellon University* in Pittsburgh, PA in 1987 and 1990 respectively. From 1990 to 1992 he was a *Post-doctoral Fellow* in *Decision and Control* at *Harvard University* in Cambridge, MA. He has been at the University of Illinois at Urbana-Champaign since 1992. He is a *Senior Member* of the *Institute of Electric and Electronic Engineers* (IEEE), and has been as Associate Editor of the IEEE Transactions on Automatic Control. He has featured in the "*Incomplete list of Instructors ranked Excellent*" at the University of Illinois at Urbana-Champaign on many occasions.

His publications that are relevant to the present project include:

1. R. Gummadi, K. Jung, D. Shah and R.S. Sreenivas, "Feasible rate allocation in wireless networks," To appear in *INFOCOM-2008*.
2. N. Singh and R.S. Sreenivas, "On Distributed Algorithms that Enforce Proportional Fairness in Ad-hoc Wireless Networks," In Proceedings of the *5th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks* (WiOpt-07), April 2007, Limassol, Cyprus.
3. N. Singh and R.S. Sreenivas, "Approximating Flow-Based Proportional Fairness in Ad-hoc Wireless Networks," Session T1s06p04, Phy/MAC Track, *IEEE Wireless Communications and Networking Conference* (WCNC), Hong Kong, March, 2007.
4. V. Kawadia, S. Narayanaswamy, R. Rozovsky, R. S. Sreenivas, and P. R. Kumar, "Protocols for Media Access Control and Power Control in Wireless Networks," In Proceedings of the *40th IEEE Conference on Decision and Control*, pp. 1935-1940, Orlando, FL, December, 2001.
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FINAL REPORT

FEASIBILITY STUDY
BROADBAND WIRELESS COMMUNICATIONS
for
CHICAGO METRA

December 17, 2007

Submitted to:
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Springfield, IL 62764

Introduction

In response to the Illinois Department of Transportation's request for an Internet access communications system on all passenger rail systems in Illinois, HierComm, Inc. has conducted a feasibility study to determine the potential ability of its enhanced WiFi communications technology to provide low cost, high speed data communications to rail passengers in the State of Illinois beginning with initial deployment on the Metra rail network serving the Chicago area. This WiFi-compatible but performance-enhanced version of IEEE Standard 802.11g is known as SERT for Shannon-Enhanced Radio Technology. Shannon's Law determines the capacity of any communications channel based on its bandwidth and its signal-to-noise ratio. Most advances in wireless communications to date have been based on the more efficient use of bandwidth, but SERT emphasizes enhancements of the signal-to-noise ratio. The SERT wireless communications system was originally developed to provide very low cost broadband wireless networks in rural areas where population densities are low and the deployment economics very challenging. SERT wireless networks employ sectoral topologies and high gain active directional antennas to extend the WiFi range and drastically lower the costs of network deployment. In the rural town of Wayne in Southern Wisconsin, HierComm was able to deploy a broadband wireless WiFi network with only four antenna sites (access points) covering a 36 square mile area. This development in advanced broadband wireless communications for rural America was sponsored by a grant from the U.S. Department of Agriculture. The goal of this grant was to develop a broadband communications system suitable for cost effective deployment in low population density rural regions. The Wayne network deployment is witness to the success of this development. The cost of such a network would be only around $100,000. SERT WiFi communications technology also lends itself very well to the proposed rail line wireless network. The small antenna beamwidth requirements of a rail line network further enhance the performance potential of a SERT/WiFi network beyond that already achieved in rural broadband deployment. For this reason, the SERT/WiFi broadband wireless communications system is believed to offer the most cost effective alternative for high speed WiFi-based data transmission services for the Illinois passenger rail network.

System Design Alternatives

Five alternative network configurations were evaluated during the feasibility study:

1. Access Point Direct Infrastructure
   -In this configuration, rail passengers will communicate directly from their laptop computers with the nearest access point along the rail line.
   -This configuration because of its reduced range will require the largest number of access points and the highest infrastructure costs.
   -Network design supported by field measurements confirmed this choice as having the highest AP density and highest cost infrastructure as detailed below.

2. Fixed Train-Mounted Network Infrastructure
   -This configuration provides a fixed transceiver-router in each of the passenger trains (set of rail cars).
   -This configuration resulted in the lowest access point density and the lowest infrastructure cost as shown in the design and field studies below.
3. Portable Train-Mounted Network Infrastructure
   -In this configuration, the train transceiver is portable but still provides for a high performance wireless network.
   -This configuration requires only a slightly higher access point density and infrastructure cost than the fixed mobile transceiver.
   -Greater flexibility with a high performance/cost ratio results from selecting this configuration.

4. Existing Mobile Cellular Network
   -In this configuration, Internet access would be achieved using an existing cellular network service converted to WiFi signals by conversion equipment in each passenger train.
   -This configuration option would be the slowest of all of the alternatives and not truly broadband in throughput as defined for this operation.

5. Higher Frequency WiFiA Infrastructure
   -This configuration is a variation of the first and second infrastructure options listed above in which the 5.8 GHz frequency is used instead of 2.4 GHz to avoid radio interference.
   -The need for this alternative depends on the amount of interference encountered during field testing. If radio interference at 2.4 GHz becomes an obstacle, one of the 5 GHz frequency bands could be used for network communications with a radio frequency conversion unit in the train providing 2.4 GHz local data transmission for passengers.

Work Plan Activities

Work activities during the feasibility study were carried out in the following time sequence:

1. Network Modeling-Based System Design
   Preliminary network infrastructure designs for the UP-N Metra rail line for four of the five system alternatives were completed using EDX Signal ™ radio propagation modeling software and the EGS Clutter, Terrain, Vector database. This modeling package allows for experimental placement of access points and subsequent determination of signal levels along the rail line to determine the required spacing of access points for a specified level of performance and service.

The remote receiver signal enhancement capabilities will vary for each of the four alternatives depending on whether a laptop computer, fixed high gain receiver or portable high gain receiver is employed in the wireless communications system. The end result is a set of four UP-N rail line designs that also are cognizant of the track direction and the surrounding area conditions. In addition to producing preliminary network infrastructure designs, network modeling also provides guidance to field testing in establishing the approximate access point spacing for each of the infrastructure alternatives. Without such guidance, more extensive field measurements would be required. With this design sequence approach, field testing provides both confirmation and parameter adjustments of the preliminary network design.

2. Field Test Equipment Assembly and Checkout
   Field testing procedures for the rail line wireless network will be similar to those used by HierComm in its wireless plan testing for rural and suburban applications. In previous testing, a vehicle with access point transceiver equipment including a 20 foot antenna mast was parked at a proposed access point. A second vehicle then roamed the proposed coverage area mapping audio signal levels and signal-to-noise (SNR) parameter data throughout the area. Such data would provide the basis for evaluating the efficacy of the access point location. By mapping all of the access points needed for community coverage, the preliminary modeling-based network plan will be both modified and confirmed.

   In this rail line-oriented application, the functional characteristics of the communication equipment used in field testing remain basically the same as in rural wireless networks with the exception of the antennas employed. With the fixed train-mounted network, the following antenna specifications apply:

   a. Access Point Antenna
      gain – 18 dBi
      beamwidth – 22 degrees
   b. Remote Transceiver Antenna
      gain – 15 dBi
      beamwidth – 30 degrees

   For the portable train-mounted network, the access point antenna is the same, but the remote antenna is omnidirectional with a gain of:

   Remote Omnidirectional Antenna
      Gain – 9 dBi

   The test equipment configuration differs also in that the remote equipment must be portable rather than truck mounted since it must be hand carried along the rail

line. The access point (AP) equipment is similar to that used in rural-suburban networks field tests. AP equipment is truck-mounted with the directional antenna on a 20 foot mast attached to the trailer hitch at the rear of the truck. The AP and remote equipment were assembled in preparation for field testing.

Field Testing

The purpose of pre-deployment field testing in wireless communications system design is to verify and/or correct the preliminary network design based on radio propagation modeling. Although modeling-based designs have proven quite accurate particularly in rural wireless networks, there are at least two major sources of error:

1. Physical modeling approximation
   -A radio propagation model is only an approximation of radio wave propagation behavior. Although HierComm has found the Anderson 2D physical model that HierComm employs remarkably accurate in its estimation of radio signal levels at varying ranges from access point sites, there are small errors even in free space radio propagation that must that must be corrected in field calibration testing studies.

2. Terrain/Clutter Database Resolution and Accuracy
   -A larger source of error in radio propagation channels involving natural (trees) and structural (buildings) "clutter" is the resolution and accuracy of the database. While terrain features are typically accurately defined, clutter definition gathered from NASA shuttle and satellite photography has resolution and accuracy limitations that are particularly noteworthy in urbanized areas. The narrow path corridor of a rail line is particularly subject to model-based signal attenuation from clutter overlap that results in greater signal attenuation than actually occurs in the rail line environment.

With such prior knowledge of radio propagation-based network design limitations, a field testing program was carried out in which a truck vehicle with a mast-mounted antenna served as a mobile access point. Parking the AP vehicle parallel to the tracks near a railroad crossing made it possible to measure signal levels and signal-to-noise ratios with a portable remote transceiver equipped with each of the two antenna types (directional and omnidirectional) to be used in the fixed and portable train-mounted network alternatives. The access point direct measurements can be made with a WiFi-equipped laptop computer. The radio propagation model-based designs provided guidance on the probable range of measurements. Such guidance greatly expedited the field testing process.

Field testing was originally planned for two sections of the UP-N Metra rail line – on the northern end in the Zion-Waukegan vicinity in Lake County and in the urban Chicago area between Rogers and Ravenwood. Testing in these two locations was necessary

because of shortcomings in the clutter-terrain database. Because of resolution limitations of the database, communications pathways will appear to have attenuation from buildings and other structures that are exaggerated. This limitation is demonstrated in the closer spacing of urban as opposed to the more open rural areas. Field measurements in both types of environment will allow for correction factors to be applied to the preliminary infrastructure plan that will expand the AP spacing in more populated urban areas.

Weather conditions in the Chicago area during the week of December 9th made field measurements on the UP-N rail line extremely difficult. Such conditions along with the need to arrange for personnel support from the Union Pacific Railroad resulted in a decision to shift the test site area to Southeastern Wisconsin. Although weather conditions were equally harsh in Wisconsin, abandoned rail lines in Wisconsin now used as bike trails represented an ideal test environment for model verification. These bike paths were also clear of snow from plowing and presented no danger to Company personnel. A particularly ideal old rain line, the Glacial Drumlin Trail, was selected since it offered a mixture of urban and rural settings east and west of Waukesha, Wisconsin.

Testing was carried out on all three advanced WiFi alternatives – the fixed train-mounted, the portable train-mounted and the access point direct. Access point spacing measurements were based on a combination of signal levels as measured in dBmW (decibels referenced to one milliwatt) and signal-to-noise ratio (SNR) as measured in dB (decibels). With a signal level standard of -65 dBmW and an SNR standard of 30 dB, the following access point spacing distances were estimated for the three WiFi alternatives:

1. Fixed Train-Mounted – 4.0 miles
2. Portable Train-Mounted – 3.0 miles
3. Access-Point Direct – 0.75 miles

These straight line, open path distance measurements now allow for model recalibration. The actual access point spacing distances will be model-determined based on track direction changes, terrain and other signal attenuation factors. The preliminary (before field testing) and the final (after field testing) network plans for the UP-N line are detailed and illustrated in the next section of the report.

The original set of wireless communications alternatives considered for Illinois passenger rail broadband communications were WiFi, WiMAX and existing third generation (3G) cellular networks such as Verizon Wireless CDMA network or AT&T's GSM network. These networks have the advantage of already being in place and ready for use. They have, however, significant disadvantages particularly their much slower throughput levels especially in the upstream direction and their need for CDMA/WiFi or GSM/WiFi conversion equipment on each passenger train. To provide a fair comparison, however, field measurements using a Verizon Wireless Qualcomm Model V620 PC card installed in a laptop computer were evaluated for throughput performance during the

week of December 9th. The CDMA technology used by Verizon Wireless is believed to be representative of the best third generation cellular wireless data communications offered in the U.S. market. In a comprehensive field evaluation of all of the cellular wireless carriers performed by the Southeastern Wisconsin Regional Planning Commission in 2006, the Verizon Wireless network out-performed the other five wireless carriers using either second generation (2G) or third generation (3G) technology. This field test sequence employed the broadband access (3G) option on the Verizon PC card. Both download and upload throughput performances were evaluated with the following results:

Download Throughput Performance

Test period - 3 hours
Data samples - 4,969
Average throughput - 1.31 megabits/second
Minimum throughput - 0.01 megabits/second
Maximum throughput - 1.69 megabits/second
Standard deviation - 0.14 megabits/second

Upload Throughput Performance

Test period - 6 hours
Data samples - 5,767
Average throughput - 138.1 kilobits/second
Minimum throughput - 1.6 kilobits/second
Maximum throughput - 191.5 kilobits/second
Standard deviation - 23.7 kilobits/second

From the above, it is apparent that the installed Verizon cellular option for passenger rail broadband communications is an order of magnitude slower in the down stream direction (1.3 vs. 13.0 Mbps) and two orders of magnitude slower in the upstream direction. Upstream processing will be particularly frustrating for professional or business rail travelers engaged in file transfers or other upstream-oriented communications.

UP-N Rail Line Broadband Network Designs

Fixed Train-Mounted Transceiver Network Designs

The preliminary fixed train-mounted transceiver network design for the UP-N Metra rail line based on EDX radio propagation modeling software, the EGS terrain and clutter database with a design signal level of -80 dBmW is shown in Map 1. Such a signal level will provide a theoretical data throughput of at least 24 megabits per second in both directions. The actual throughput rate will be in the 12-17 megabits per second range based on rural Wisconsin experience. Eighteen (18) access points were required over an approximate distance of 34 miles for AP average spacing of 1.89 miles. AP spacing is

much closer in urban areas because of the database limitations previously referenced. This discrepancy is corrected below based on field measurements.

In this design, as with all of the other alternatives, backhaul links can be provided at selected AP locations depending on the availability and location of fiber gateways. Other AP sites not located near fiber gateways would backhaul through adjacent access points. It is difficult to finalize the backhaul design until the fiber gateway locations are identified. Since a 5.8 GHz backhaul radio will be located at each AP, the system is flexible in providing numerous backhaul options.

The revised fixed train-mounted transceiver network design based on field measurement-based recalibration is shown in Map 5. The signal level threshold for access point spacing was elevated to -65 dBmW in order to provide an increased signal loss safety margin. Such an improvement in potential network performance was made possible by the better than expected field measurements. The number of access points was reduced from eighteen (18) to eight (8). The open space nature of rail line transmission results in greatly reduced radio signal attenuation. Such low signal attenuation coupled with the high gain active antennas employed allow for a low cost, long range WiFi infrastructure. The average access point spacing distance expands to 4.25 miles. It is important to reemphasize that each access point is bi-directional, so that the link distance of each of the two transceivers at each AP is half the spacing distance or 2.12 miles.

Portable Train-Mounted Network Design

The preliminary portable train-mounted transceiver network design for the same UP-N Metra rail line using the same software, database tools and -80 dBmW design standard is shown in Map 2. Twenty-two (22) access points were required over the same 34 mile rail line distance for an average AP spacing of 1.54 miles. Again, this number of access points was reduced after adjustments from field testing. Backhaul connections in this design would be handled in the same manner as in the previous fixed remote design.

The revised portable train-mounted transceiver network design derived from field test-based model recalibration is shown in Map 6. Using the same -65 dBmW signal level standards, the number of access points was reduced 50% from twenty-two (22) to eleven (11) for an average AP spacing of 3.1 miles. The shorter spacing distance results from the need to use an omnidirectional antenna rather than the higher gain directional antenna used in the fixed transceiver design. Additional losses will result from the interior location of the portable transceiver on the train.

Access-Point Direct Network Design

This design requires no wireless communications equipment on the moving train. Lacking local transceivers and routers, laptop computer users will communicate directly with access point transceivers along the rail line. The low transmit power and receiver

sensitivity of the laptop computer is the weak link in the communications chain. The combined effect of these two shortcomings is the need for 65 access points to service the 34 mile line for an average AP spacing of 0.52 miles. Once again, some reduction in this AP density may be expected after field test adjustments. The preliminary model-based design is illustrated in Map 3.

The revised access point direct network design resulting from field test model recalibration is shown in Map 7. Based on the same signal level standards, the number of access points was reduced from sixty-five (65) to forty-three (43) with an average AP spacing distance of 0.79 miles. With each AP transceiver ranging 0.40 miles (about 2100 feet), this distance exceeds normal WiFi range coverage because of the high gain antennas at each access point.

Higher Frequency Fixed Train-Mounted Network Design

The above three network design alternatives are all based on operation in the 2.4 GHz unlicensed frequency band. Field testing will determine the current state of radio interference in this frequency band. Because the proposed wireless network designs are based on high gain, narrow-beam, point-to-point network structures, it is believed that such radio interference should not present a major problem. In the event, however, that such interference is determined to present an unreliable noisy environment at 2.4 GHz, a WiFiA higher frequency 5.8 GHz design has been model designed but not field tested. This network design shown in Map 4 was prepared using the same software, database and standards as the other 2.4 GHz band designs. Since most laptop computer WiFi communications operate at 2.4 GHz, only those two alternatives with train-mounted equipment are viable for this alternative design. A 5.8/2.4 GHz frequency conversion function on the train must be provided with this alternative. Only the fixed train-mounted network alternative was evaluated. The design requires only 16 access points along the UP-N rail line for an average AP spacing of 2.12 miles.

It may seem somewhat surprising that the 5.8 GHz WiFiA network is lowest in infrastructure cost since higher frequencies result in higher radio wave attenuation. This frequency-based attenuation factor, however, is more than compensated by the increased transmitter power allowed by the FCC in this frequency band and the higher gain provided by the directional antenna.

Field testing was not performed in the 5.8 GHz frequency band. If radio frequency interference problems are encountered in the pilot network operation, the frequency of the system could be shifted from the 2.4 GHz band to the 5.8 GHz band by an exchange of antennas at each access point since each AP transceiver is designed to operate in either 2.4 GHz or 5.8 GHz band. An option will be offered in the Pilot Project budget to evaluate 5.8 GHz operation during the pilot demonstration period.

Network Design Summary

The fixed train-mounted transceiver network design with 8 access points offers the lowest infrastructure cost alternative using either the 2.4 GHz or the 5.8 GHz band. The 5.8 GHz design would still allow the rail passenger user to employ the standard 802.11g, 2.4 GHz network interface card. The portable train-mounted transceiver network design with 11 access points, however, seems to be the most attractive alternative with only a slightly higher infrastructure cost. The portable mobile transceiver design requires no permanent changes to rail car equipment and offers significant flexibility in network operation. Multiple mobile transceivers may be used on a given passenger train depending on its length and the expected number of users. The access point direct method requires no fixed or portable equipment on the train, but it will have an infrastructure cost at least four times that of the other two network design alternatives. The 5.8 GHz network alternative has advantages beyond lower susceptibility to radio interference. It should be evaluated during the pilot demonstration program.

The WiMAX Alternative

WiMAX along with the advanced, long range version of WiFi proposed here was suggested as an alternative technology for this passenger rail broadband application. Evaluation of the current state of WiMAX (IEEE Standard 802.16) strongly indicates its unsuitability for deployment at this time for the following reasons:

1. Cost
   WiMAX access point infrastructure equipment currently costs about three times the equivalent WiFi equipment with no performance advantage. Although the access protocol on WiMAX is more sophisticated than that of WiFi, this slight advantage would be lost in any event because of the need to convert to WiFi in order to serve current passenger train users equipped only with WiFi network interface cards.

2. Emphasis on Licensed Frequency Bands
   Most WiMAX communications equipment is being developed for the licensed 2.5 GHz and 3.5 GHz frequency bands. Obtaining a license for these bands would be extremely costly if it could be obtained at all. The narrow rail line corridors of the communications channels also would not justify an area wide license. The only justification for using licensed bands is their freedom from radio interference. The high signal levels and the directive nature of the broadband rail network should make it immune from 2.4 GHz band radio interference. If significant interference is experience during the pilot demonstration, conversion to the less used unlicensed 5.8 GHz band may be accomplished with minor equipment changes.

3. Ease of Future Conversion to WiMAX
   The innovative features of the proposed SERT/WiFi System are all in the radio frequency (RF) "front end" part of the system. This RF front end will work equally well with WiMAX as with WiFi technology. If lower cost unlicensed band WiMAX with performance advantages becomes available in the future, the system could be converted to WiMAX at a fraction of the total system cost.

UP-Rail Line Budget Estimates

This budget is prepared for State of Illinois planning purposes even though some items of a UP-N Rail Line Pilot Demonstration Program such as the cost of access point mounting structures, electrical power connections and Internet gateway connections are still uncertain. These budget items will be verified in a formal cost proposal by HierComm, Inc. Despite these budget item uncertainties, the overall cost per mile budget estimate is believed to be accurate within a range of +/-10%.

Even a preliminary budget estimate on the UP-N rail line must contend with three current unknown cost categories:

1. Backhaul – Gateway Connections
   The availability and cost of Internet gateway interconnections is not yet well defined. The cost of backhaul equipment is included in the budgetary estimate below, but the number of backhaul connections is still unknown. The most direct solution is a backhaul connection for each access point, but such an approach would require gateway availability in the vicinity of each access point. Such availability must still be determined. The budget estimates below assume a backhaul for each AP.

2. Electric Power Connections
   The availability and cost of electric power connections are still unknown.

3. Access Point Pole and Mounting Structure
   Uniform positioning of access point directional antennas and the lack of other suitable antenna mount structures make it advisable to adopt a standard access point pole and mounting structure. Network performance critically depends on the parallel alignment of directional antennas with the rail line.

With these uncertainties in mind, initial budget estimates for network access points and then for each of the four alternative network designs are tabulated below:

Access Point Budget

1. Transceiver Modules
   2 @ $1500 = $3,000
2. Directional Antennas
   2 @ $55 = $110
3. High Gain Amplifiers
   2 @ $440 = $880
4. Auxiliary Components
   and Equipment = $850
5. Installation and Startup = $3,500
6. Access Point Pole and
   Mounting Structure = $5,000
   Total, AP Budget $13,340

Fixed Train-Mounted Network Budget

1. Access Points
   8 @$13,340 = $106,720
2. Internet Gateway Connections
   8 @$5,000 = $40,000
3. Network Monitoring System = $20,000
4. Project Management
   and Engineering = $178,800
   $345,520

Portable Train-Mounted Network Budget

1. Access Points
   11 @$13,340 = $146,740
2. Internet Gateway Connections
   11 @$5,000 = $55,000
3. Network Monitoring System = $20,000
4. Project Management
   and Engineering = $178,800
   $400,540

Access Point Direct Network Budget

1. Access Points
   43 @$13,340 = $573,620
2. Internet Gateway Connections
   43 @$5,000 = $215,000
3. Network Monitoring System = $60,000
4. Project Management
   and Engineering = $200,000
   $1,048,620

5.8 GHz Portable Train-Mounted Network Option

Task: Modify and test network operation at 5.8 GHz frequency band.
Budget: Additional $45,000

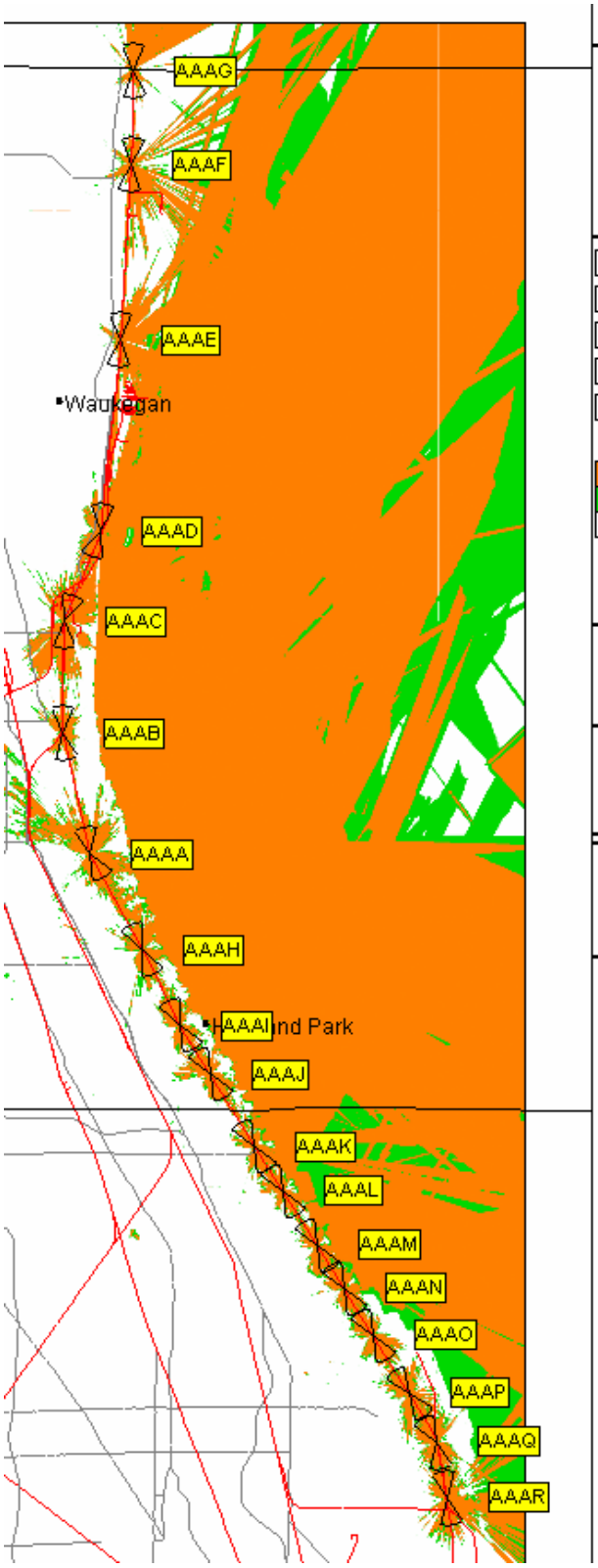
Portable Train-Mounted Transceiver/Routers

For the portable train-mounted transceiver network design, portable remote units are estimated at $800 per unit. A budget for 20 units or $16,000 is recommended.

A budget for the fixed train-mounted equipment is estimated at $2,000 per unit including installation for a 20-unit budget of $40,000.

Note 1: No budgetary costs for property purchase or rental is included in this budget.

Note 2: No operating costs for fiber Internet service is included in this budget. A level of upload and download throughput performance must be specified before these operating costs can be estimated.



EDX SignalPro™: ILLINOIS RAIL PROJECT - TRAIN MOUNTED

Prop. model 1: Anderson-2D v1.00
Time: 90.0% Loc.: 90.0%
Prediction Confidence Margin: 0.0dB
Climate: Continental Temperate
Land use (clutter): EDX .GCV format
Atmospheric Abs.: none
K Factor: 1.333

County Boundries
Railways
Interstates
Primary Roads
Secondary Roads

Received Power at remote

>	-118.0 dBmW	24 to 54 Mb Modulation
	-127.0 to -118.0 dBmW	6 to 24 Mb Modulation
<	-127.0 dBmW	Out of Specification

Display threshold level: -128.0 dBmW
RX Antenna - Type: DA
Height: 10.0 ft AGL Gain: 12.85 dBd

Notes

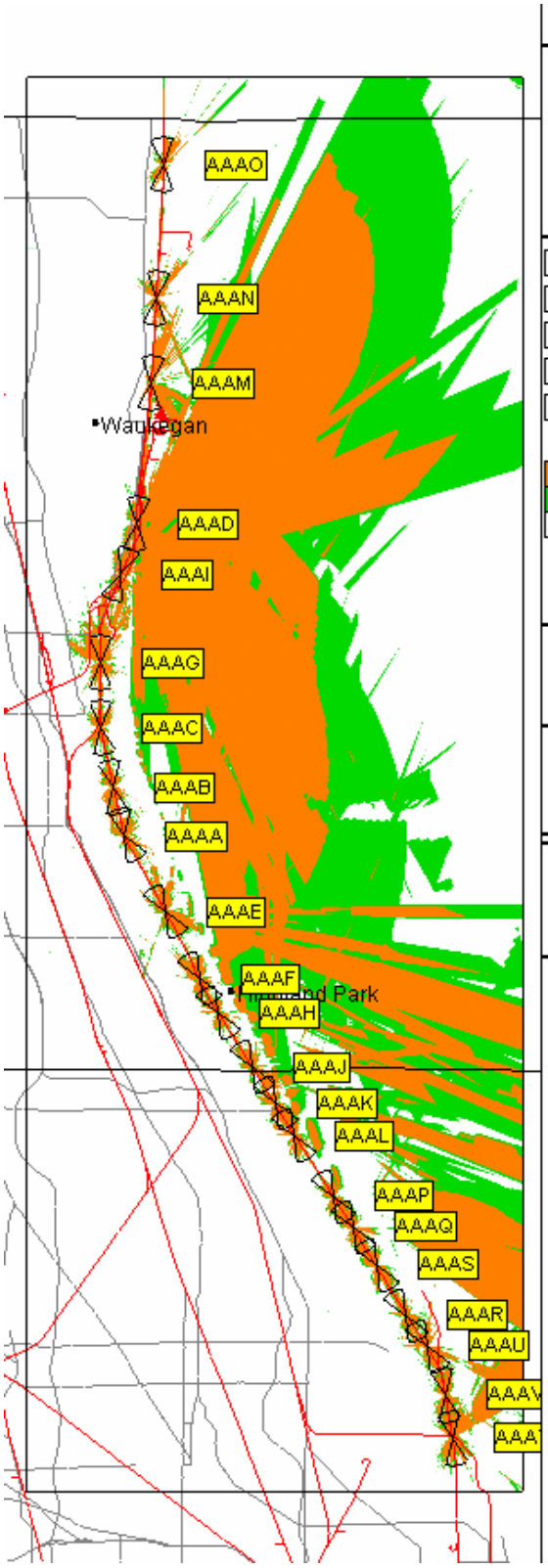
Access Point height: 20 ft.
Access Point Antenna Gain: 18 dbi

MILES
-1 0 4

Illinois DOT Rail Project - Map 1

Fixed Train-Mounted Wireless Network

23 db preamplifier



EDX SignalPro™: ILLINOIS RAIL PROJECT - MOBILE CPE

Prop. model 1: Anderson-2D v1.00
Time: 90.0% Loc.: 90.0%
Prediction Confidence Margin: 0.0dB
Climate: Continental Temperate
Land use (clutter): EDX .GCV format
Atmospheric Abs.: none
K Factor: 1.333

County Boundries
Railways
Interstates
Primary Roads
Secondary Roads

Received Power at remote

>	-112.0 dBmW	24 to 54 Mb Modulation
	-121.0 to -112.0 dBmW	6 to 24 Mb Modulation
<	-121.0 dBmW	Out of Specification

Display threshold level: -121.0 dBmW
RX Antenna - Type: OMNI
Height: 6.0 ft AGL Gain: 6.85 dBd

Notes

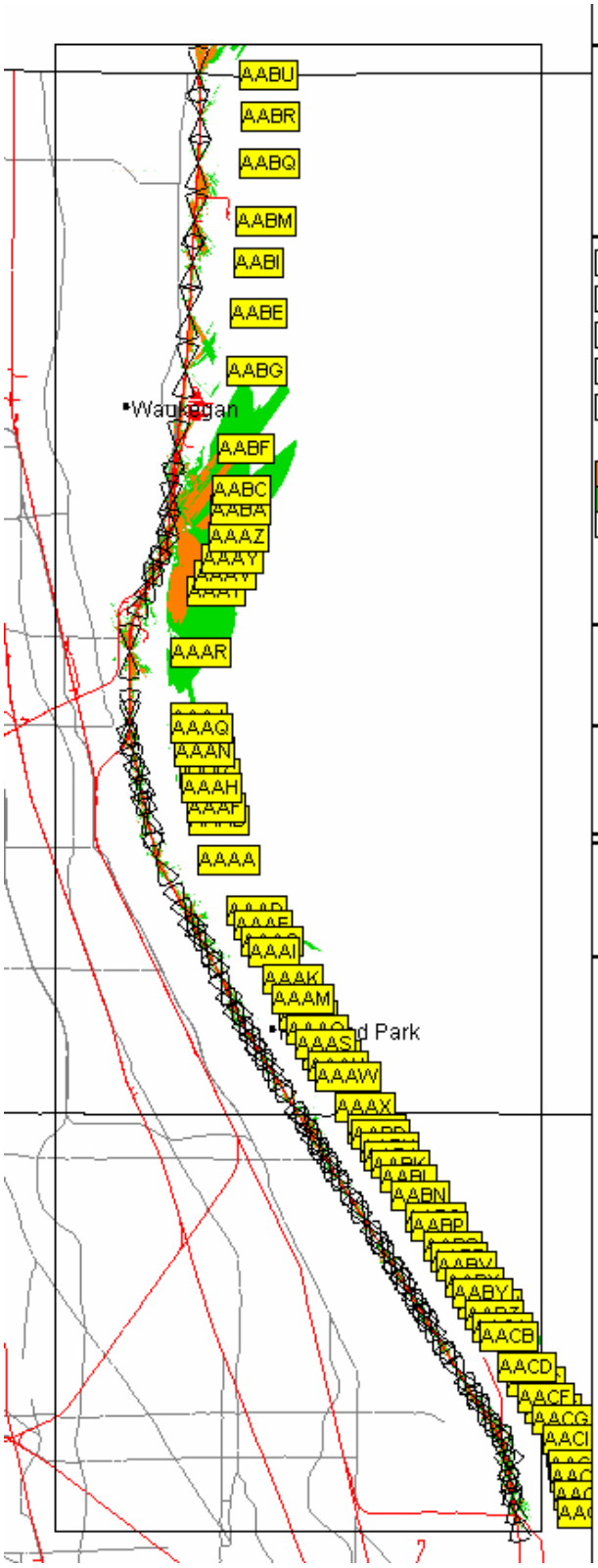
Access Point height: 20 ft.
Access Point Antenna Gain: 18 dbi

MILES
-1 0 4

Illinois DOT Rail Project - Map 2

Portable Train-Mounted Wireless Network

23 db preamplifier



EDX SignalPro™: ILLINOIS RAIL PROJECT - LAPTOP USER

Prop. model 1: Anderson-2D v1.00
Time: 90.0% Loc.: 90.0%
Prediction Confidence Margin: 0.0dB
Climate: Continental Temperate
Land use (clutter): EDX .GCV format
Atmospheric Abs.: none
K Factor: 1.333

- County Boundries
- Railways
- Interstates
- Primary Roads
- Secondary Roads

Received Power at remote

>	-80.0 dBmW	24 to 54 Mb Modulation
	-89.0 to -80.0 dBmW	6 to 24 Mb Modulation
<	-89.0 dBmW	Out of Specification

Display threshold level: -89.0 dBmW
RX Antenna - Type: OMNI
Height: 10.0 ft AGL Gain: -2.15 dBd

Notes

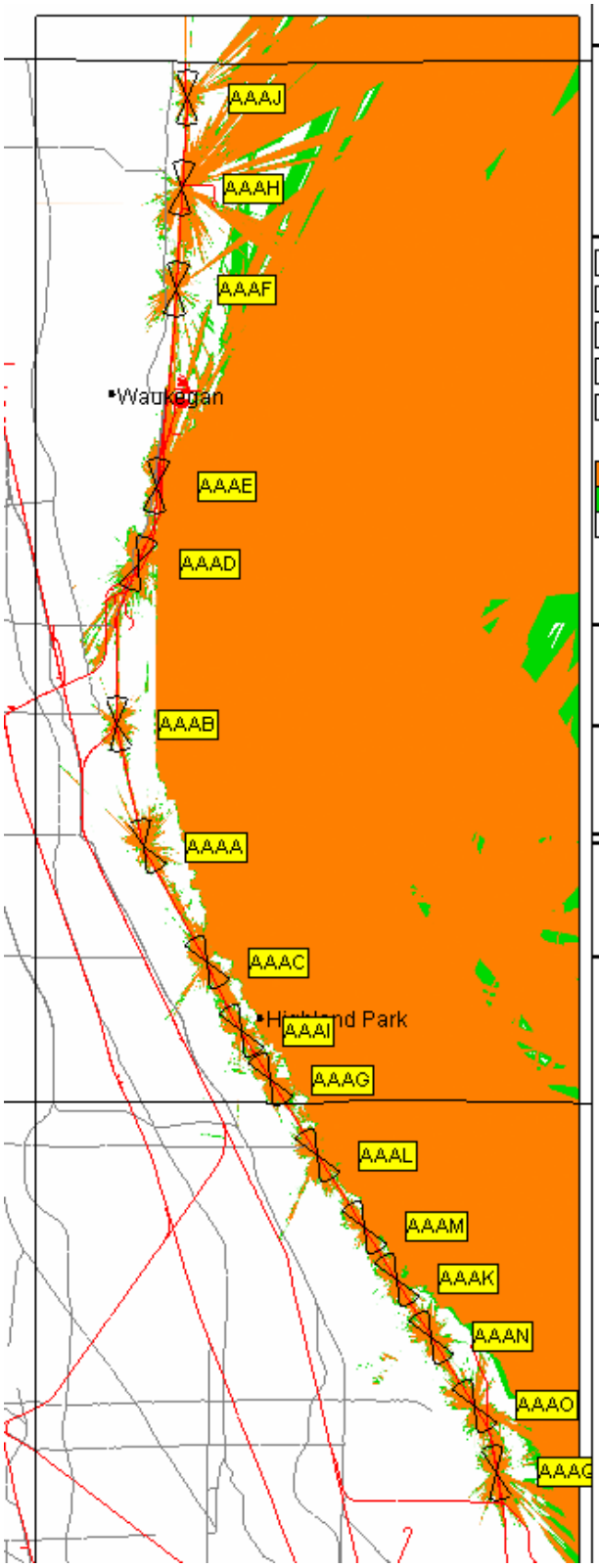
Access Point height: 20 ft.
Access Point Antenna Gain: 18 dbi

MILES
-1 0 4

Illinois DOT Rail Project - Map 3

Access Point Direct Wireless Network

no preamplifier



EDX SignalPro™: ILLINOIS RAIL PROJECT - 5.8 GHZ - TRAIN

Prop. model 1: Anderson-2D v1.00
Time: 90.0% Loc.: 90.0%
Prediction Confidence Margin: 0.0dB
Climate: Continental Temperate
Land use (clutter): EDX .GCV format
Atmospheric Abs.: none
K Factor: 1.333

County Boundries
Railways
Interstates
Primary Roads
Secondary Roads

Received Power at remote

>	-122.0 dBmW	24 to 54 Mb Modulation
	-131.0 to -122.0 dBmW	6 to 24 Mb Modulation
<	-131.0 dBmW	Out of Specification

Display threshold level: -131.0 dBmW
RX Antenna - Type: DA
Height: 10.0 ft AGL Gain: 16.85 dBd

Notes

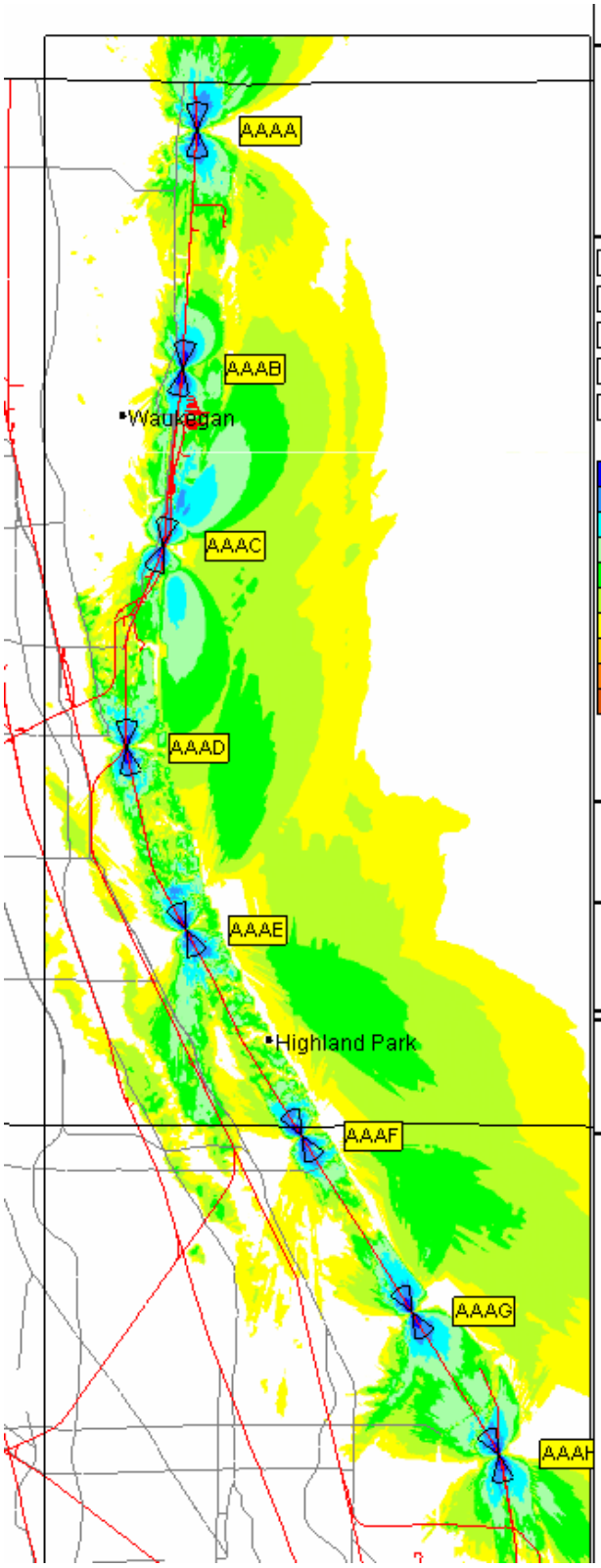
Access Point height: 20 ft.
Access Point Antenna Gain: 22 dbi

MILES
-1 0 4

Illinois DOT Rail Project - Map 4

5.8 GHz Train-Mounted Wireless Network

23 db preamplifier



EDX SignalPro™: ILLINOIS RAIL PROJECT - TRAIN MOUNTED

Prop. model 1: Anderson-2D v1.00
Time: 90.0% Loc.: 90.0%
Prediction Confidence Margin: 0.0dB
Climate: Continental Temperate
Land use (clutter): none
Atmospheric Abs.: none
K Factor: 1.333

- County Boundries
- Railways
- Interstates
- Primary Roads
- Secondary Roads

Received Power at remote

>	-48.0 dBmW		-10 or greater
	-58.0 to	-48.0 dBmW	-10 to -20
	-68.0 to	-58.0 dBmW	-20 to -30
	-78.0 to	-68.0 dBmW	-30 to -40
	-88.0 to	-78.0 dBmW	-40 to -50
	-98.0 to	-88.0 dBmW	-50 to -60
	-108.0 to	-98.0 dBmW	-60 to -70
	-118.0 to	-108.0 dBmW	-70 to -80
	-128.0 to	-118.0 dBmW	-80 to -90
<	-128.0 dBmW		-90 to -100

Display threshold level: -108.0 dBmW
RX Antenna - Type: DA
Height: 10.0 ft AGL Gain: 12.85 dBd

Notes

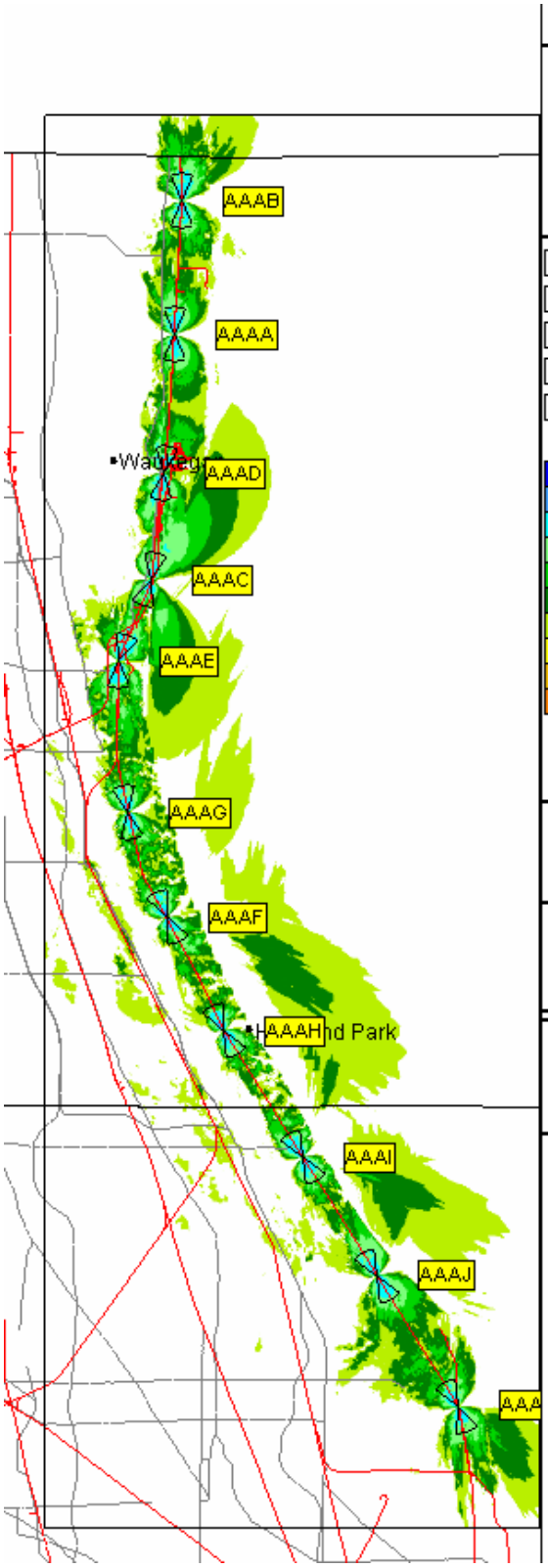
Access Point height: 20 ft.
Access Point Antenna Gain: 18 dbi

MILES
-1 0 4

Illinois DOT Rail Project - Map 5

Fixed Train-Mounted Wireless Network

23 db preamplifier Revised



EDX SignalPro™: ILLINOIS RAIL PROJECT - MOBILE CPE - REVISED

Prop. model 1: Anderson-2D v1.00
Time: 90.0% Loc.: 90.0%
Prediction Confidence Margin: 0.0dB
Climate: Continental Temperate
Land use (clutter): none
Atmospheric Abs.: none
K Factor: 1.333

- County Boundries
- Railways
- Interstates
- Primary Roads
- Secondary Roads

Received Power at remote

>	-42.0 dBmW		-10 or greater
	-52.0 to	-42.0 dBmW	-10 to -20
	-62.0 to	-52.0 dBmW	-20 to -30
	-72.0 to	-62.0 dBmW	-30 to -40
	-82.0 to	-72.0 dBmW	-40 to -50
	-92.0 to	-82.0 dBmW	-50 to -60
	-102.0 to	-92.0 dBmW	-60 to -70
	-112.0 to	-102.0 dBmW	-70 to -80
	-122.0 to	-112.0 dBmW	-80 to -90
<	-122.0 dBmW		-90 and below

Display threshold level: -102.0 dBmW
RX Antenna - Type: OMNI
Height: 6.0 ft AGL Gain: 6.85 dBd

Notes

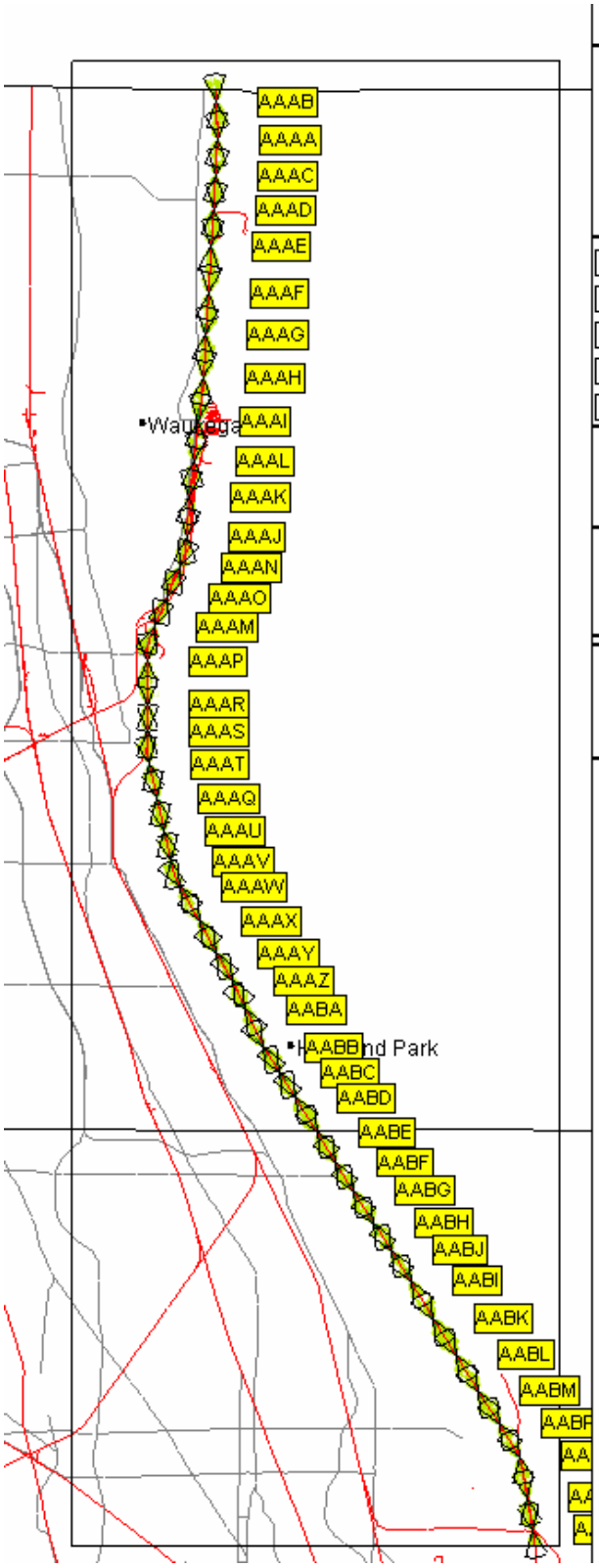
Access Point height: 20 ft.
Access Point Antenna Gain: 18 dbi

MILES
-1 0 4

Illinois DOT Rail Project - Map 6

Portable Train-Mounted Wireless Network

23 db preamplifier Revised



EDX SignalPro™: ILLINOIS RAIL PROJECT - LAPTOP USER - F

Prop. model 1: Anderson-2D v1.00
Time: 90.0% Loc.: 90.0%
Prediction Confidence Margin: 0.0dB
Climate: Continental Temperate
Land use (clutter): none
Atmospheric Abs.: none
K Factor: 1.333

- County Boundries
- Railways
- Interstates
- Primary Roads
- Secondary Roads

Notes

Access Point height: 20 ft.
Access Point Antenna Gain: 18 dbi

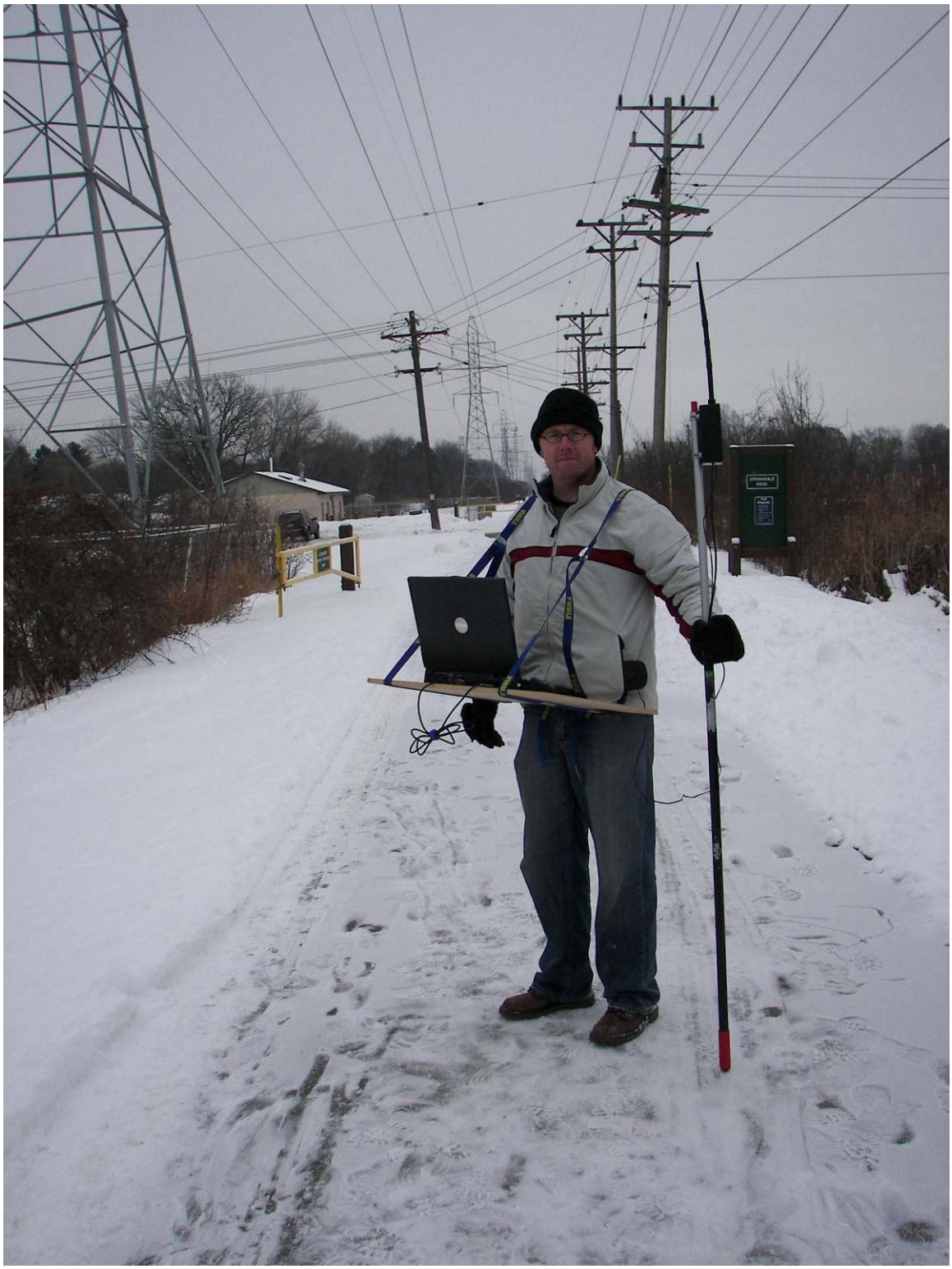
MILES

-1 0 4

Illinois DOT Rail Project - Map 7

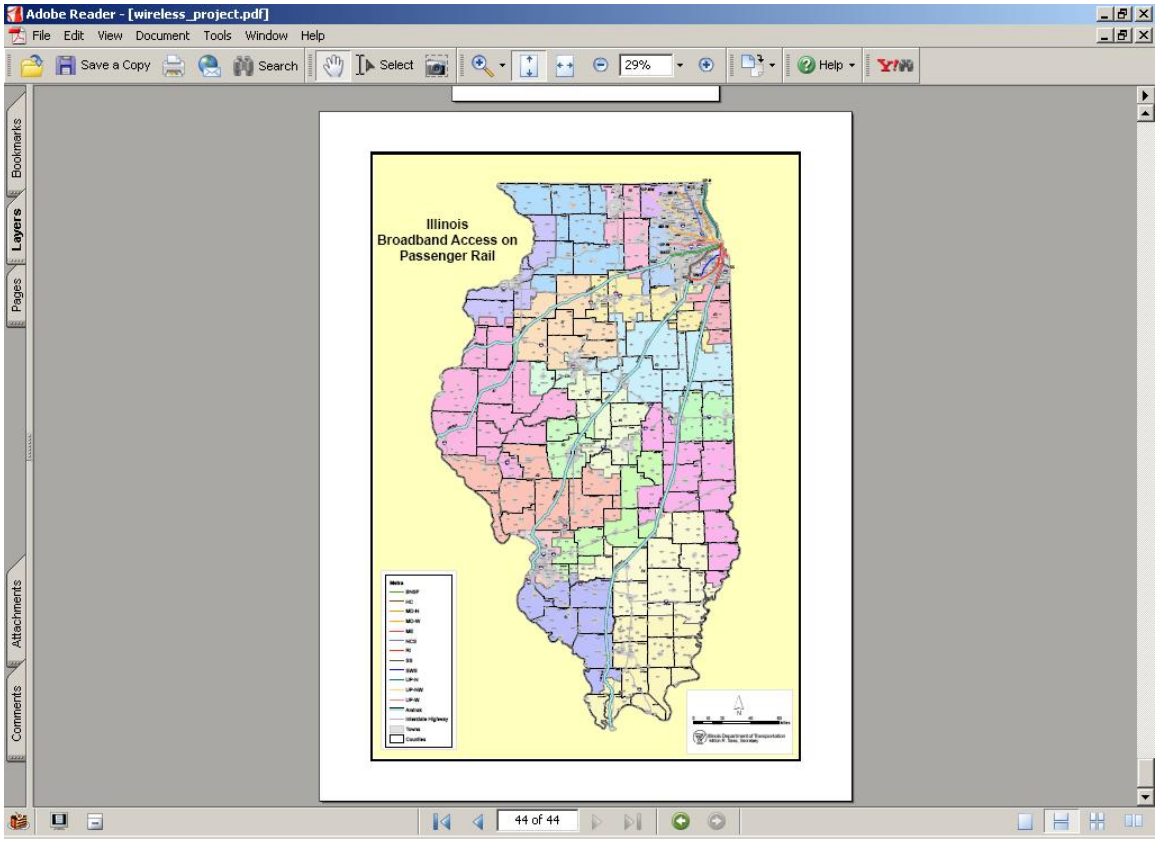
Access Point Direct Wireless Network

no preamplifier Revised

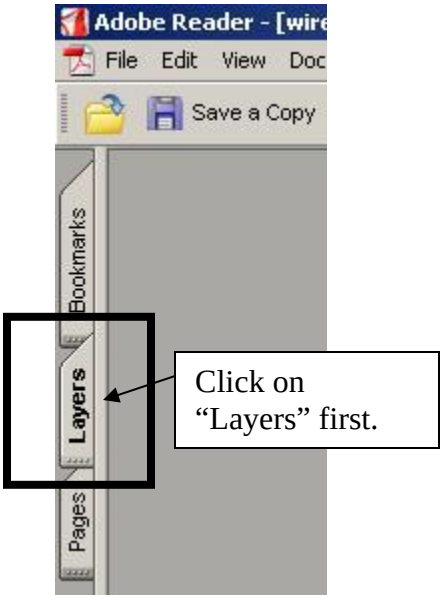


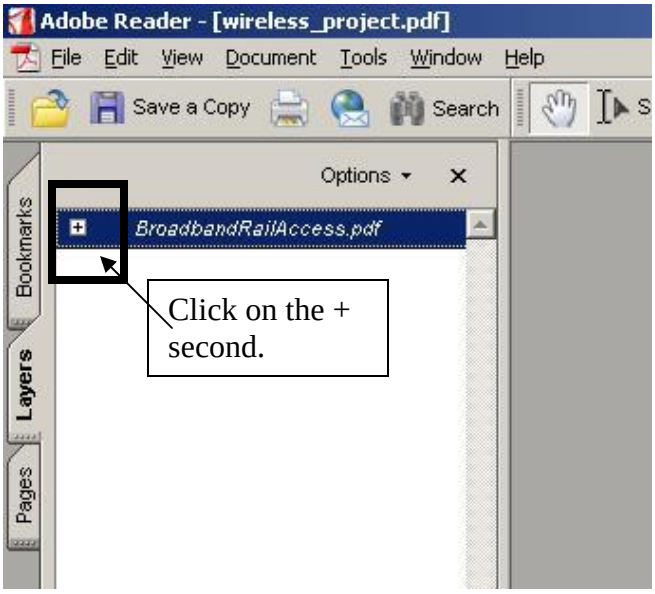
Instructional Guide on Using the Interactive PDF Map

1. The map opens at the statewide level with all map layers displayed. Use the standard Adobe Reader tools to zoom in/out, and pan around the map. This is an interactive map which contains several layers which may be “turned on” or off to provide additional reference frames for viewing.

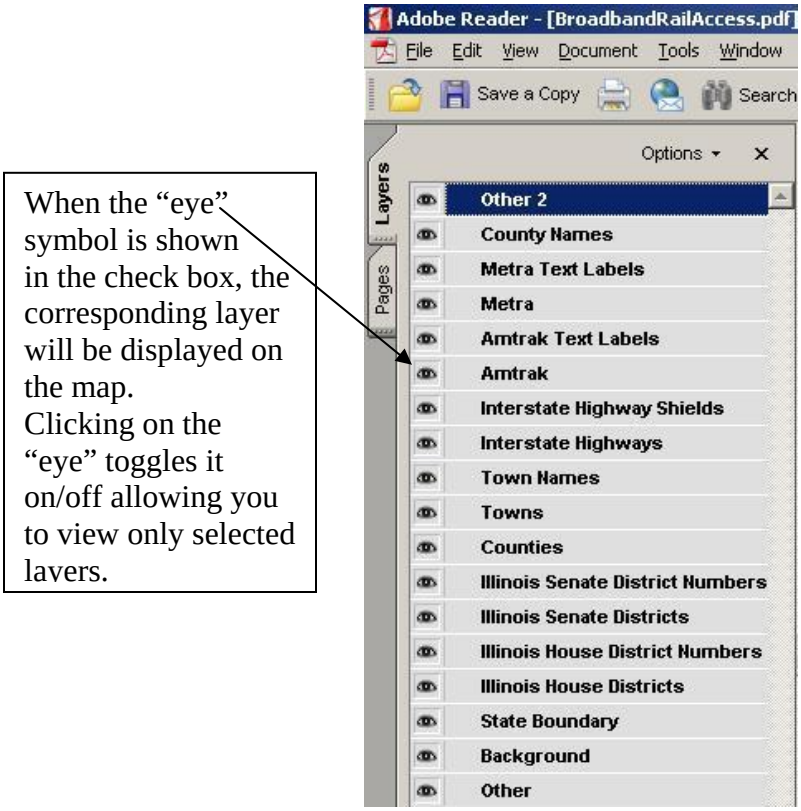


2. To take advantage of the ability to interactively display various layers, first left-click on the “Layers” tab which is in the upper left of the page. Then left-click on the + next to “BroadbandRailAccess.pdf” to display all the map layers.

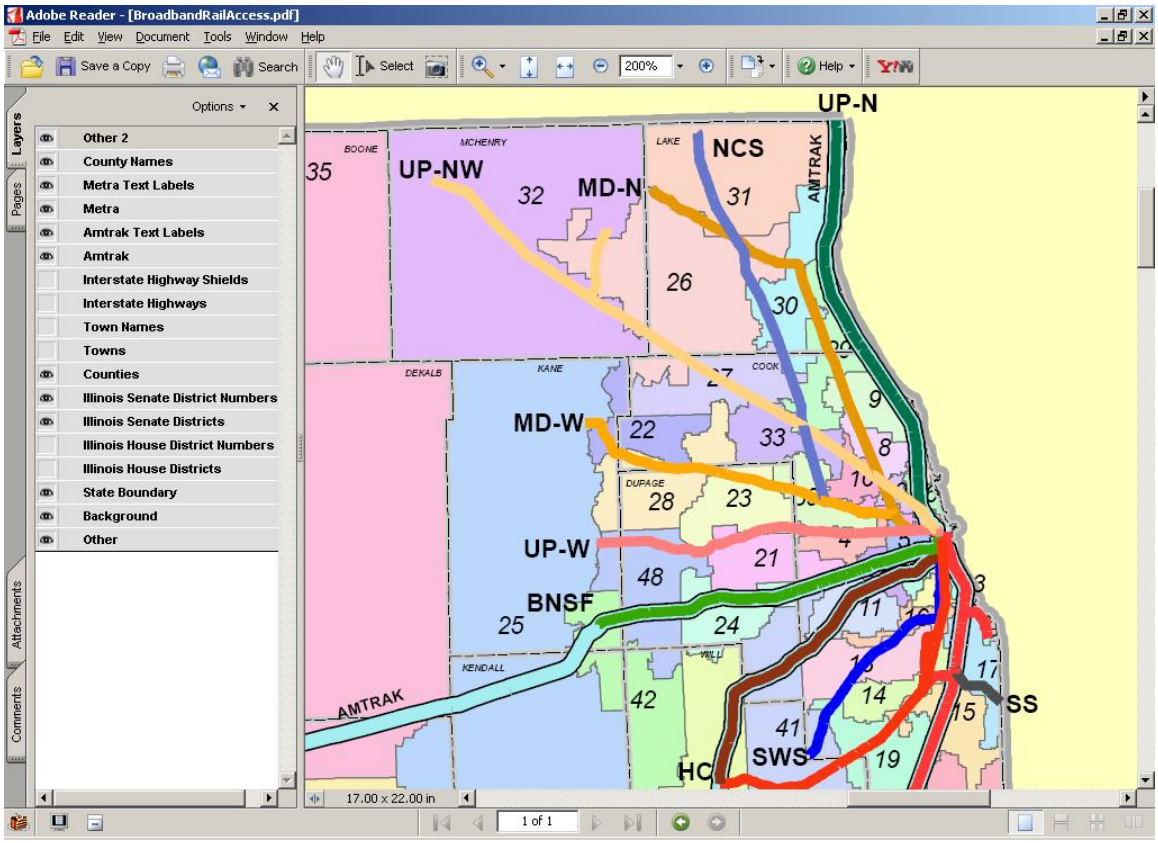




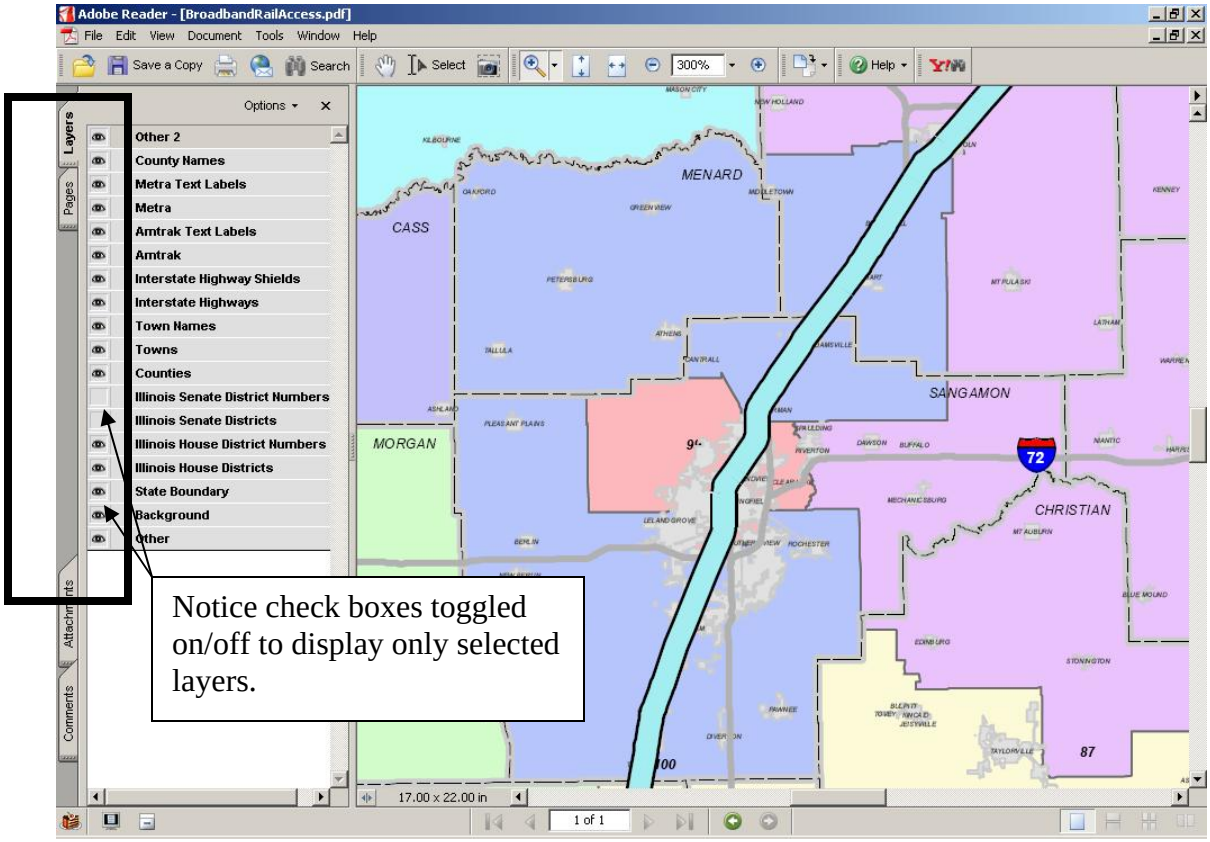
3. A list of available map layers will be displayed. At the start, all layers are displayed. To view only selected layers, simply left-click in the check box to the left of the layer name to toggle off display of the layer on the map.



4. Toggle layers on or off by left-clicking with your mouse in the check box next to the appropriate layer. The “eye” symbol will appear/disappear as you click with your mouse. At the same time, the corresponding map layer will display or disappear. This function allows you to interactively view various map layers. For example, in the view below, several layers have been toggled off (Interstate highway shields, interstate highways, town names, towns, Illinois House District Numbers, and Illinois House Districts). This allows for a less cluttered view of Senate districts, Metra and Amtrak lines.



5. In the view below, other layers are toggled on/off in order to see House districts, Amtrak lines, interstate highways, and towns.



Illinois Broadband Access on Passenger Rail