Feasibility study of WLAN technology for the Uppsala - Stockholm commuter train

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1. Introduction

The purpose of this study is to investigate different solutions to provide high speed Internet access on a train travelling at 200 km/h using WLAN equipment. Every day about 15000 people commute between Uppsala and Stockholm and it is reasonable to assume that about 10% of those could use the time better on the train if they had a connection to the Internet. A study [37] in the UK has shown that 80% of the business travellers work on the trains and would use WLAN if it was available. At least two companies in Sweden offer a service for this but they use expensive technology with low bandwidth.

The aim of this feasibility study is to investigate if it is possible to build an infrastructure with WLAN equipment and offer the customer the bandwidth of about a normal broadband connection at home. The task is also to make estimations of the costs for different solutions to be help decide about a continuation of the project.

1.1. Problem description

1. Is it possible to build an infrastructure between Stockholm and Uppsala with WLAN technology? What is the cost?

2. Is it possible to avoid placing a gateway for forwarding the network traffic on the train?

3. What capacity is needed, how to handle access-rights to the network and how “future proof” is the technology?

1.2. Goals of the study

- Presenting an overview over of similar projects and commercially available solutions.

- To investigate possible solutions for with directed antennas and leaking cables.

- Examine limitations with handover and latency when roaming.

- Estimations of cost for different solutions.

- Proposal of how to continue the project.

2. Existing solutions

2.1. Mobile phone technologies

Here is a short survey of the existing technologies for mobile telephony to get an idea of what kind of bandwidth is offered with each technique existing today. An explanation of all abbreviations can be found in Appendix C.

2.1.1. GSM/GSM-R

A GSM datachannel has a bandwidth of 9.6 kbps but can with some providers support up to 14.4 kbps. An extension to the GSM-standard is GSM-R were the R stands for Rail. This extension was made to support high speed nodes and additional services for trains. GSM-R uses other frequencies than normal GSM.

2.1.2. HSCSD

Some providers offer HSCSD which is a way to bundle several GSM-channels together to form a high speed datachannel. A bandwidth of maximum of 57.6 kbps can be reached with this technology.

2.1.3. GPRS

The following generation is GPRS which is a more general service. GPRS is packet-based and offers more flexibility than previous systems. The theoretical maximum speed for GPRS is 171,3 kbps when all eight timeslots are used. Which is about three times faster than speeds possible over today's fixed line telecommunications, but this speed is unlikely to be reached in reality. The currently used coding-scheme CS-2 gives a data-rate is about 40 to 50 kbps.

2.1.4. 3G

The new 3G system which is currently under construction is designed to have a bandwidth of 384 kbps at max 500 km/h. At short range and with speed less than 10 km/h a bandwidth of 2 Mbps is possible.

2.1.5. Price vs bandwidth

The available bandwith for a node travelling at high speed with current mobile phone technology is limited and the cost for a continous service can be expensive. The price to transfer one MB today over GPRS is about 10-15 kr with a special subscription. One can argue about the future development of the price, but it is for sure that the heavy investment in the 3G infrastructure is going to be have to be repaid and that does not speak for a fast decline in price per MB.

2.2. Use of satellites

Satellites can be used to serve a train with a bandwidth downlink of about 2 Mbps, but a drawback is that the train needs a channel for the return-traffic which can be solved by using GPRS or similar. The equipment for using satellite communication is expensive and requires good conditions, e.g. a good angle from the train to the satellite. Another drawback is the latency introduced by the physical construction with geostationary satellites. The distance alone makes 240 ms which is substantial.

Another problem with using geostationary satellites are the angle to the satellites. In the northern parts of Sweden, in this case above Gävle, the satellites will be too low over the horizon to be able to support a reliable connection to the trains. Wireless Train System (WTS) [3] report this from trials with SJ.

2.3. Solutions for trains

2.3.1. Icomera

A company called Icomera [2] have a product called "Wireless Internet Onboard" which can use any available data channel e.g. GSM, 3G, Satellite, Digital TV, DAB ((Digital Audio Broadcast), etc. It can automatically switch between the different techniques to choose the most effective combination. Their main idea to get good economy for the service is to use the different existing infrastructures mentioned to produce a continuous stable connection to the Internet. For example, they can run a satellite downlink together with bundled GSM-lines for uplink traffic. When they reach a tunnel they can switch to run both down- and uplink traffic over GSM. Their product includes a billing system to enable integration with AAA (Administration, Authorization, and Authentication) systems.

The railcompany Linx [5] which is partly owned by SJ [6] ran the product from Icomera as a pilot study as of the autumn of 2003. A U.K. based company, GNER [11], have used the product for limited trials during autumn 2003.

2.3.2. Travel Vision

The products from Travel Vision [1] ranges from passive “offline” solutions with public displays to interactive “online” solutions where the customer can interact through touch screens or an onboard WiFi network. Their idea is also to use the existing infrastructure to the deliver the different types of services that they offer.

Their simplest “offline” solution consists of screens that show selected information e.g. traffic information and news. The content-server is updated at stations equiped with WLAN or via DAB and similar techniques. The service can be improved by interactive touch screen that allow the customer to choose from the available content to check the latest news or where the adjoining train departs.

A more advanced solution is to add an onboard WLAN to this service and let the customers use their own laptops to access all the content through the wireless network and a portal. This portal can give access to mirrors of electronic newspapers, ability to send email, print documents, movie-on-demand, games etc.

To gain even more productivity out of the time spent on the train the service can be extended with online connection to the Internet via satellite or any suitable technology like GSM/3G etc. This is the only service that is comparable with Icomera since they only offer Internet connectivity.

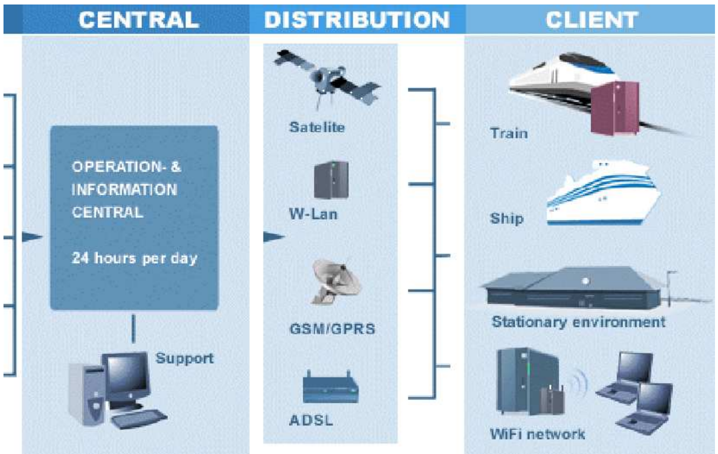

Figure 1: Travel Vision system overview

On the Arlanda Express Travel Vision has a running installation of a passive information and entertainment system onboard since April 2000. The installation consists of screens directed towards groups of seats and they show a loop of news and traffic information. The content is updated through DAB and WLAN from the information central in Stockholm.

"Tåg I Bergslagen" have decided to run a commercial pilot project with several media channels onboard their train. Travel Vision will install and operate interactive services (through an onboard WLAN network), public displays for traffic information and news and interactive touch screens for traffic information, destination information and tourist information. Starting date for this service will be May 2004.

2.3.3. Wireless Train Systems

Wireless Train Systems is a small company that are working with a new solution to be able to support high speed datalinks for trains. They are developing a special transceiver technique tailored for the complex environment. Plans are to use the same towers Banverket are using for their own GSM-R network for mounting their equipment. Real world experiments are currently (spring 2004) on hold because lack of funding. The experiments would require about 1.5 mkr of extra funding.

2.3.4. Others

A company called PointShot wireless [4] have a similar product to Icomera. They use different technologies in a combination to be able to maintain a connection to the Internet. They have tested their technique during short times on the Altamont Commuter Express (ACE) [13]. The phone company Orange [30] has done some trials with 3G basestations along a testtrack. Not much is known about their trials other than they seem to have had problems handling large amounts of handovers.

3. Using WLAN technology

The best solution to give access to the network on the train would be a solution that avoids modification of the train. This would allow any passing train to use the service. This is however not an easy task since the customer is traveling in high speed in a shielded metal box.

3.1. Experiments with WLAN

3.1.1. Cisco

The high speed of a train will also cause problems with fading- and doppler-effects. Cisco have done in-lab tests where they have verified that WLAN should be possible to use in speed up to 250 km/h. Beat Stettler who made the test for Cisco reports that they have done further real world trials and that it works but the results are closed due to NDAs (Non Disclosure Agreement). Cisco [17] have also done real world trials together with Deutsche Bahn [8] and Bombardier [9] in Hannover. Results are again locked by NDAs.

3.1.2. Wireless Train Systems

Wireless Train Systems conducted experiments with 802.11b together with SJ and Chalmers between Karlstad and Kil to verify how it would function in a real world setup. WTS report that with a speed of about 80 km/h they were able to receive some signal and reach about 500 Kbps. When a speed of 120 km/h was reached there were only traces of the signal left. WTS believe some causes could be problems with the rough ground and existing metal in the vincinity reflecting the signal and effects from the high voltage powerlines. New experiments to verify the results are planned to take place during the fall of 2004.

3.2. Leaking coaxial cable along the track

In subways a common technique called “leaking cable” is used to create coverage for mobile phones. This is as it sounds, a cable with holes where the signal leak in and out. It does not give a great range but since the cable can be placed close to the train this is not a problem. The great advantage with a system like this is that the trains could remain unmodified and that the customer would be connected directly to the main WLAN.

However, there are a few problems with existing techniques. The dampening in the cables at 2.4 GHz are about 10 dB/100m which makes the weak signals unusable after about 100-150 m of cable. It may be possible to use amplifiers but they cost about 5-20 kkr per amplifier and also need power which will be expensive to support. The second major thing is that the cable will be about 2.5-5 cm wide making it rigid and heavy. In tunnels the cable is normally stitched to the wall every meter. A fence along the track would have to be built or a strong wireconstruction to hang the cable on the towers.

3.3. Antennas mounted on towers along the track

Another solution is to place towers with APs (Access Point) along the track. If it is possible to have the customers connected directly to this network that would mean that no modifications to the train are necessary and therefore a cheaper solution. This solution has two great drawbacks.

The first is that all the customers have to use equipment that is compatible with the APs and that can handle the problems with the high speed of the train etc. The second problem is that when a large number of clients want to change AP at the same time the AP can be overloaded with the task of updating the routing information.

These two problems can be solved by placing a gateway on the train which has a radio interface that can handle the high speed of the train and aggregate the traffic from the customers in order not to overload the APs with routing-information created by the roaming. This comes at the cost of the loss of unmodified trains and the advanced equipment needed on the train.

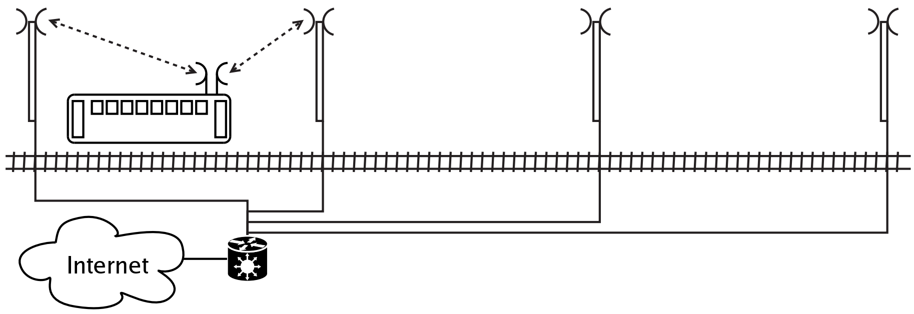

Figure 2: Every tower connected to the backbone.

3.3.1. Every AP is connected

The first and simple solution is to have a number of towers along the track with APs mounted on top of every tower (figure 2). In this case every AP is also connected to the network backbone. This makes the network simple to manage and provides each AP with fast and reliable connection to the backbone. The low latency to the APs is also a necessary support for very fast handovers. The main drawback of this solution is that it is expensive to have a permanent connection to each AP.

3.3.2. APs used as repeaters with central antenna

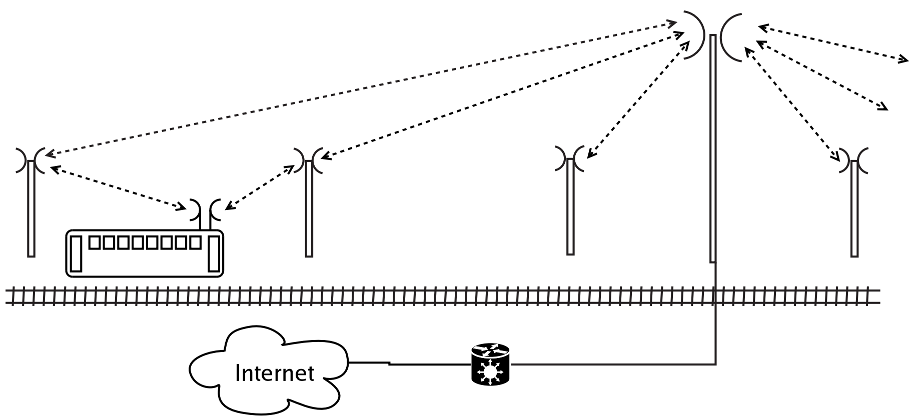

Figure 3: Every tower is connected to a "backbone-tower" which is higher than the other towers and has a connection to the wired LAN.

A much cheaper solution is to build the backbone with wireless links. One way is to have every AP directly connected to a central tower which has a connection to the wired LAN (figure 3). This can be used if there is LOS to the central tower. One drawback is that there will probably be a lot of antennas on the central tower.

3.3.3. APs used as repeaters and local routing

This is another version of the previous solution but with APs that are locally interconnected with wireless links (figure 4). The APs route the traffic to a central AP which is connected to the wired LAN. Here you do not need LOS to the central AP which could be a common case. The big drawback is the latency introduced with each hop and the fact that the a chain of links are more probable to have errors.

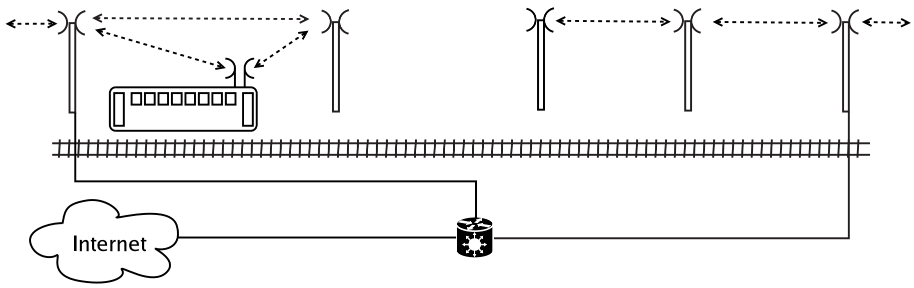

Figure 4: Interconnected APs act as repeaters who route among each other to the central AP which is connected to the wired LAN

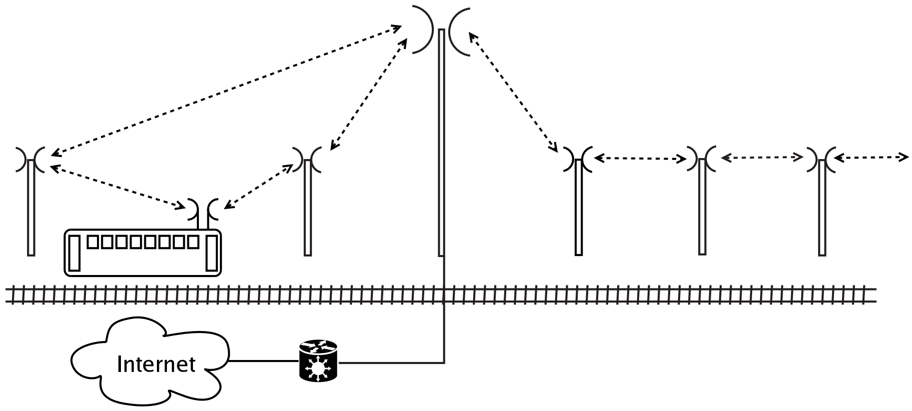

Figure 5: A combination of direct and indirect links can be used where a long straight if followed by a turn where there is no LOS (Line Of Sight) to the "backbone-tower".

3.3.4. Passing a tower

When passing a tower with the antennas placed together on the train a problem occurs when both antennas are out of range (figure 6). This could be solved by placing another set of antennas in the other end of the train. The drawback is that the radios on the train needs to be interconnected to handle the handover.

3.3.5. Nosecone antennas

If it is hard to use the roof of the train the antennas could be placed in the aerodynamic nosecones in fiberglass that almost all of the modern trains have (figure 7). One important problem with this solution is that when passing a tower none of the antennas will able to stay in contact with the tower. This could be solved by a third short range antenna on the roof or "very" overlapping lobes from the towers. The latter solution will be much more expensive since it require a more dense placement of the towers.

3.3.6. Directed antennas

This scenario (figure 8) may pose a few problems when the train passes the tower. The connection will be abruptly cut and require an immediate handover. With no possible preparations it will cause a pause in the connection to the network. It could also be the case that while passing just by the tower none of the APs can be reached due to the construction of the directed antennas so the non-planned handover could be longer than normal handover due to loss of signal.

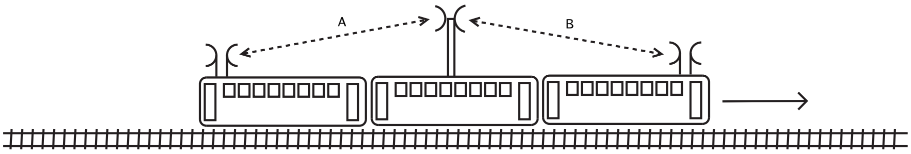

Figure 6: Train with a dual set of antennas to enable the train to stay in contact with the tower when passing.

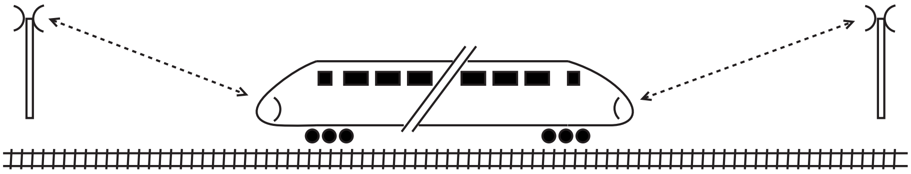

Figure 7: Antennas placed in the nosecones instead of the roof

3.3.7. Combined directed antennas

To evade handover when passing the tower two antennas can be combined to form one antenna (fig 9). This give a much simpler system but the drawback is that the antennas will be about half as effective. This leads to a need for more dense placement of APs.

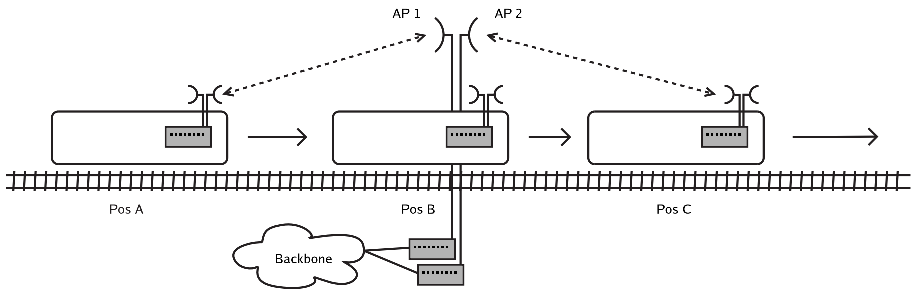

Figure 8: A scenario where each direction has its own antenna and AP.

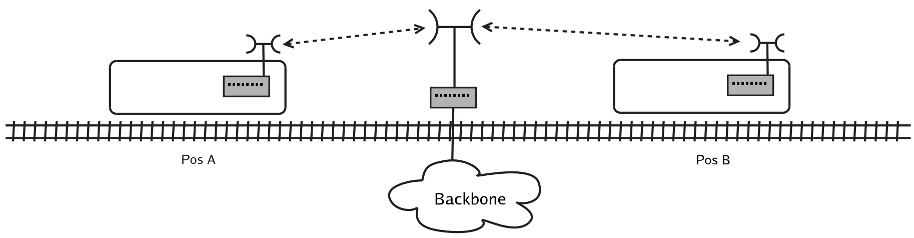

Figure 9: Two antennas combined to form one antenna to evade handover when passing the tower.

4. Radio-layer

4.1. WLAN/WiFi (802.11 a,b,g)

Available radio-equipment for WLAN exist for a number of frequencies. The more common are 2.4, 3.5 and 5 GHz. The 2.4 and 5 GHz band are unlicensed but the 3.5 is not. The advantage of using 3.5 GHz for access to the train is that the medium is controlled and very few people own equipment which give greater security and secured capacity. Costs for a licensed frequency are not clear.

Standard	Speed	Freq	Channels
802.11a	54	5.7	11
802.11b	11	2.4	3
802.11g	54	2.4	3

Effective speeds in the different standards are about half of the theoretical bitrate. E.g. a 11 Mbps link will offer about 5.5 Mbps in reality. The effective capacity is then reduced by the protocols used and the size of the packets sent over the link. UDP together with large packets result in a very low loss of capacity and TCP with small packets suffers a loss of about 50%. There are several solutions to solve a possible problem with capacity usage. E.g. a tunnel running UDP or TCP could be used to encapsulate the traffic over the link to control the flow.

See Appendix D for more information about each standard.

4.2. 802.16/WiMax

From the future standards the one nearest to completion is 802.16, commonly called WiMax.

WiMax is a not yet finished standard for wireless metropolitan area networks. The main goal is to be able to support 74 Mbps with distances up to 50 km with LOS and up to 10 km with NLOS. This standard are expected to use the frequencies in the range 2-6 Ghz. The standard lacks support for mobility and roaming features.

Redline Communications [25] has a 802.16a system which offers a throughput of 70 Mbps with a range of up to 30 kilometers. It will work for point-to-point and point-to-multipoint deployments and is currently in trials.

4.3. Active antennas

Along with classic antenna designs such as yagi, parabola and panels, a few companies are working with so called “active antennas”. They simulate a directed antenna with a cluster of small antennas. The antennas are combined with an advanced DSP to create virtual directed antennas that give greater range and faster connections than normal directed antennas.

Two companies, Vivato [21] and Airgo Networks [22] have products for WLAN but at least Vivato’s solution does not allow for any faster mobility than walking.

4.4. Link budget

To get an idea about what kind of limits the WLAN technique has both in range and capacity an example of a possible system has been made. This should be extended with an example of a system using 802.11a when sufficient data about radios and antennas are available.

Example with 802.11b

	Tower:	**Train:**
Radio (Orinoco black)	15 dBm	15 dBm
Cable (lowloss)	20 m, 9 dB	10 m, 4.5 dB
Antenna	18 dBm	12 dBm
EIRP	23.9 dBm	22.5 dBm

Link budget

Standard	**Speed**	**Margin**	**Range**
802.11b	11 Mbps	10 dB	1.5 km
802.11b	11 Mbps	5 dB	2.8 km
802.11b	11 Mbps	0 dB	5 km
802.11b	1 Mbps	10dB	6.3 km
802.11b	1 Mbps	5 dB	11 km
802.11b	1 Mbps	0 dB	20 km

The link budget made with 802.11b is calculated for a connection with maximum bandwidth, i.e 11 Mbps with a large margin. This results in 300-500 kbps/customer if we have 10 active customers on a train. If we have more than one train within the same 5-10 km network section and a radio-backbone a bottleneck can occur in the backbone if 802.11b is used there as well.

5. Specifications/Demands

The main demands on the connection to/from the train are reasonable speed and latency. One can never have too much bandwidth but the lower bound is more important. A lower bound for the speed per customer should be set to the interval 100-200 kbps which is 2-4 times faster than a modems used today. A normal homepage for a newspaper can then be downloaded in 5-40 seconds. A reasonable upper bound can be set to 500-1000 kbps/customer.

The demands on latency are easier to define since they are based on known psychological human factors. A latency of about 0.1s are required for realtime interactive systems like remote desktop applications etc. For web-browsing a latency of about 1-2 s is ok but if it gets worse the customer will turn their concentration to other things. A latency of about 10 s or more is commonly called a “batch-system” and is usable for receiving mails etc but not for much else.

6. Handover

In 802.11 the decision to roam to another access point is initiated by the client which at a certain threshold of the signal level listens for other APs to connect to. If a better one has been found the client establish a connection to the new AP.

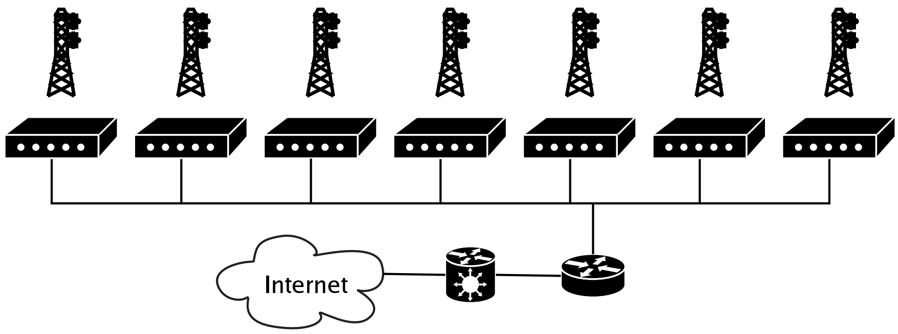

Figure 10: Old fashioned decentralised network with powerful APs.

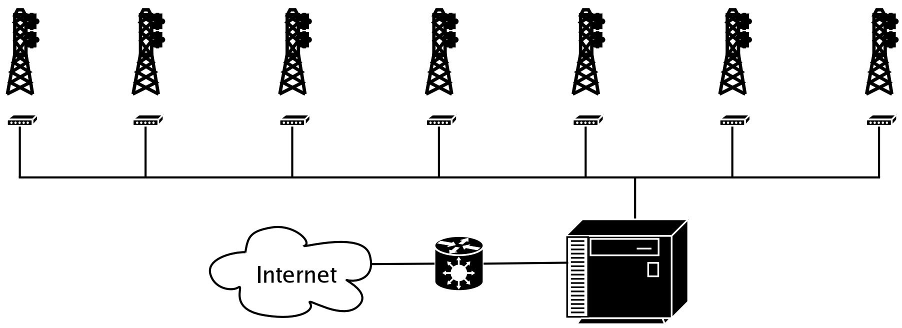

Figure 11: A network with most of the switching intelligence centralized.

6.1. Decentralized

One cost of doing a “uncontrolled” handover (fig 10) is the potential loss of packets existing in the buffer in the AP which can be large.When roaming in a network without security the handover is “cheap” in terms of complexity. When more advanced authorisation is used the handover becomes more complex and the time for handover can be very long due to transactions to a central server having to be made.

Possible loss of packets when roaming together with time-consuming re-authorisation makes a plain handover a bad solution. Some vendors has made their own solutions to this problem and parts of them has resulted in a "Inter Access-Point Protocol"(IAPP) standard, the 802.11f. The IAPP is able to transfer a already negotiated state to another AP if the APs are located on the same LAN. The latency for doing this according to Nortel [19] is about 50 ms.

6.2. Almost centralized

Recently a totally different approach to build WLANs have been introduced. The aim is to make it cheaper to build larger WLANs. The idea is to make the APs as simple as possible and place the complex electronics in a central switch (fig 11). This makes the APs easier to maintain and cheaper to buy. Another advantage of this design is that extremely fast handovers are possible since all the states about authorisation etc are stored on the central switch. According to Aruba [20] the time for an entire handover takes 1-2 ms on their equipment. The drawback with a centralised system is the SPOF (Single Point Of Failure).

These techniques are for handover with one client. On a train there would be a need for a number of antennas, each acting as a client. To enable a gateway to route the traffic through the right client/interface depending on the connections additional software has to be developed.

7. On-train technology

The technology needed on the train can be adjusted to suit many needs. The most basic are the antennas, the gateway and the local access technologies. When planning what technology to place on the train a number of factors have to be evaluated. One of the more important ones is what type of train the technology will be placed on.

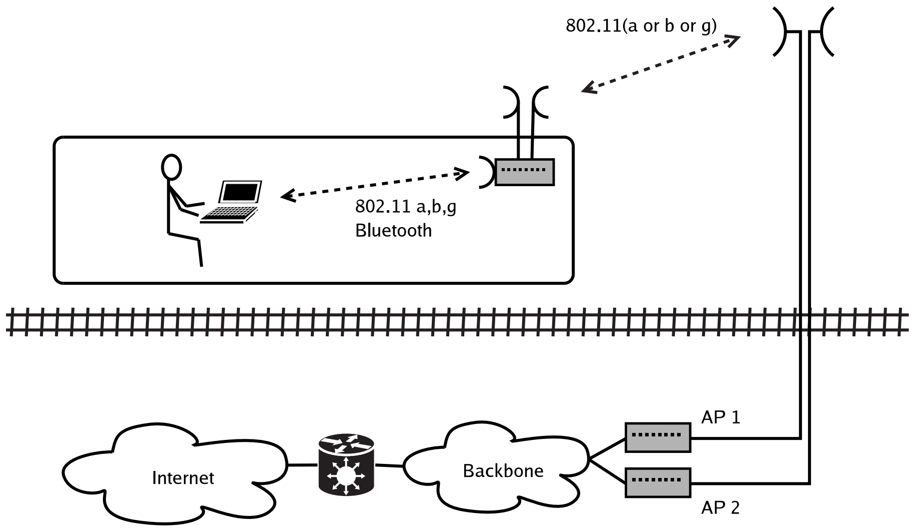

Figure 12: A simple schematic figure of how a system could look like.

7.1. The trains

This is a small section with facts about the trains used or will be used for commuting in the region. The is to be able to do planning of possible placements of antennas,gateways etc.

Name	Length	Height	Seats(total)	Speed	Built
Engine train	190/295m	?	450/750	160 km/h	1960-
X52-2	54m	3.9 m	182	200 km/h	2000-2003
X52-3	81m	3.9 m	272	200 km/h	2000-2003
X40-2	55m	4.6 m	205	200 km/h	2004
X40-3	81m	4.6 m	319	200 km/h	2004
X60	212	?	770	160 km/h	2005

7.2. Local access technologies

A number of access technologies can/should be used on the train to maximize the availability to the customers. A combination of a standard box with support for 802.11a,b,g and an extra interface for Bluetooth like the Bluetooth Possio [18] could be a possible solution.

7.3. Administration, Authorization, and Authentication (AAA)

AAA in the network can be solved in a number of ways depending on different ways to authenticate the customer if needed. One solution is SwedenOpen.Net [35] which is a system that supports multiple Internet Service Providers that the customer can choose from. Another similar solution can be provided by WLAN Alliance [36]. Their idea is that the customer can choose from a number of phone-operators and then have the time used for the service billed on their normal phone. The solution for billing used by Telia Homerun has been built by ServiceFactory [34].

8. Budget

This is a coarse estimation of the cost for building a WLAN infrastructure along the railroad between Uppsala and Stockholm. The track is 65.5 km long and 55 km consists of straights of about 3 km. Fortunately there already exists a lot of infrastructure which can be used. There are 20 “teknikhus” equipped with network and power, see Appendix B. 11 of them are equipped with towers for the GSM-R network that can be used. The budget is calculated with the possiblity to place the APs on the small towers that carry the powerlines for the trains. Important! The budget does not include the costs for the transmission to the “teknikhus” yet. The infrastructure owned by Banverket is undergoing extensive upgrades and the cost for the services should be available after the summer.

The price for a solution with fiber to each small tower is very coarse due to the unknown facts about the ground where the fiber would be placed. The fiber can be plowed into the gravel next to the track with a plow mounted on a traincar. This is the easiest and cheapest way which costs about 120-150 kr/m. Where this is impossible and the fiber have to dug into private ground the price rices to about 500 kr/m. It is not certain that it is possible to use the cheaper method for this project depending on who is going to own the cables. The cost then could vary between 5-10 mkr to 18-35 mkr.

8.1. Maintenance/running costs

A large portion of the maintanance costs will probably be the rent from the backbone that Banverket will deliver if they are going to be rented. Banverket are right now (spring 2004) rebuilding their network and will not have the possibility to deliver prices for the transmission until the fall of 2004.

8.1.1. Hardware support costs

An estimation of the cost of maintain the hardware can only be very coarse with the amount of uncertain data about the proposed system, i.e. equipment, system availability etc. Håkan Romlin at Swedia Network which has the support for e.g. Telia Homerun has given the following example of the costs for maintain a “normal system”.

With a 2-hour service level and normal MTBF regardless of place, type of installation and equipment a normal fee is about 8000kr/year and site. This includes necessary work on cables, power, ventilation, hardware and software in a busy railroad environment. This is without replacement parts, logistics of equipment, warranty agreements and possible costs for rents, vandalism, education, system surveillance and other costs that are not defined by normal MTBF.

With a system of 20-40 sites a lower bound for the support costs for the hardware is about 170-340 kkr. This does not take into account the fact that a larger system benefits from possibilities of streamlining and coordination.

8.2. Future upgrades

The need for more bandwidth increase with time and a infrastructure should have support for upgrade. The capacity of WLAN-equipment used today should have a lifespan for at least 3-7 years. When an upgrade is needed it can be solved in several steps. As a first step the APs alone can be replaced if the next generation use the same frequencies at a cost of about 0.5-1 mkr. If new antennas are needed the costs are increased with about 60% to 0.8-1.6 mkr. If a fiber backbone is built instead of using radio then that will “never” have to be upgraded apart from new mediaconverters.

The main fiber-backbone that is owned by Banverket can be upgraded when needed. The fiber itself has a “unlimited” capacity and it is only the end-equipment that need to be replaced. However, the cards included in the budget will have a capacity to support a much longer lifespan.

8.3. Preliminary budget

Initial costs

Track	65.5 km		**Main Central**	Switch	200
Main towers	11 st			Work	50
Stretches	10 st	(6.6 km)			250 kkr
Fibercost	500 kkr/km		**Wireless link**	AP	6
				Antenna	4
					10 kkr
			Central tower	2 NICs	40
				Switch	10
				2 links	20
				Work+extra	30
					100 kkr
			Small tower	2 links	20
				Power	5
				Work+extra	14
					39 kkr

Extra towers	**Distance**	**Lobe range**	**Fiber needed**	**Radio**	**Fiber**
1	3.3 km	1.6 km	3.3 km	200 kkr	16,375 kkr
2	2.2 km	1.1 km	4.4 km	400 kkr	21,833 kkr
3	1.6 km	0.8 km	6.6 km	600 kkr	32,750 kkr

Total initial costs

Extra towers	**Total nr of towers**	**Towers alone**	**Radio backbone**	**# AP**	**Fiber backbone**
1	21 st	1,490 kkr	1,940 kkr	62 st	17,405 kkr
2	31 st	1,880 kkr	2,530 kkr	102 st	23,253 kkr
3	41 st	2,270 kkr	3,120 kkr	142 st	34,560 kkr

Maintenance per site and year		8 kkr
Total maintenance costs	168	- 328 kkr
Future upgrade, APs only	372	- 852 kkr

Comments:

The “extra towers” are the towers added between the existing towers for the mobile network per stretch. The calculations has been made since it depends on the equipment and the track what range that is usable.

9. Conclusions

9.1. Commercially available solutions

Travel Vision and Icomera have solutions for interactive Internet access on trains. They both use available infrastructure such as GSM/satellite/3G/DAB etc. Wireless Train Systems are developing a new radio suitable for trains but it is currently on hold due to lack of funding.

Travel Vision have a complete portfolio of different services that could be useful on a train. All the way from passive information-screens to interactive services like Internet connectivity. In order to get a budget proposal a meeting is necessary to discuss possible cases.

Icomera products target only Internet/corporate connectivity. The price for using the solution from Icomera would cost 15-30 mkr yearly depending on their fee which is connected to the number of departures.

9.2. Leaking cables expensive, directed antennas flexible

Using leaking coaxial cable seem to be a very cost effective solution (see budget below) if it is even possible to construct such a system. The high dampening in the cables makes it more or less unusable and even with a huge number of APs the cable would need a fence or similar to mount it on. Directed antennas is a flexible solution that can be combined into several solutions. The big question is how to build the backbone. If to go for expensive but high performance and future proof fiber or try to build a cheaper backbone with directed antennas and repeaters.

9.3. Fast handovers possible

The problem with handover can be solved by using either AP supporting 802.11f/IAPP or a centralised handover technology. With IAPP a latency of about 50 ms is reachable. The equipment from Aruba [20] are reported to be able to do a handover in 1-2 ms. A problem still unsolved is how to do the routing of the traffic over the different interfaces on the gateway on the train.

9.4. WLAN technology seems possible to use?

The answer to the question if it is possible to use WLAN technology seems to rest entirely on the possible problems with fading and related effects. Cisco have reported that their lab-tests show that 802.11b is ok to use in speeds up to 250 km/h. Beat Stettler who made the test for Cisco reports that they have done further real world trials and that it works but the results are closed due to NDAs (Non Disclosure Agreement). Wireless Train Systems reports that WLAN were impossible to use for speeds above 80 km/h but that they plan new trials for the fall of 2004.

All other problems seems to be solvable:

- Backbone, fiber or radio
- Handover, 802.11f or Aruba Networks or similar
- Gateway on the train

9.5. Costs for different solutions

Here are two coarse estimations of the costs of building a WLAN network for the commuting train between Uppsala and Stockholm. This should give some understanding about the different costs for different choices of design. The first one is for a solution with leaking cable and is a low estimation. Because of the high costs and low probability that the solution would work this solution was considered in the detailed budget. The second is for the solution with directed antennas and different type of backbones.

Leaking cables:	
Cable	3-7 mkr
Deploy	6-13 mkr
AP	1-4 mkr
Backbone	2-3 mkr
Fiber alone	8-33 mkr
Total	19-60 mkr

Directed antennas:	
Train	50-300 kkr per train
Towers	2-3 mkr
Backbone	Radio: 0.2-0.6 mkr **or** fiber: 5-35 mkr
Total	Radio: 3-4 mkr **or** fiber: 7-38 mkr

9.6. Capacity in the network

When using fiber or 54 Mpbs radio backbone the capacity bottleneck is likely to be the link to the train. The link budget made results in a capacity of 300-500 kbps/customer if there are 10 active customers. This is about 6-10 times a normal modem.

A backbone made with radio-links would cost about 1/3 of a backbone with fiber. The main drawbacks apart from the enormous difference in capacity would probably be that it would be more expensive to maintain due to its complexity. The latency when doing a handover is also a unknown factor in this case because of the effects of the latency introduced by the backbone links.

A fiber backbone would be “absolutely future proof”. The current capacity of a fiber is about 100-1000 times the capacity of the radio-layer. A extended use of a fiber backbone could be used to support wireless broadband to the countryside to make better use of the capacity.

9.7. Future proof technology?

When thinking about the future and the costs for upgrading the network within a few years some estimations can be made. The towers and antennas could probably stay the same while replacing the APs at a cost of about 0.5-1 Mkr. If a radio backbone is built the backbone links/APs also needs to be replaced at a cost about 1-2 Mkr. If a fiber backbone is built then that will “never” have to be upgraded apart from new mediaconverters because of the fiber capacity.

10. Continuation of the project

As seen earlier there exists services for enabling Internet access on trains and they use phone and/or satellite technology. The trials made by Beat Stettler at HSR should be investigated further to verify their results if there is a decision to go further regarding a WLAN infrastructure along the track.

10.1. The Vision

The initial step would be trials with a simple offline solution with a content-server combined with WLAN for accessing the customers and for updating the server. The server could include information such as news, timetables, possible delays etc. It would preferably be tested on an X-52 trains which is a train in the new generation used by SJ.

The next thing would be to continue and add an interactive service like online Internet access via GPRS/Satellite or similar. The customers would then be able to access the Internet at all times on the train. The customers could pay for the connection either via direct payment through vouchers, creditcards or indirectly through commercials. This would be a soft start that could help to build up the customerbase while not investing too much money.

When suitable, the final step could be taken to start to build a high capacity wireless backbone to support the commuter trains.

A. Contacts

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B. Existing infrastructure

Place	**Network**	**Tower**
Uppsala	x	x
Bergsbrunna/säby?		x
Ekeby	x	x
Knivsta	x	x
Myrbacken	x	x
Märsta	x	x
Norslunda	x	
Rosersberg	x	
Skavstaby	x	x
Upplandsväsby	x	
Rotebro	x	(x)
Häggvik	x	
Sollentuna	x	x
Kummelby	x	
Helenelund	x	
Ulriksdal	x	
Hagalund	x	x
Solna	x	
Tomteboda	x	x
Stockholm C		x
Total	18	11 (12)

C. Abbreviations

AAA	Administration, Authorization, and Authentication
AP	Access Point
DSP	Digital Signal Processing
GSM	Global System for Mobile Communications
GPRS	General Packet Radio Service
HSCSD	High Speed Circuit Switched Data
IAPP	Inter Access-Point Protocol
LAN	Local Area Network
LOS	Line Of Sight
NLOS	No Line Of Sight
Mbps	Megabits Per Second
RIP	Routing Information Protocol
SPOF	Single Point Of Faiulure
WLAN	Wireless Local Area Network

D. Overview of the 802.x standards

This is a list with short comments about the most commons standards from IEEE as a quick guide.

D.1. 802.11a

Operating in the 5 GHz band, 802.11a supports a maximum theoretical data rate of 54 Mbps, but more realistically it will achieve throughput somewhere between 20 Mbps to 25 Mbps in normal traffic conditions. In a typical office environment, its maximum range is 50 meters at the lowest speed, but at higher speed, the range is less than 25 meters. 802.11a has four, eight, or more channels, depending on the country.

D.2. 802.11b

Most WLANs deployed today use 802.11b technology, which operates in the 2.4 GHz band and supports a maximum theoretical data rate of 11 Mbps, with average throughput falling in the 4 Mbps to 6 Mbps range. In a typical office environment, its maximum range is 75 meters at the lowest speed, but at higher speed its range is about 30 meters. Bluetooth devices, 2.4 GHz cordless phones and even microwave ovens are sources of interference (and thus limit performance) for 802.11b networks. Minimizing interference can be difficult because 802.11b uses only three non-overlapping channels.

D.3. 802.11e

802.11e provides Quality of Service (QoS) support for LAN applications, which will be critical for delay-sensitive applications such as Voice over Wireless IP (VoWIP). The standard will provide classes of service with managed levels of QoS for data, voice, and video applications.

D.4. 802.11f

IAPP (Inter Access-Point Protocol) is designed for the enforcement of unique association throughout a ESS (Extended Service Set) and for secure exchange of station's security context between current access point (AP) and new AP during handoff period. Based on security level, communication session keys between APs are distributed by a RADIUS server.

D.5. 802.11g

802.11g offers the throughput of 802.11a with the backward compatibility of 802.11b. 802.11g operate in the 2.4 GHz band and deliver data rates from 6 Mbps to 54 Mbps. Like 802.11b, it has up to three non-overlapping channels. 802.11g uses orthogonal frequency-division multiplexing (OFDM) modulation as does 802.11a, but, for backward compatibility with 11b, it also supports complementary code keying (CCK) modulation and, as an option for faster link rates, allows packet binary convolutional coding (PBCC) modulation.

Its "backward compatibility" with 802.11b means that when a mobile 802.11b device joins an 802.11g access point, all connections on that access point slow down to 802.11b speeds.

D.6. 802.11h

This standard is supplementary to the MAC layer to comply with European regulations for 5GHz WLANs. European radio regulations for the 5GHz band require products to have transmission power control (TPC) and dynamic frequency selection (DFS). TPC limits the transmitted power to the minimum needed to reach the furthest user. DFS selects the radio channel at the access point to minimize interference with other systems, particularly radar. Pan-European approval of 802.11h is not expected until the end of 2003.

D.7. 802.11i

This supplemental draft standard is intended to improve WLAN security. It describes the encrypted transmission of data between systems of 802.11a and 802.11b WLANs. It defines new encryption key protocols including the Temporal Key Integrity Protocol (TKIP) and the Advanced Encryption Standard (AES). AES require new hardware.

D.8. 802.11n

Next generation of WLAN standards following the 802.11a,b,g series. It will have a bandwidth of 100-320 Mbps and will probably be completed in 2005-2006.

D.9. 802.16/WiMax

WiMax is a not yet finished standard for wireless metropolitan area networks. The main goal is to be able to support 74 Mbps with distances up to 50 km with LOS and up to 10 km with NLOS. This standard are expected to use the frequencies in the range 2-6 Ghz. The standard lack support for mobility and roaming features.

D.10. 802.16e

This is an extension to the 802.16(a-d) standard to enable “mobility”. It will allow allow the user to move around in speeds up to 150 km/h and handle handoff between cells.

D.11. 802.20

802.20 will be a specification of physical and medium access control layers of an air interface for interoperable mobile broadband wireless access systems, operating in licensed bands below 3.5 GHz. It will be optimized for IP-data transport, with peak data rates per user in excess of 1 Mbps. It supports various vehicular mobility classes up to 250 Km/h and a range of 15 km.

D.12. 802.21

The latest addition of the IEEE working gruops are the 802.21-group which aims for standardizing the way handoffs take place between heterogenenous type of 802-based networks. The goal is to enable a client device to automatically choose the available network connection type and to seamlessly hand off sessions among different networks without user involvement.

E. Towers used along the tracks

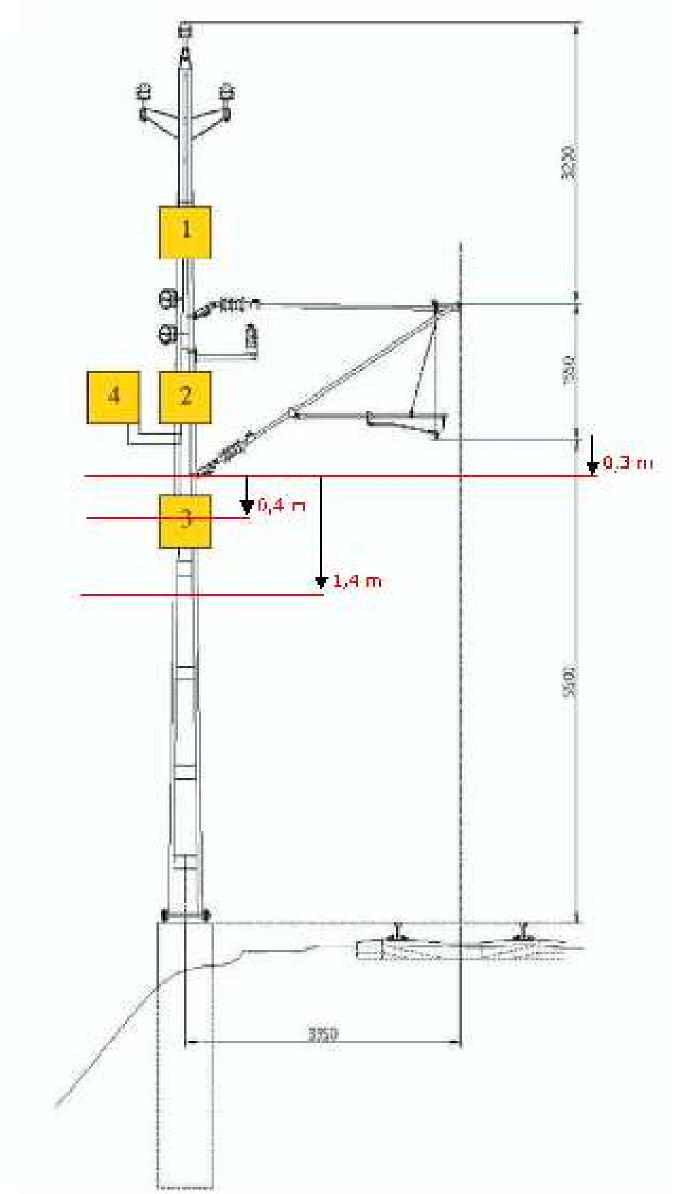

Figure 13: Antenna placement proposal. The only place that could be used for antennas wihtout cutting the power is place nr 3. There is a minimum distance of 0.4 - 1.4 m to the powerline to avoid cutting the power but apart from that it is ok to use the power mast.

F. Article from BBC News [37]

F.1. Wi-fi may tempt train travellers

Wireless net access could tempt many more people into using the train. A survey found that 72% of business travellers asked said onboard wi-fi web access would make them more likely to choose trains over cars or planes.

It also found that the longer the journey that people took, the more interested they became in using web access on trains to get some work done. Passengers on the longest journeys said they would be willing to pay up to £12 per trip for an internet connection.

F.1.1. Train surfing

The survey found that 78% of the business travellers it asked said they would use wi-fi if it became available in carriages. "This puts bums on seats," said Magnus McEwen-King, head of Broadreach that commissioned the survey. "It gets them off the road and out of the skies and on trains and that's good for everyone." GNER is running its own wi-fi trials Mr McEwen-King said both business travellers and commuters would be interested in using wireless services on trains. Already more than 50% of business train users carry a laptop or another web-capable device with them when travelling.

The survey found that 80% of business travellers already work during train journeys but most of it involves paperwork or making phone calls. Of those questioned 52% said having wi-fi net access would make this time more productive. Some already use the web on trains via mobile phone technologies such as GSM and GPRS. But the survey found that if travellers could use wi-fi time spent online was likely to increase by one-third and the number of potential users could grow 13 times.

Those questioned were divided over how to pay for the service. Some preferred to have the cost bundled in with their ticket, others preferred it added to their monthly net access bill. Another group wanted to use vouchers. Mr McEwen-King said Broadreach was working with five firms that run trains in the UK and was aiming to have wi-fi installed on more than 700 trains within the next four years. Two commercial trials of the service on long distance routes are planned for later this year. Commuter routes will follow later. "We believe that the connected carriage has arrived and will be leaving from a platform shortly," said McEwen-King. The survey was carried out in March and April of 2004 and more than 1,600 people were questioned.

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