Abstract — Provision of high speed Internet access on moving trains is a challenging task, recently addressed by several research projects and also network operators, resulting in different proprietary solutions involving different telecommunication technologies. Some solutions are being tested in pilot networks while there are already some in commercial operation.

The most challenging aspect is the provision of (seemingly) uninterrupted service in all different sections of the railway line, including those with particularly unfavourable radio propagation environment such as valleys, dells and tunnels. As a consequence, the sole use of the 2G/3G access technologies such as GPRS, EDGE, UMTS/WCDMA or HSPA for the access to the broadband services on trains is inadequate both economically as well as technically in most countries. Thus, some rail operators are already offering high speed internet access based on hybrid solutions which are comprised of various wireless access technologies such as uni- or bi-directional satellite links, 2G/3G technologies, WiMAX and WiFi.

In this paper we provide a brief overview of different technical solutions for provision of broadband access on trains, along with the most important providers, trials and commercial implementations, and discuss the feasibility of implementation of broadband service delivery on trains in Slovenia.

Keywords — broadband access on trains, onboard service delivery

I. INTRODUCTION

We are facing a vast amount of information and a rapidly changing world in the modern IT society. Since most part of the information exists in electronic format and mobile devices such as laptops, PDA's, smart phones are accessible to average consumers, commuters as well as long distance travellers can efficiently make use of everyday travelling time to stay updated with news, reply emails and perform other types of business or private operations via mobile devices. While in the metropolitan areas there is satisfying cellular coverage and hotspots, on the railway routes, broadband connectivity is sparse. Besides passengers, railway operators could also benefit from on board broadband services to increase efficiency, security and revenues. In fact, in recent years, we are witnessing in many countries the increasing demand for wireless Internet access on trains. According to industry research firm BWSC, a study conducted in the UK, continental Europe and the US estimates that by 2008, train passengers will spend $315 million per year on transit WLAN services. Almost one billion hotspot passengers and train operators are expected worldwide every year [1].

A decision for on train broadband service deployment has to be taken based on studies determining the viability and eventual success of such an enterprise. A successful model for deploying on train broadband services can be resumed in three steps: route profiling and passenger analysis, network planning and onboard train trial [1]. First, the requirements for services should be determined based on the number of passengers and passenger profiles, as well as on the demands coming from the rail operator. Rail operators typically ask for security applications, e-ticketing, point of sale applications, scheduling and tracking of trains, etc. Furthermore, network availability along the train routes has to be determined and train characteristics have to be analysed in order to determine the necessary technical configuration for installing hardware. Second, for the network planning step, detailed studies are required for proposing coverage plans for delivering the required services for passengers at lowest possible costs. Each coverage plan should include solutions for delivering required bandwidth, for covering coverage gaps, it should recommend specific technical solutions and provide operation and cost analysis. The third and final step consists of the on board train trial. At this stage, a live test environment is provided in order to assess passenger experience and network configuration [1].

In this paper we provide a brief overview of different technical solutions for provision of broadband access on trains, along with the most important existing providers, be in a trial phase or already in a commercial use. The rest of the paper is organised as follows. In Section II we describe the system architecture and possible technologies for broadband service delivery on trains separately for the three segments of the system, i.e. access network and the intranet on the train, and the backhaul between the train and ground-based infrastructure. This is followed by an overview of the main trials and commercial
implementations in Section III, with more detailed description of the presently most widely spread and commercially successful solution developed by Icomera. In Section IV we discuss the feasibility to provide broadband access on trains in Slovenia and finally in Section V summarise the paper.

II. SYSTEM ARCHITECTURE

Providing reliable broadband services on trains, especially the ones travelling at high speeds is a challenging task. The rail tracks cross various terrain configurations such as flat planes as well as steep valleys and long tunnels making the transmission channel for the wireless signal rapidly changing. A single technology is not likely to offer a satisfying grade of service for broadband services, especially on such difficult landscape as Slovenia has. In order to offer broadband services to travellers a carriage/train LAN has to be deployed in such way so that the customers can connect to it. The on board LAN has to connect wirelessly via a gateway to an Internet Service Provider’s (ISP’s) network and further to the internet. We have identified three main components of the broadband delivery system architecture: the access network, the intranet and the backhaul. Suitable technologies and protocols for each of the three components are detailed next.

A. Access network

The access network permits travellers to connect to the internet from lounges, station hotspots and carriages. The most popular ways to connect to a LAN are by Ethernet/IEEE 802.3 and WiFi (IEEE 802.11). Typically, the second solution is used since it is cheaper and faster to deploy, several types of mobile devices are compatible with it and it does not require plugging of wires.

Wired: A wired on board access network allows users to connect and use on train broadband services by plugging their mobile devices to the sockets built in the carriage and use Ethernet/IEEE 802.3. This solution, however, is relatively expensive [2], slow to deploy and limits the types of mobile devices that could benefit from the offered services since smart phones, PDAs, etc do not have built in the appropriate adapters.

Infrastructure Wireless: WiFi (IEEE 802.11 a/b/g) access points are considered to be the most appropriate to deploy for the on board access network [3][4]. Users wirelessly connect their mobile devices to the in carriage access point, the traffic is then further directed to the gateway.

B. Intranet

The access points or the Ethernet sockets on board the train are connected to the central unit on the train forming the train’s intranet.

Wired: The access points deployed in the carriages are connected to the on board central unit (server) via copper cable or multimode fibre optics using Ethernet/IEEE 802.3. This train digital “backbone” can be used for other purposes as well, forming a general-purpose LAN to reduce wiring [5].

Infrastructure Wireless: Another way to interconnect the carriages and concentrate the traffic to the gateway is via wireless infrastructure. IEEE 802.11 wireless bridges or routers are placed at the extremities of the carriage to interconnect them [4][3].

C. Backhaul

The backhaul is the high speed, aggregated traffic connection from the train to ground-based infrastructure. There are several possible solutions for this part:

Satellite: Satellite links (typically Ka/Ku bands) to high-speed trains might prove a relatively low cost infrastructure for long distance tracks and fast to deploy since it requires no trackside infrastructure. The performance of such a solution is easy to predict by determining the line of sight between the train and the satellite and is suitable for international trains since it does not depend on a national operator. Nonetheless, line of sight might be seriously restricted on some rail routes. Tracking antennas and efficient modems for satellite communications are quite expensive. Furthermore, the size of the antennas can be too large to deploy on the train carriages at certain latitudes.

Bandwidth cost for satellite links is high and variable (one order of magnitude higher per MB of data comparing to cellular) and there is a limited choice for operators in Europe [7]. In the future, satellite links might be replaced by high altitude platform (HAP) links providing lower bandwidth costs and lower propagation delays [8].

Cellular: Both bandwidth and equipment for a cellular backhaul are relatively cheap and usually there is a broader choice of operators. GPRS/EDGE speeds are not high enough to be a trusted candidate for delivering real on board broadband services but they are considered for filling coverage gaps. 3G offers high data rates and they are improving relatively fast as can be seen with HSPA, HSOFA and Flash-OFDM. The main disadvantages of UMTS are that coverage is still limited, the throughput decreases fast with the speed, there are no QoS guarantees and it is not feasible for international trains since, even though the European Committee is trying to push them down by up to 70%
[6], roaming charges are still high [7]. Other cellular technologies such as Flash-OFDM, HSPA, HSOPA are not yet widely deployed.

**Trackside wireless:** Inexpensive on board equipment, high data rates, bandwidth and QoS control make trackside wireless technologies appropriate for delivering broadband services on trains. This technology requires trackside infrastructure that is costly and needs time to be deployed. In station infrastructure can be based on IEEE 802.11 and allows equipment on the train to rapidly connect and perform latent data transmission. IEEE 802.11 is not suitable for on road infrastructure due to small coverage and frequent handovers. Other standards for fast moving terminals such as IEEE 802.16e have been recently completed but certified cost effective equipment is still not available [7]. Work on the IEEE 802.20 standard is still undergoing.

### III. TRIALS AND COMMERCIAL APPLICATIONS

There had been several trials testing the delivery of broadband services on board train carriages in the last few years. Some of these trials turned into commercial products, especially in Scandinavia and the United Kingdom, and generated high revenues for the rail operators. Table 1 lists a chronologically ordered selection of trials that have been carried out as well as the companies and operators that were involved and the backhaul technologies used. The wireless on trains hype seems to have started in Europe (mainly in Scandinavia and the UK) but it has been tested also in Canada and North America. Besides trials listed in the table, EPIN Technologies is due to deploy wireless broadband services in Chinese stations and train carriages before the start of the 2008 Olympic Games and the Swiss rail operator SBB, RailTel in India, Trenitalia in Italy and Hitachi in Japan have also performed trials.

The most successful commercial solutions (see the highlighted rows in Table 1) proved to be based on a combination of satellite (for downlink) and cellular (for uplink) technologies for providing backhaul connections, and on WLAN (IEEE 802.11) for providing in carriage access and inter-carriage connection. There are several advantages when using hybrid systems such as: increased coverage, increased capacity and transmission cost optimization [11]. Hybrid systems are able to switch between technologies based on signal levels and transmission costs in order to offer high broadband at the lowest cost. Mobile Wireless MAN technologies were not fully standardized until recently so that some providers used proprietary so-called “pre-mobile WiMax” solutions. Bidirectional satellite systems were also on trial but seems like they have not succeeded to be commercially available, perhaps due to the fact that they relied on single and expensive radio technology.

The first on train Wi-Fi trial was carried out by Icomera who, in January 2003, together with the Scandinavian train operator Linx, began providing real-time broadband Internet access on board a train between Gothenburg and Copenhagen. The service aimed to enable Linx business and standard class passengers, as well as staff to surf the Internet and check emails whilst travelling on-board their high-speed trains [7]. Since then, the provider equipped other operators with on train broadband service. Typically, the system provided by Icomera is an end to end solution including hardware, software and communication channels using satellite for broadband capacity and multiple GSM links in parallel for reliability and is called Icomera Mobile System (IMS). The IMS is made out of several components: the antenna unit, the high voltage protection unit, the Icomera Mobile System Rack (IMSR) and the on board

<table>
<thead>
<tr>
<th>Trial start date</th>
<th>Country</th>
<th>Company</th>
<th>Train operator</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan, 2003</td>
<td>Scandinavia</td>
<td>Icomera</td>
<td>Linx</td>
<td>One-way satellite + GPRS</td>
</tr>
<tr>
<td>Jul, 2003</td>
<td>Canada</td>
<td>PointShot</td>
<td>Via Rail</td>
<td>One-way satellite + CDMA</td>
</tr>
<tr>
<td>Aug, 2003</td>
<td>US</td>
<td>PointShot</td>
<td>ACE</td>
<td>One-way satellite + CDMA</td>
</tr>
<tr>
<td>Sep, 2003</td>
<td>UK</td>
<td>QinetiQ</td>
<td>Virgin Trains</td>
<td>One-way satellite + GPRS</td>
</tr>
<tr>
<td>Oct, 2003</td>
<td>US</td>
<td>PointShot</td>
<td>The Capitol Corridor</td>
<td>One-way satellite + CDMA</td>
</tr>
<tr>
<td>Dec, 2003</td>
<td>UK</td>
<td>Icomera</td>
<td>GNER</td>
<td>One-way satellite + GPRS</td>
</tr>
<tr>
<td>Jun, 2004</td>
<td>Spain</td>
<td>21Net</td>
<td>Renfe</td>
<td>Two-way satellite</td>
</tr>
<tr>
<td>Jan, 2005</td>
<td>Sweden</td>
<td>Icomera</td>
<td>SJ</td>
<td>One-way satellite + 3G</td>
</tr>
<tr>
<td>Feb, 2005</td>
<td>UK</td>
<td>Nomad Digital</td>
<td>Southern Railways</td>
<td>Pre-mobile WiMAX + UMTS</td>
</tr>
<tr>
<td>Apr, 2005</td>
<td>Belgium/France</td>
<td>21Net</td>
<td>Thalys</td>
<td>Two-way satellite</td>
</tr>
<tr>
<td>Dec, 2005</td>
<td>Germany</td>
<td>T-Mobile</td>
<td>DB</td>
<td>UMTS + Flash-OFDM</td>
</tr>
<tr>
<td>Aug, 2006</td>
<td>US</td>
<td>Nomad Digital</td>
<td>Caltrain</td>
<td>Pre-mobile WiMAX</td>
</tr>
<tr>
<td>Feb, 2007</td>
<td>The Netherlands</td>
<td>Opalis</td>
<td>NS</td>
<td>WiFi + 3G</td>
</tr>
</tbody>
</table>
wireless network (OWN). The antenna unit typically includes GPS, 3G and WLAN capabilities [10], but the »brain« of the solution is the Connection Manager (CM) [11]. The CM manages the radio connections based on availability and configurable policies that can be dictated by the priority, by time, by the position and by cost. The system has the ability to provide a seamless handover from satellite to cellular (3G, GPRS, EDGE) connections though using multiple radio technologies in order to increase the coverage and the capacity as well as to optimize the transmission cost. A typical commercial configuration is formed by: four 384 kbit/s UMTS slots (~1.5 Mbit/s), four 112 kbit/s GPRS/EDGE slots (~400 kbit/s) and 2 Mbit/s SAT DVB-S connections for the backhaul and 11/54 Mbit/s IEEE 802.11 b/g connections for on train intra net and user access [11]. IEEE 802.11 b/g access points enhance the customer access and the carriages are connected via IEEE 802.11 b/g bridges.

When a ticket for a journey is purchased, the train operating companies (TOC) ticketing system notifies the authentication, authorization and accounting (AAA) (see Figure 1) that creates an account and the passenger gets the password for accessing the network printed on the ticket. From the carriage, the traveller connected to the local WLAN and the user generated traffic concentrates at the on board Mobile Server after passing through the on board firewall. The traffic is sent via a backhaul radio technology (satellite, cellular, wireless) to the system's intranet that is connected to the Internet via a proper gateway.

Figure 1: Network Architecture

When a high speed train passes through a tunnel or under a bridge, satellite signal is lost and this may lead to service disruption on the client side. Two main solutions are implemented in order to avoid this problem: the first one performs web caching and email storing and forwarding on the server on board the train [16] and is especially preferred for solutions in which satellite links do not have terrestrial wireless backup. The second solution is switching to terrestrial wireless communication (cellular, WiFi) when the satellite LOS is unavailable [10][17]. For this second solution, special infrastructure has to be deployed in such obstructed areas.

As technology evolves, standards are approved and certified equipment becomes available, more backhaul solutions for providing broadband services will be available. IEEE 802.16e standards have been recently approved, 3G technologies like HSPA, HSOPA and Flash-OFDM promise higher data rates, and HAPs so called »atmospheric satellites«, might eliminate some of the disadvantages of the satellites.

IV. SOLUTION FOR SLOVENIA

Before the deployment of broadband to train services in Slovenia an in-depth analysis of operational, commercial and user requirements should be carried out. The most critical issue in the system architecture design is the selection of the backhaul solution, which depends on the route characteristics and on the availability and the costs of the technologies. Among most important railway route characteristics are the type of the route (e.g. urban, suburban, regional, long, distance, international), terrain configuration along the route (i.e. number and length of tunnels and cuttings), type of electrical posts (lateral posts with horizontal brackets, trellises), train speed (maximum and average), number of coaches, seats per coach, power outlets availability, average journey length and the train usage profile (business vs. domestic).

Slovenian railway network is composed of 1228.6 km of railway tracks with some 37.4 km of tunnels and galleries and 128 stations. Nevertheless, considering the journey durations and expected profile of the user we assume that broadband access on train would likely be available, at least in the initial phase, only along the two main routes, which are part of the European fifth and tenth corridor, i.e. Jesenice-Dobova and Koper-Maribor. In addition to tunnels and galleries, which occupy between 1% and 2% of the above mentioned routes, an important additional problem in service provisioning is represented by deep cuttings, especially in the Zasavje region, which significantly obstruct the signal propagation.

Considering relatively low utilisation of Slovenian railways in terms of the number of passengers, as well as the specifics of the railway routes in Slovenia, with many sections built away from the main roads, through less populated areas and the rather short routes even among the most distant stations, it is clear that any significant additional infrastructure required for the backhaul solution cannot be economically justified. Thus, taking into account also the terrain configuration, it is clear that only a hybrid solution...
consisting of all existing technologies that currently provide at least partial coverage of railway routes (i.e. satellite and 2G/3G cellular, as well as WiMAX expected in the near future) can be used in Slovenia. Hybrid solutions are frequently used in the configuration having satellite links for the forward connection (download) and 2G/3G networks for the return connection (upload). In the case of lack of satellite visibility the forward links could be implemented over 2G/3G, trackside wireless or gap fillers. It is also possible to use bidirectional satellite links with additional gap fillers for tunnels and cuttings or available cellular and track side terrestrial networks.

To choose the appropriate solution, the satellite visibility and the 2G/3G cellular network coverage should be analyzed. UMTS network is mainly reachable along highways and in urban and some suburban areas. In the rural part mostly 2G or in best case 2.5G is available, while in regions with deep cuttings even 2G signal may not be always available, as well as satellite coverage. Tunnels and galleries along these routes are not seen as a major problem, apart for real-time services, because of their short length. In such short tunnels and galleries, the broadband connectivity can be virtually maintained through the on board caching functionalities. In the regions with no satellite visibility or 2G/3G network coverage, a new track side wireless infrastructure should be built (e.g. using WiMAX, Flash-OFDM or adding 2G/3G base stations, depending on the network operator interested in provision of broadband access on trains).

Even if not economically justified, the implementation of broadband access on trains in Slovenia might be seen as an interesting project from at least two aspects. The first is the provision of a similar broadband service on trains as available in neighbouring countries along the fifth and the tenth corridors, maintaining cross-border broadband connectivity of international passengers provided the trains are equipped with appropriate equipment. The second, perhaps more important, could be part of a wider campaign pursuing to revitalise and popularise travelling by trains in Slovenia at least between major cities, making better use of travelling time by the access to broadband services either for leisure or business.

V. SUMMARY

In the globalized world, people spend more and more time travelling, be for/to/from the business or for leisure, and many of them want to make use of this travelling time for reading and writing email, staying up to date with the news, doing business, play distributed games, etc. Several railway operators recognised these requirements as a business opportunity and instigated the development and implementation of broadband service access on trains using various technologies such as GPRS, EDGE, UMTS/WCDMA, HSPA, WiMAX and satellite links. In recent years we witnessed several successful trials, and some of them already outgrew in commercial applications.

In this paper we provided an overview of technical solutions used by different providers of broadband access on trains and discussed the feasibility of implementation of broadband service delivery on trains in Slovenia. The economical feasibility of the introduction of broadband access on trains, of course, depends on several country specific factors such as the type of the route, terrain configuration, train configuration, train usage profile, etc., rendering the transfer of available solutions difficult. In case of Slovenia it is rather clear that the only technically viable solution needs to be based on a combination of various available broadband access technologies, yet in order to recommend the most suitable technical solution, we need to carry out a detailed analysis of the signal coverage (cellular and satellite, focusing on EDGE and UMTS networks and a suitable EUTELSAT’s satellite) along the railway routes of interest.

Ideally, for the forward link VSAT DVB-S or UMTS/HSPA connections should be used. Regarding the costs of the connections, the required capacity and the availability of the networks, a seamless handover between technologies should be provided. From the economical point of view the return traffic must be handled through the available 2/2.5/3G technologies. In the larger stations, where the train stops last more than a few minutes, two way broadband connectivity should be maintained using WLAN access networks. As mentioned, the tunnels and galleries do not pose significant problems, unless for real-time services, however in the regions with the deep cuttings (Zasavje, part of the route Zidani Most - Celje) where there is no suitable broadband technology available, additional wireless infrastructure has to be built.

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