Broadband Wireless Internet Access in Public Transportation[1]

Andreas Roos, University of Applied Sciences Leipzig, 04277 Leipzig, Germany
Nico Bayer, University of Applied Sciences Friedberg, 61169 Friedberg, Germany
Dmitry Sivchenko, University of Applied Sciences Friedberg, 61169 Friedberg, Germany
Peyman Behbahani, School of Engineering and Mathematical Sciences, City University, London EC1V 0HB, UK
Michael Flegl, University of Applied Sciences Leipzig, 04277 Leipzig, Germany
Profn. Dr. Sabine Wieland, University of Applied Sciences Leipzig, 04277 Leipzig, Germany
Prof. Dr. Joachim Habermann, University of Applied Sciences Friedberg, 61169 Friedberg, Germany
Dr. Veselin Rakocevic, School of Engineering and Mathematical Sciences, City University, London EC1V, UK
Dr. Bangnan Xu, T-Systems, ENPS (Technologiezentrum), 64295 Darmstadt, Germany
Dr. Gerd Zimmermann, T-Systems, ENPS (Technologiezentrum), 64295 Darmstadt, Germany
Dr. Gerhard Kadel, T-Systems, ENPS (Technologiezentrum), 64295 Darmstadt, Germany

Abstract

Mobile broadband Internet access is an important issue for next generation networks. Users not only want to access their broadband services and applications at home but also en-route. This is technically challenging especially in the transportation environment as it has to deal with high mobility and many customers. The "Broadband Wireless Internet Access in Public Transportation" (BIT) project will solve these challenges. In particular the project focuses on the issues of mobility, land infrastructure, authentication, authorisation and accounting (AAA), security, novel transport protocols and the vehicle-land connectivity within such a transportation environment. This paper gives an overview of the project as well as an insight into the different areas of research.

1 Introduction

The Internet with its services has changed many areas of today's life. New network applications and services are constantly being developed. Until the present time, the customers mostly get broadband Internet access by means of a fixed wired connection, like Digital Subscriber Line (DSL). However, this trend is changing as new services are been traditionally not associated with Internet Protocol (IP) networks are extending their services into the realm of the Internet, such as telephony via voice over IP (VoIP) and television via IPTV. Thus the provisioning of so called "Triple Play" services (Voice, Video, Data) will become more and more important for network operators.

However, users not just want to access these services at home or at office but also en-route. Thus wireless networks will play a key role in future communication systems. The initial mobile network generation (G), like 2G Global System for Mobile Communications (GSM) and 2.5G General Packet Radio Service (GPRS), provide only limited bandwidth of up to 53 kbps. Solutions such as Enhanced Data Rates for GSM Evolution (EDGE) or the 3G network Universal Mobile Telecommunication System (UMTS) provide an "extended" bandwidth for Internet connectivity. However, future services (Triple Play) need broadband Internet access. Current developments like high speed downlink packet access (HSDPA), Institute of Electrical and Electronics Engineers (IEEE) 802.16 standard (Worldwide Interoperability for Microwave Access – WiMAX) or fast low-latency access with seamless handoff - Orthogonal Frequency Division Multiplexing (Flash-OFDM) seam to be viable solutions to provide broadband wireless Internet access.

The "Broadband Wireless Internet Access in Public Transportation" (BIT) project is focusing on the provisioning of Triple Play services in high-speed public transportation scenarios and respectively trains. A solution enabling network connectivity for customers in high-speed vehicles which can move up to 300 km/h is aimed. However, this is a challenging task and many issues are still unsolved.

The vehicle-land connectivity is a very important issue to provide broadband Internet access. One of the challenging aspects is the train speed and the different types of wireless access technologies to obtain connectivity with land infrastructure [1], [2], [3] and [4]. Only a small number of wireless access technologies, allow connectivity for high-speed vehicles. However, this technology is not available everywhere. Thus combination of different access technologies will be unavoidable to fulfil the requirement of broadband Internet access in public transportation. From this heterogeneity it follows that mobility support is a precondition in such a system. The handover behaviour respectively the handover time of the access technologies while moving between different network cells, as

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well as different network types is significant to provide continuous vehicle-land connectivity.
Wireless technologies suffer from the trade-off between coverage and capacity. For broadband vehicle-land connections this means that many base stations or access points are needed. Furthermore, every station needs a broadband connection to the core network. Traditionally this is realised with optical links. However, this is very expensive. Within BIT a wireless mesh multi-hop network as land infrastructure is envisioned to connect land stations with the core network. Mesh technology is still in its infancy and many problems are still unsolved. BIT focuses in particular on the quality of service (QoS) provisioning in mesh networks in order to support Triple Play services.
Link characteristics, like signal strength, of wireless networks change in a fast manner. As result, the available bandwidth between two network nodes is changing as well. The TCP protocol is very popular in the Internet and used by nearly all data applications. However, it is not designed for the specific characteristics of wireless networks. It is not able to handle the changing conditions of the wireless channel. The Stream Control Transmission Protocol (SCTP) [5] is a novel transport protocol able to solve these problems and to improve the overall network performance. The aim of the BIT project is the deployment of this feature in the BIT architecture and to compare with TCP derivatives.
Privacy and security in the BIT network architecture is essential for customer acceptance and trust in services. Otherwise, business models will fail. Hence, it is necessary to guarantee the privacy of customers. It is essential to hide the current location of a customer against a third person. Furthermore, security concepts are needed to protect customers and data against misuse and repudiation. In this context security in mesh networks is also investigated.
Beside security and privacy, AAA is the precondition to provide secure customer access to the access network. To enhance the customer acceptance of applications and services an overarching AAA concept is needed that supports simplified network and service access. An additional benefit of an overarching AAA system is service and customer data management. As a result roaming behaviour and service integration will be simplified.
In the following sections this paper presents an overview of the research project BIT. The requirements on mobility are presented in section 2.1. The application of wireless mesh networks for the land infrastructure is discussed in section 2.2. Section 2.3 outlines the importance of privacy, security and AAA aspects. Furthermore, in section 2.4 the demand for an enhanced communication protocol is discussed. The challenges to provide connectivity between high-speed vehicles and land infrastructures are presented in section 2.5. Conclusions from the paper are drawn in section 3.

2 BIT Project Overview

The BIT project considers provisioning of services to customers within high-speed vehicles, like trains. Challenges of broadband wireless connectivity and Internet access in transportation environments will be evaluated and investigated. The research project aims to develop mechanisms and concepts to fulfil the requirements of a mobile train network provider.

2.1 Mobility

The high speed of moving vehicles challenges in frequent and fast changes of the points of attachment to the network (PoAN) used as gateways to the wired land network infrastructure. An appropriate mobility solution has to be developed to handle this issue. A typical mobility scenario considered in the BIT project is shown in **Figure 1**.

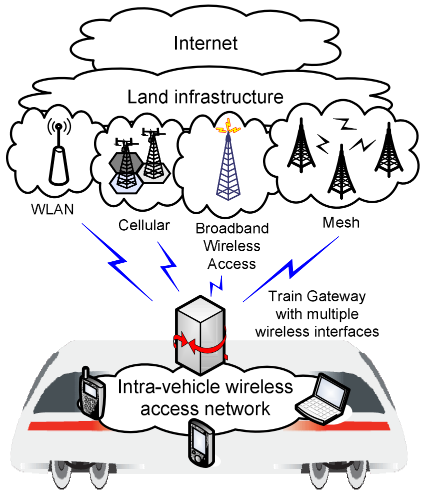

Figure 1: Mobility Scenario in the BIT Project

A number of customers within the moving vehicle use the intra-vehicle wireless access network to connect to the train gateway (TG). The TG provides all operations needed to establish vehicle-land connectivity. Besides the security procedures required for authenticating the TG at the new PoAN or in the new access network, mobility mechanisms have to be applied to re-route the incoming traffic to mobile nodes.
The Mobile IP protocol [6] is well known by the Internet community and is a de-facto solution applied to provide uninterrupted network connectivity for nodes changing their IP address while maintaining established communications. It operates at the network layer and uses IP encapsulation in order to deliver data packets destined to a moving mobile node via its actual PoAN. The Network Mobility (NEMO) [7] standardisation activities develop a mobility solution that can be performed in similar scenarios where an entire network changes its PoAN and thus its reach-

ability in the network topology as a particular unit. Both Mobile IP and NEMO approaches can barely be applied in the BIT scenario. First, they consider only one transmission path to the moving network unit and second, they do not offer any mechanisms to provide QoS support for mobile nodes. Usage of one transmission path causes large re-registration delays during handovers resulting in packet delay and loss for high-speed transportation. A data link layer handover can takes up to 2 seconds. This time behaviour is not suitable for seamless services provisioning. A TG, however, may have several network interfaces of diverse wireless technologies that can simultaneously be used for data transmission between the train and the land gateway. The fluctuating quality of different wireless channels at high-speeds requires an additional ability to switch data flows of customers between available access networks. Differentiation of packets generated by different applications or passengers may be realised in the TG. Thereby a support for different QoS levels may be introduced. Neither Mobile IP nor NEMO consider such functionality. Therefore, a new control mechanism must be developed to observe and manage the state of the present access networks. The control mechanism must be able to re-route customer flows among available wireless accesses. Moreover, the new management entity can be applied to transfer customer data over multiple air interfaces. Thus network diversity may be exploited to increase available bandwidth for customers within a moving vehicle that will be discussed in Chapter 2.5.

2.2 Wireless Mesh Networks for Land Infrastructure

To provide broadband Internet access to passengers in fast moving trains is very challenging as the vehicle-land connection is based on wireless technologies. The capacity of wireless networks is proportional to the coverage of the deployed wireless equipment. The coverage of IEEE 802.11 access points is generally limited to a couple of hundred metres. Base stations in case the IEEE 802.16 standard is used range up to some kilometres. Thus a broadband vehicle-land connection requires many stations on land side. This is very expensive as many stations are needed and as every station needs a broadband connection to a core network or the Internet. It is obvious that there is a gap between technical and economical requirements.

Wireless mesh networks are able to fill this gap. Their ability to forward data over multiple hops at high data rate eliminates the requirements to connect each access point to the wired Internet and therefore reduces costs. At the same time, capacity and reliability can be increased.

Thus the BIT project proposes to use a mesh backbone network at land side to connect land stations with the Internet. An overview about this architecture is shown in **Figure 2**. The proposed mesh backhaul architecture is organised in a three-tier architecture and consists of mesh base stations which act as wireline gateways, mesh routers and the vehicle-land connection. The mesh base stations connect the mesh network with external networks and thus provide Internet access. The mesh routers are at fixed sites and form a wireless mesh backbone. The vehicle-land connection is established between the gateways on the train and the mesh routers along the track. The challenges of the vehicle-land connection are presented in detail in Chapter 2.5. However, to realise this connection, the equipment must be installed in the train gateway and in the mesh routers along the track. For instance if the IEEE 802.16e standard is used for theses purposes, the train gateway must be equipped with the client adapter and the base station is installed along with every mesh router.

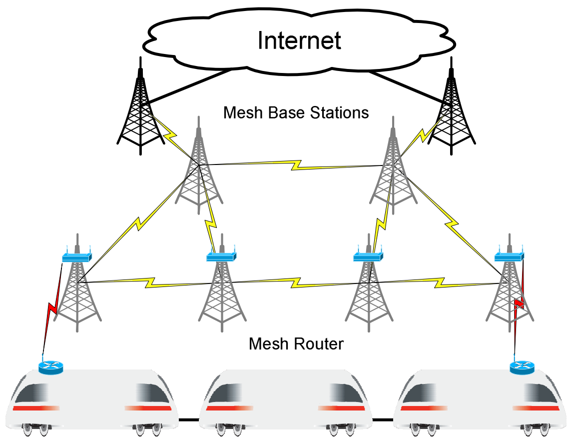

Figure 2: Wireless Mesh Backhaul Network

Due to their benefits and characteristics, wireless mesh networks have triggered advances at various levels. First, vendors are pushing their wireless mesh network (WMN) solutions with proprietary mesh protocols. Second, community mesh networks like the MIT Roofnet [8] or the Freifunk in Berlin [9] grow organically to provide connectivity and capacity. Third, research testbeds are developed to experimentally evaluate mesh networks and understand their limitations and capabilities. Fourth, standardisation activities focus on multi-hop mesh networks, including the IEEE 802.11s for Wireless Local Area Networks (WLANs), IEEE 802.15 for Wireless Personal Area Networks (WPANs) and sensor networks and finally the IEEE 802.16 activities with focus on Wireless Metropolitan Area Networks (WMANs).

Unfortunately, some challenges are still unsolved. Lack of QoS provisioning is one of the most important drawbacks of current mesh solutions. QoS in wireless multi-hop networks is challenging as these networks suffer from often changing channel characteristics, along with the difficulty of sharing the channel me-

dium with many neighbours, each with its own potentially changing QoS requirements.
The aim of the BIT project is the development of a joint media access control (MAC) and routing layer approach to provide end-to-end QoS provisioning within the mesh network in order to support Triple Play services. Therefore the routing protocol must be QoS aware. It must obtain routes able to satisfy multiple QoS constraints (metrics), e.g., bandwidth and delay. This is completely in contrast to the traditional routing protocols as they mostly use a single metric (such as hop count) in order to find the shortest routes. Additionally, the MAC layer needs to distinguish between different traffic classes in order to be able to satisfy different QoS constraints. Furthermore, it must provide mechanisms for resource reservation.
As basis for the mesh investigations in BIT the IEEE 802.16 standard was selected. The carrier sense multiple access / collision avoidance (CSMA/CA) mechanism applied in current IEEE 802.11 networks is not optimal for QoS provisioning as it belongs to the group of random access mechanisms. In contrast the IEEE 802.16 MAC layer can be expected to provide the necessary guarantees via time division multiple access (TDMA) mechanism. Unfortunately, the 802.16 standard only provides a framework of the mesh mode, and at the current stage many specifications are still undefined and need further investigations. Initial results show that the current version of the 802.16 mesh mode has a scalability problem that strengthens the QoS problematic in mesh networks [10].

2.3 AAA and Security

The AAA requirements of fast moving vehicles, like high-speed trains, e.g. ICEs, are challenging. Connectivity in fast moving vehicles is one part but authentication is another part. The permanent changing conditions, like changing the locality and the vehicular speed of the train, results in changing of access networks alongside the railway, shown in **Figure 1**. The duration time of staying within a radio cell depends on the range of the access technology, like UMTS, WiMAX or WLAN and is limited to a few seconds. In the same intervals the train gateway has to authenticate or re-authenticate himself against the home authentication server. Due to this authentication mechanisms with short authentication times or pre-authentication are needed. The behaviour of fast authentication and consequently for mobile service provisioning requires the interaction of AAA with mobility as well as with QoS to provide overarching AAA concepts [11].
The usability of provided services is a precondition of customer acceptance and as a result for the services success. Many offered procedures to get Internet access in Hotspots are customer uncomfortable. Customers have to enter parameters of their home Internet provider or need a voucher before entering the Internet in the Hotspot. Internet access has to be established in a user-friendly and easy manageable way for customers. A solution to achieve user-friendly Internet access for customer is the applying of mobile phones SIM card. All relevant customer information for customer authentication is delivered by the SIM card and consequently Internet access can be provided in a user-friendly way.
Overarching AAA systems are the precondition for economic service provisioning of carriers. But the protection of privacy and security of customers are the basis to trust in services. The concept of the network infrastructure has to provide privacy of customers. No third person should be able to find out the current locality of customers. By means of data encryption confidentiality of customers' data could be obtained and the avoidance of eavesdropping. Moreover, providing of data integrity is possible as well. Development of enhanced and novel AAA systems without the integration of privacy and security aspects will not fulfil requirements of future services. It is mandatory to pay heed to these topics.
The transport of payload and user data within the carrier backbone has to be protected as well. In this context security within mesh networks is considered. Based on the routing protocol mesh networks are easy extensible and able to change their topology depending on available mesh nodes. Thus malicious mesh nodes are also able to get unauthorised access to the mesh network. It is challenging to solve the gaps of today's mesh networks to provide secure mesh access networks for carrier. Illegal redirection, tapping or modifying of customer data by a third person has to be avoided.
The access technologies providing the vehicle-land connectivity, e.g. GPRS, UMTS, WLAN and WiMAX contain their own security and authentication mechanisms. But these mechanisms are not compelling basis of the overarching AAA system. BIT focuses an overlaying security and AAA infrastructure based on an access aggregation network, including different access technologies, shown in **Figure 1**.
The integration of AAA functionalities, user-friendly usage behaviours and security aspects is very challenging to fulfil the requirements of an overarching AAA and security approach for carriers. This approach will consider the capability of today's applied AAA protocol, like RADIUS [12] and also the successor of RADIUS Diameter [13]. To provide future stableness of the AAA concept the infrastructure is based beside the Internet protocol IPv4 on IPv6. Furthermore, the IP multimedia subsystem (IMS) characteristics and features will be considered. The IMS concept regards mobility, QoS and AAA support in order to setup a standard conform AAA solution for carriers.

2.4 Novel Transport Protocols

In the observed BIT network architecture the train gateway is used as an interface between the radio network and the user equipments. The TG also provides a broadband Internet connection for the vehicle and the customers. In this part of project transport-layer solutions for improving the end-to-end connection robustness and throughput are investigated. By increasing the reliability of connections mobility is being managed and subsequently there is a clear improvement in the QoS for the end-users. The rationale for this work is to minimise the events when the connection because of handover or wireless link failure is broken.
Often, end-to-end connections have a single point of failure. This failure can happen in the wired or in the wireless part of the connection. In the wired part of the network, routing protocols can tackle the link failure using different re-routing techniques.
In the wireless part link a failure can occur because of random errors in the medium, low bandwidth and mobility. It is reasonable to say that the likelihood of a link failure is much greater in the wireless than in the wired part of the network. Link failure has direct effect on higher layers, because transport-layer connections rely on the network connectivity, and applications rely on the transport-layer connections. This is the main drive behind the work to develop novel solutions for including the transport layer in dealing with random link failures in mobile networks.
One concept that is very attractive and is gaining increased interest in the research community is the concept of *multihoming*. Multihoming, shown in **Figure 3**, addresses the problem of link failures by allowing a transport layer session to bind multiple IP addresses at each end point.

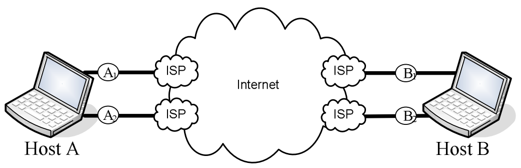

Figure 3: Multihomed Scenario

This feature provides both endpoints with multiple communication paths, and thus the ability to *failover* (switch) to an alternate path when a link failure occurs. The simultaneous connectivity can be realised using multiple Internet Service Providers (ISPs) or multiple access technologies, such as cellular networks (e.g. GPRS or UMTS) and wireless LANs and MANs (e.g. IEEE 802.11 or IEEE 802.16).
The current transport protocols, TCP and UDP, do not support multihoming. TCP allows binding to only one network address at each end of connection. This is the main reason why a new transport-layer protocol, the Stream Control Transmission Protocol (SCTP) [5] is being investigated in this research. SCTP allows binding of one transport layer association to multiple IP addresses at each end of the association. SCTP has a built-in failure detection and recovery system, known as *failover*, which allows associations to dynamically send traffic to an alternate peer IP address when needed. SCTP's *failover* mechanism is static and does not adapt to application requirements or network conditions.
SCTP also offers partial reliable data transfer [14] which can be used in some application and with only one transport layer protocol, carry reliable content - like text pages, billing and security information, setup signalling – and unreliable contents e.g. multimedia packets or voice that is sensitive to the timeline, when generating a new packet has more advantages than transmitting the old one.
SCTP multihoming is originally designed for wired base networks. The aim of the BIT project is the deployment of this feature in the BIT architecture. The project presents detailed analysis of a potential solution for improving the reliability and robustness of transport-layer connections in a heterogeneous mobile environment with multiple vertical handovers. Improving the end-to-end QoS, seamless vertical and horizontal handover in a heterogeneous mobile network, load balancing and load sharing will be some of the result of this project.

2.5 Vehicle-Land Connectivity

The customers inside the train get access to the intra-vehicle wireless access network via a WLAN access points (AP). These APs are connected to the train gateway [15]. The TG includes different radio technologies to provide broadband connectivity to the land infrastructure [1]. Thus the train is independent of the available radio access networks along the railway and is able to select the best connection to the Internet.
The challenges of the vehicle-land connectivity are on the first side the broadband connectivity with a minimal bandwidth demand of 384 kbps for up- and downlink to provide a basic Internet connectivity to customers. The reliability and reachability of the vehicle-land connectivity is the second side even at high vehicular speeds with up to 300 km/h. Beside vehicular speed, power lines along the tracks influences propagation characteristics of wireless systems [2].
Common wireless technologies like GSM support Internet connection for slow moving vehicles only. Furthermore, GSM is not able to provide broadband connectivity between mobile vehicles and land infrastructures. The UMTS system delivers relatively low data rates but is able to support mobility of fast moving vehicles. High data rates can be delivered by the IEEE 802.11b technology but for slow vehicular speed only. The IEEE 802.16 standard is not able to provide high velocity as well. The next evolution lev-

els of IEEE 802.11 and 802.16 expects enhancements of mobility support, like channel estimation capabilities and handover mechanisms [2]. The proprietary wireless technology Flash-OFDM provides already connectivity at high vehicle speeds, but in contrast to the standardized systems mentioned before, the data rate is limited due to the current signal bandwidth of only 1.25 MHz. Enhancements based on the so-called FlexBand technology are in preparation.

Only a slight amount of currently available systems are able to provide seamless mobility. But most of them are built for slow or non vehicular speed. It is necessary to evaluate and investigate the current state of the art wireless systems to develop an approach for a wireless vehicular Internet access platform. Besides, it is important to consider new wireless systems to keep on improving the vehicle-land connectivity solution.

A new mobility management entity being developed in the BIT project may be used to transmit user data over multiple air interfaces. Therewith a channel bundling can be realised that will increase available bandwidth proportionally to the number of bundled channels. Hence, access technologies providing support for high level mobility but offering low bandwidth may be bundled to provide broadband network access in a high-speed vehicle. A trade-off between the common bandwidth and supported mobility of access technologies is achieved.

3 Conclusion

The importance of the Internet is increasing constantly. New services will be produced and traditional services, like telephony or television move into the realm of the Internet. Moreover, these services have high bandwidth demand and customers want service access en-route. Thus broadband wireless Internet access is a key issue in future communication systems.

This paper presents an overview of the BIT project which aims to solve these challenges of broadband wireless Internet access in public transportation. Therefore, the project focuses a multilayer approach. Appropriate wireless systems are investigated that are able to provide broadband Internet access to vehicles, like trains. Mobility is another issue that needs to be investigated to support seamless service provisioning. Beside mobility the capability of wireless mesh multi-hop networks is discussed for the application as land infrastructure. Furthermore, security requirements are presented and also the demand to protect customers' privacy and data from misuse. Moreover, the requirements of overarching AAA systems are discussed to provide service provisioning independent of access networks. Finally the typical properties and capabilities of the SCTP protocol is described which are able to enhance the mobility support of mobile devices.

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