Managing Ethernet Aggregation Networks for Fast Moving Users

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ABSTRACT

Delivering broadband services to fast moving users (e.g., in trains) involves both wired and wireless networks. In this article we demonstrate that a hierarchical wired Ethernet aggregation network in combination with Ethernet-based wireless access networks is an interesting approach for realizing broadband access to fast moving users. The focus of the article is on fast and autonomic setup and removal of tunnels in the Ethernet aggregation network for providing broadband services to trains. The resulting moving tunnels realize seamless connectivity for the users on a train with an efficient resource reservation in the aggregation network. A hybrid approach is presented, which allows tunnel-setup times to be minimized and provides accurate tunnel-setup triggers. A testbed has been set up to evaluate the hybrid approach and the results of this work are intended to be used as a guideline for network service providers on how to set up an Ethernet-based aggregation network for fast moving users.

INTRODUCTION

Providing broadband Internet access to railway passengers is a challenge. Given the current emerging trials and early commercial releases, it is only a matter of time before best-effort Internet on a limited number of trains will become a reality. The satellite-based communication systems were the first solutions on the market but they lack uplink connectivity from train to satellite. These systems can combine satellite communication with GSM or GPRS receivers to ensure continuous up- and downlink coverage along the entire train trajectory [1]. The first commercial bidirectional satellite communication system (4 Mb/s down and 2 Mb/s up), which offers high-speed Internet to high-speed trains, has been realized [2]. However, measurements on a typical high-speed train with Internet connection via satellite show that the achieved bandwidth of approximately 1 Mb/s is low and the measured latencies (approximately 616 ms) are high, making real-time communication impossible. The observed latencies are high due to the fact that the signal has to travel four times the distance an Earth satellite travels (twice for query and twice for answer). Currently, WiFi is also used as a technology to deliver broadband Internet to trains. Japan Telecom has announced that they have successfully demonstrated stable wireless broadband Internet connections onboard a train using WiFi hotspots placed along the railways. An alternative architecture based on the WiMAX pre-IEEE 802.16e standard (also called the Mobile WiMAX standard or WiBro) is gaining interest: on-roof antennas with WiMAX base stations located near the railroad track provide a bidirectional connection of 32 Mb/s with seamless handoff for high-speed trains [3]. The used WiMAX technology is the fixed variant of WiMAX, based on the IEEE 802.16-2004 specifications. Mobile WiMAX (802.16e standard) will be commercially deployed in 2007–2008, and will only require a basic update to the fixed WiMAX systems that are already deployed. Finally, also UMTS, Flash-OFDM, HSDPA, and 3G/WCDMA can be used as technologies for delivering Internet to fast moving users [4].

However, besides the good results with WiFi and good mobility support in the Mobile WiMAX standard, the aggregation network is still responsible for the transport of data traffic from the fast moving users to the service providers' networks and vice versa. Because of the fast moving aspect, this configuration has to be done in a timely fashion. We propose that the transport of data traffic between the service providers' domains and the WiFi and WiMAX antennas be done by means of tunnels in the aggregation network. The challenge is to design telecom networks in such a way that high-bandwidth services which require a high level of quality of service (QoS) — such as multimedia content delivery, video phoning, and on-line gaming — can be provided. These tunnels are needed in order to guarantee the required QoS. Since the management of the tunnels in the aggregation network is an important aspect, it is tackled in detail in this article. As presented in

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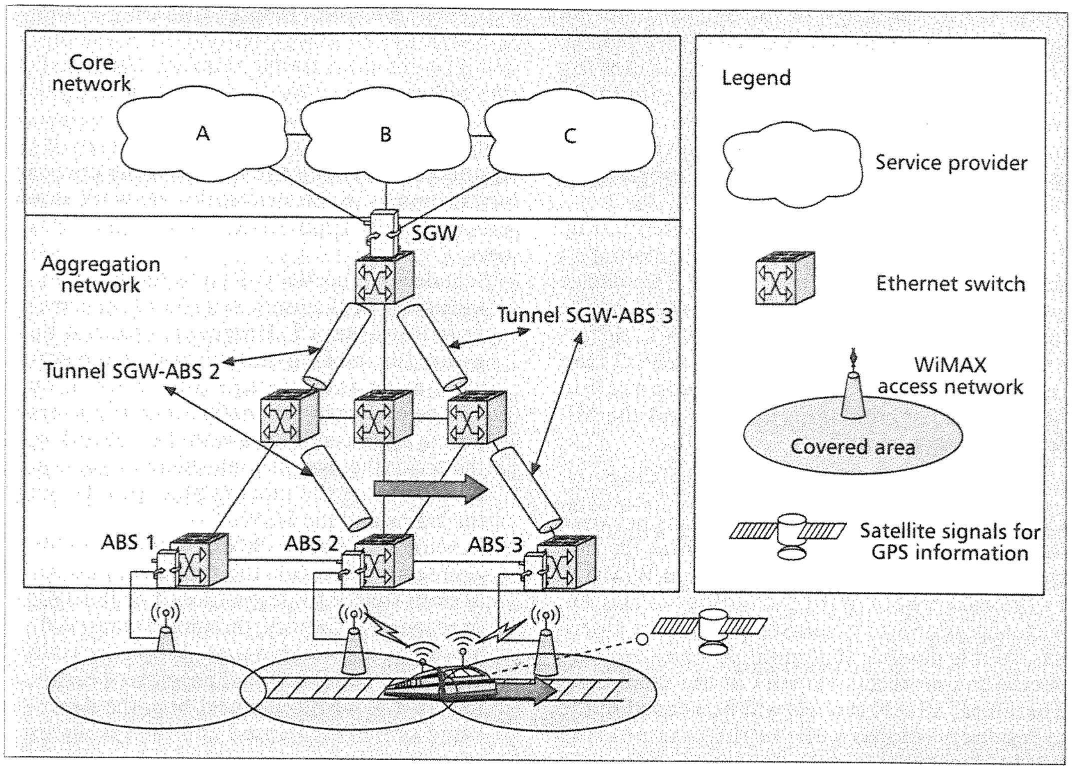


Figure 1. *Total network architecture with core network, aggregation network, and access networks. This architecture has already been extensively described in a previous paper by the authors [5]. We use Ethernet in the aggregation network. For the access networks, there are two options: WiFi and WiMAX. In the figure only the WiMAX case is shown.*

For the configuration of VLANs, we have two options: it can be performed automatically by means of the standardized GVRP or it can be done in a management-based way by contacting every network device separately, e.g. by using SNMP.

the following section, Ethernet is a strong candidate for delivering broadband services to fast moving users. This article describes an overall solution for mobility in Ethernet-based networks. Different telecom operators are already using Ethernet in the aggregation networks, and Ethernet is also becoming the standard for other networks (e.g., access networks). In order to measure our solution in a real-life case, we focus on an architecture enabling broadband Internet for commuters on trains. The architecture consists of a core network, an aggregation network, and different access networks. This article introduces a hierarchical Ethernet aggregation network. Based on the hierarchical structure of the Ethernet aggregation network, a hybrid approach for fast tunnel setup is further discussed. We clarify our solution, highlighting the management of this network. Then the evaluation results of the solution are presented. This is followed by a brief presentation on how an Ethernet-based aggregation network for fast moving users can be deployed.

Ethernet Aggregation Network

This choice for *Ethernet* in the aggregation network is motivated by the fact that telecom operators tend (mainly for economical reasons) toward networks consisting of standard QoS-aware Ethernet switches. With the introduction of the IEEE 802.1s Multiple Spanning Tree Protocol (MSTP), the bandwidth efficiency can be improved by maintaining multiple trees instead of a single tree, which is the case with the IEEE 802.1D Spanning Tree Protocol (STP) and the IEEE 802.1w Rapid Spanning Tree Protocol (RSTP). Almost every commercial switch is IEEE 802.1q/p compliant, that is, they all support virtual LAN (VLAN) technology and are QoS-aware (based on priority scheduling). VLANs provide a way of separating the physical topology in different logical networks and can be used to define end-to-end tunnels in the network. For the configuration of VLANs, we have two options: it can be performed automatically by means of the standardized GARP VLAN Registration Protocol (GVRP) or it can be done in a management-based way by contacting every network device separately, for example, by using the Simple Network Management Protocol (SNMP).

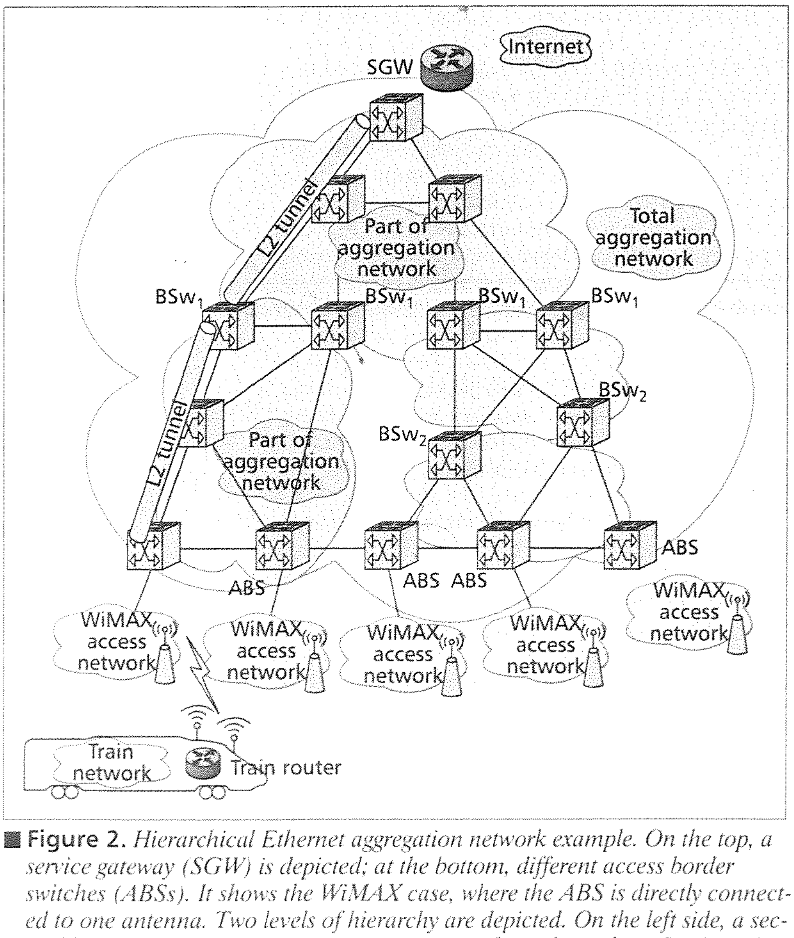
In summary, the ease of use and the auto-configuration of standard Ethernet, in combination with the recent advances in QoS support, are probably Ethernet's strongest features. The scalability issues are addressed in detail below.

Why is *IP* not an option in the aggregation networks? If Layer 3 mobility is used in the aggregation network, the IP addresses of the users in the trains change each time the train connects to a next hop. By placing an IP router on the trains, we observe a moving IP behavior while the IP addresses of the users on the trains remain unchanged during the whole length of their trip. Although different research groups have proven that the Mobile IP protocol can be used for single moving users, it has not been proven that it also works for the scenario of the aggregation of a large number of fast moving users. We believe that for a large group of users,all moving together (e.g., in trains), an aggregated tunnel (or multiple tunnels) per train will be more manageable and efficient, even in the access networks, instead of a per user tunnel management.

The overall architecture is depicted in Fig. 1. At the top of the aggregation network, a service gateway (SGW) is installed. This device acts as the uplink toward the Internet. At the lower side of the aggregation network, different access border switches (ABSs) are installed. They establish the connection between the aggregation network and the different access networks.

Access Networks

Considering the wireless connections between the moving trains and the antennas near the railroad, there are two options: WiFi and WiMAX. In the case where WiFi technology is chosen, each access network consists of different antennas, so it is possible that multiple trains are connected to one access network at the same time. Therefore, VLAN tunnels will be needed in the access networks as well. In the case of using WiMAX technology, only one antenna is needed per access network, so no further tunneling is necessary in the access networks when WiMAX is chosen.



■ **Figure 2.** *Hierarchical Ethernet aggregation network example. On the top, a service gateway (SGW) is depicted; at the bottom, different access border switches (ABSs). It shows the WiMAX case, where the ABS is directly connected to one antenna. Two levels of hierarchy are depicted. On the left side, a second level is not necessary because the number of switches is low. On the right side, a second level is shown as an example.*

Moving Tunnel Concept

While commuters on the train are moving along the railroad trajectory, their attachment point to the aggregation network hops from one access network to another. In order to preserve the connection between the train and the core network, tunnels in the aggregation network should move with the trains. This is done for two reasons:

- Seamless connectivity: Due to the fast moving aspect of the users, seamless connectivity is not assured. However, this can be assured by making on-time resource reservations in the aggregation network by means of moving tunnels. Since the users have a fixed connection with the network in the train, the overall connectivity is guaranteed by using the moving tunnels between the trains and the SGW.
- Resource efficiency: By using tunnels in the aggregation network, the traffic goes directly from source to destination. For the sake of resource efficiency, the tunnels must only be set up at their due time. When the train does not need the tunnel anymore, because the train moved to the next hop, the deprecated tunnel is released and the resources are released again.

It is often assumed that every train has multiple antennas on its roof and that each antenna it is using uses a single associated tunnel in the aggregation network. By using multiple tunnels per train, a continuous connection can be achieved, even during the handover process of one antenna. These tunnels on which the data connections of fast moving users will be mapped are VLAN-based tunnels which are responsible for the delivery to the correct connection point in the aggregation network.

Hierarchical Ethernet Aggregation Network

Different scalability issues make Ethernet difficult to use in large aggregation networks. Firstly, the use of spanning trees is inevitable as the spanning tree avoids loops in the network, and secondly, routing in Ethernet networks is based on the nonscalable MAC learning and forwarding principles. To avoid the latter, we do not use the different MAC addresses of all the users for routing the packets; instead, VLAN tunnels are used to route the packets in the aggregation network from source to destination. Each packet is routed through a VLAN tunnel, without learning its MAC address. Still, the spanning trees make Ethernet not scalable enough to use it in large aggregation networks. To solve this problem, a hierarchical approach is proposed. Different levels of the hierarchy are distinguished by defining the border switches' level n, BSw_n, in the aggregation network. The aggregation network can be interpreted as different smaller aggregation networks, each bordered by SGWs or BSw_n values at the upper part (toward the uplink) and ABSs or BSw_n values at the lower side (toward the trains), as depicted in Fig. 2. The required VLANs are installed in each small aggregation network separately; thus, VLANs are only defined in a small part of the aggregation network and a spanning tree is only needed in each small aggregation network. This is done by means of the Multiple Spanning Tree Protocol (MSTP); more specifically, each aggregation network defines its own Multiple Spanning Tree Instance (MSTI). The BSw_n nodes act as intermediate nodes between the aggregation networks. The tunnels in the separate aggregation networks go from one border switch to another border switch of the next or previous level. The SGW can be seen as the lowest level border switch, while the ABS can be seen as the border switch of the highest level. As the tunnels are set up in each part of the aggregation network separately, the BSw_n nodes are responsible for the continuation of a tunnel in one aggregation network to another tunnel in the next aggregation network.

Related Work

Generally, two types of mobility are considered in order to maintain the overall session mobility: macromobility and micromobility. Problems with macromobility are addressed by mobile IP, whereas cellular IP is used to tackle the problems that come with micromobility. Hierarchical IP has been proposed to improve the efficiency of mobility management in mobile networks. It reduces the overall registration signaling overhead, generated by mobile IP, by using regional registrations. In this hierarchical IP scheme the mobile anchor point (MAP) is introduced. An MAP handles mobility management for mobile nodes (MNs) within a network domain. More information on mobility support for IP-based networks can be found in [6]. In the European project IST-Magnet, another solution for mobility in IP is worked out [7]. Also, in other domains mobility plays a role (e.g., the management of Ambient Networks), and the term ubiquitous connectivity is mentioned [8]. All solutions are considered as solutions for use in access networks because they handle every user separately (e.g., in UMTS networks). They are all constructed from a client-perspective view. Considering mobility issues from the server side, solutions based on a per client handover is not an option, especially if large groups of users are moving together at high speed (e.g., commuters on a train).

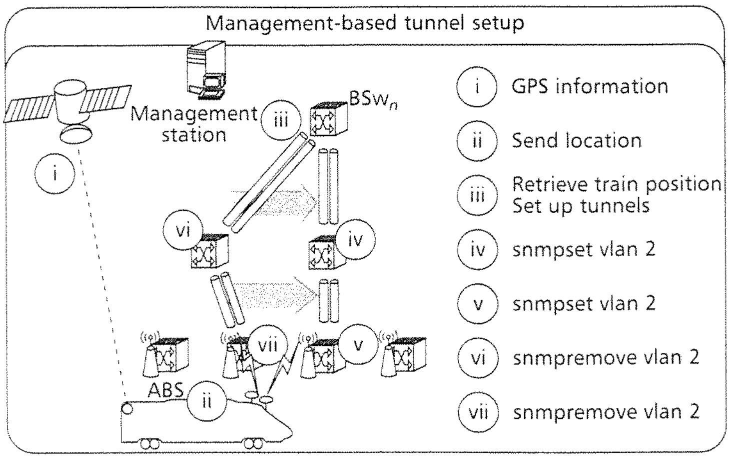


Figure 3. *Management-based tunnel setup and teardown in the aggregation network. The depicted network devices form a part of the total aggregation network. It is important to remark that the lower network devices are not always ABSs. The depicted network could also be in the middle of the overall aggregation network. The thicker tunnels are used for the data packets, the thinner ones for the management traffic.*

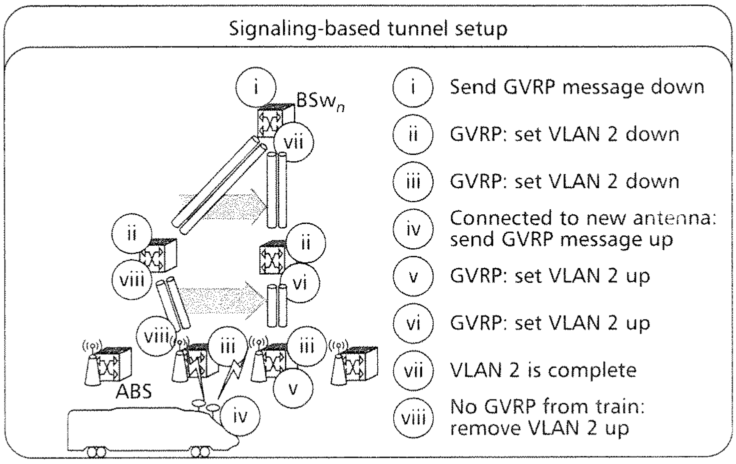


Figure 4. *Signaling-based tunnel setup and teardown. The depicted network devices are part of a small aggregation network. The thicker tunnels are used for the data packets; the thinner ones are used for management traffic.*

Automatic Tunnel Management

As motivated, we need an automatic tunnel configuration so that tunnels automatically follow the appropriate trains. Two different moving tunnels are involved: the tunnels in the aggregation network and the tunnels in the access networks. For both tunnels, we opt for Layer 2 tunnels, by means of VLAN tunnels. By tunneling the IP packets through those Layer 2 tunnels, there is no need to change the IP addresses of the packets while being transported from source to destination, nor will the IP addresses of the users in the trains change. The setup and teardown procedures of the tunnels can be performed automatically by means of the standardized GVRP or can be done in a management-based way by contacting every network device separately. Most commercial Ethernet switches already support GVRP.

Tunnel Setup Approaches

Management-Based — This is based on the location information of the trains by means of the GPS information of each train. Depending on the position of the train, the appropriate tunnel is used, as depicted in Fig. 3. The train sends its position to the management platform. Based on this information, the correct tunnel is set up and the packets meant for that train are sent through the correct tunnel. The configuration of the VLANs on the Ethernet switches is done by SNMP, via the management station. Once the train is connected to another AGW,

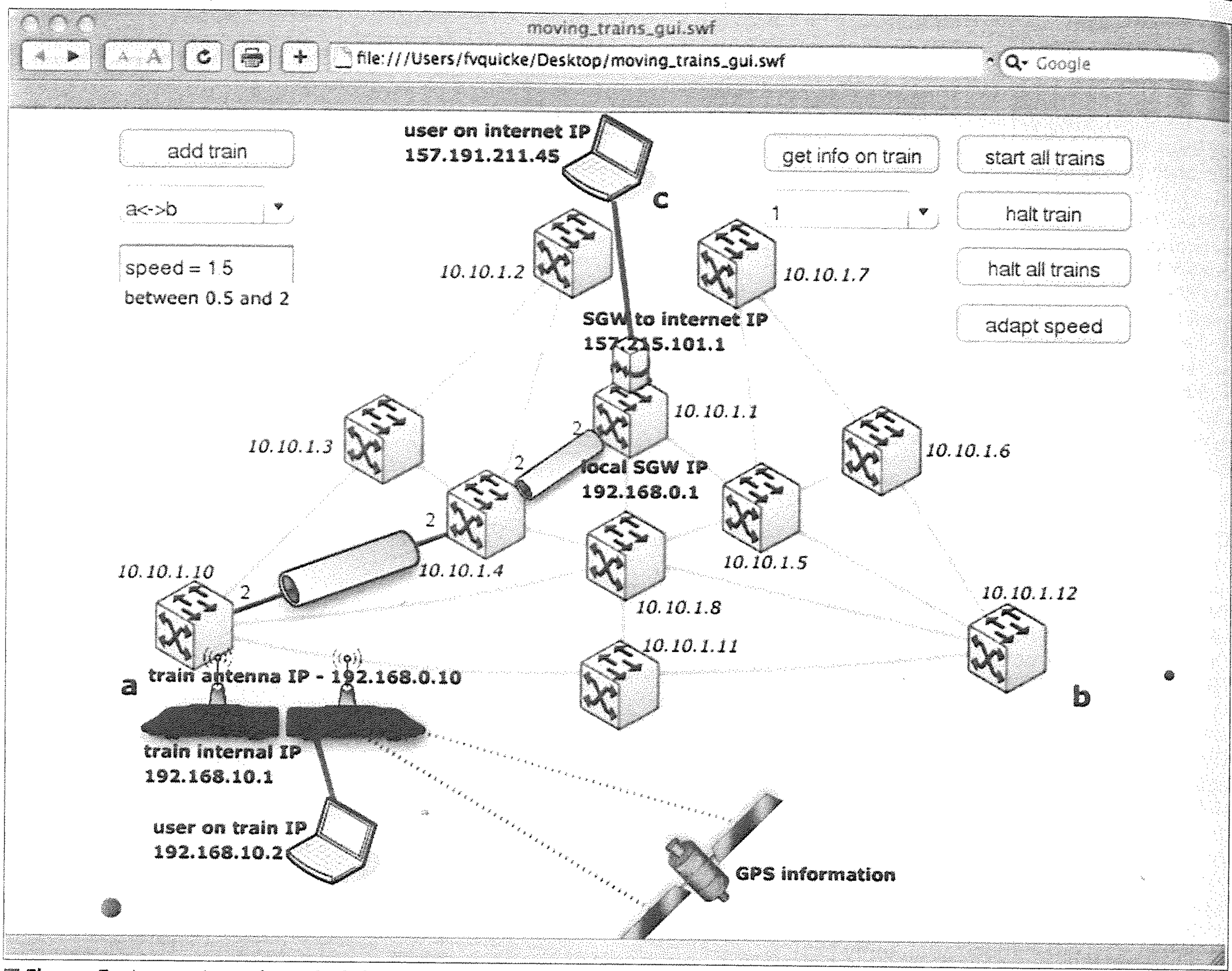


Figure 5. *A scenario on the testbed shown in the GUI. The GUI shows the moving trains and the tunnels used for the connectivity of each train. In this example, one train is moving between a and b, and VLAN 2 is used by the train. The IP addresses are given for the interfaces of the switches. The addresses in italic are used in the management layer.*

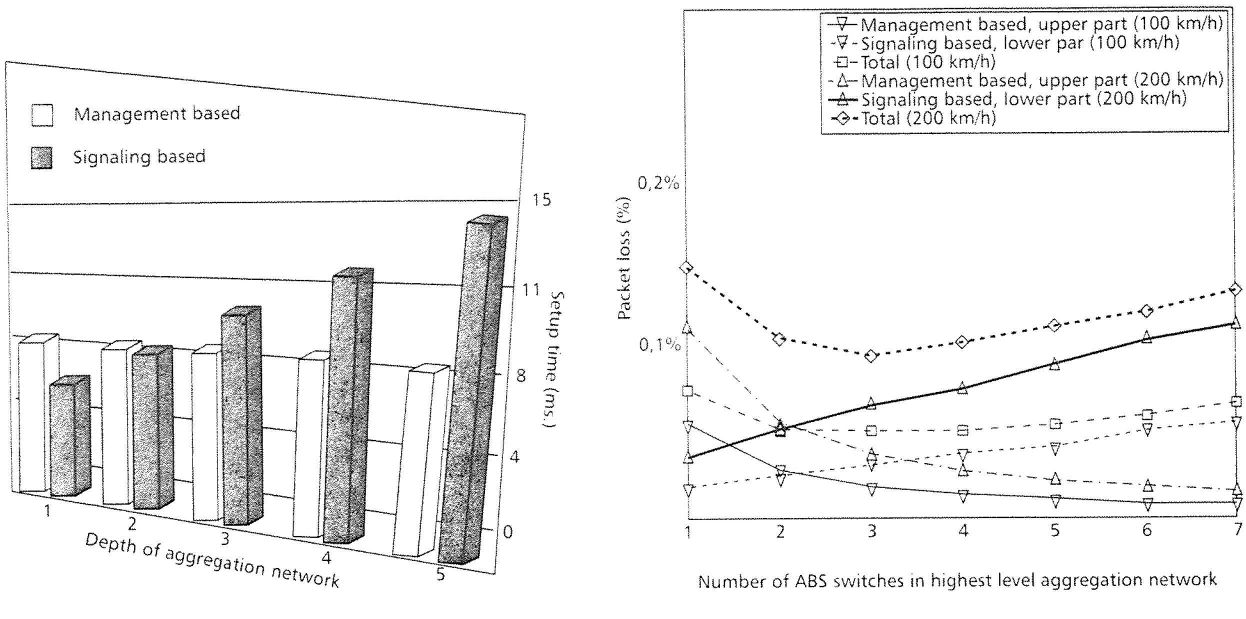
the deprecated tunnel is removed by the management station, together with all the made resource reservations in the network. It is important to mention that the tunnels do not move in time; they are installed before the trains are using the tunnel. It is the responsibility of the management platform to set up and tear down the tunnel so that it is usable when needed.

Signaling-Based — This is achieved by installing GVRP-aware switches on the trains. The train will signal its presence at the access network by means of sending a GVRP message to the antenna on the ground. This automatically sets up the tunnels for the train between the ABS and the train. This is the opposite of the tunnels installed by the management-based approach: those tunnels are set up before the trains are using it. Because the tunnels in the management approach are static, complex traffic engineering is inevitable, in comparison with the signaling-based dynamic tunnel management. They are not static, but move with the trains and are automatically set up and torn down by the signaling protocol. The tunnels are automatically torn down when a timer runs out. The signaling-based approach is depicted in Fig. 4. The train sends GVRP messages so that one half of the tunnel is set up. The other half is set up by the GVRP messages sent by the upper BSw_n toward the trains.

Hybrid Approach — A final approach is the hybrid approach, consisting of both management- and signaling-based tunnel setup and teardown. Assume the total tunnel is divided into different smaller parts. For each part of the tunnel, a management-based or signaling-based approach can be used to set up and tear down that part of the tunnel. A detailed description and motivation of this hybrid approach is applied later.

Address Assignment

A scenario is depicted in Fig. 5 in which a user on a train sets up a connection with a user on the Internet. During startup of his/her device



(a) Tunnel setup times. (b) Packet loss.

Figure 6. *a) Management-based vs. signaling-based tunnel setup times (as obtained through measurements on several commercial switches, connected to each other in a row); b) packet loss for different speeds of the train in the upper and lower part of the aggregation network and total packet loss (as measured on our testbed, with position updates every 10 ms for the management-based solution).*

on the train, the device receives its IP address via DHCP from the IP router on the train, which receives a range of IP addresses at his turn from the DHCP positioned nearby the SGW. The management system now knows which range of IP addresses are connected to which train router. The data from the customer on the train are sent from the device via the train router to the Internet, using the route toward the SGW which is permanently stored in the route table of the router on the train during startup of the router. All the data are tagged with the train VLAN and sent through to the appropriate VLAN tunnel between the AGW and the SGW.

EVALUATION RESULTS

TESTBED IMPLEMENTATION

Our testbed consists of 12 nodes connected to each other with UTP cables. The hardware specifications of the nodes are an AMD Athlon XP 1700+ with 256 MB RAM and the used NICs are Intel® PRO/100 S Desktop. The used software is built on Debian Linux 2.4.26 with Click 1.4.2, a MySQL database, and our own implementation of GVRP [9]. The moving behavior of the train is simulated by activating and deactivating the links between the train and the ABS nodes to which the train is connected. The activation and deactivation is driven by a module that emulates the position of the train by means of GPS coordinates. A GUI has been developed with the complete testbed, of which a screenshot is shown in Fig. 5. This testbed has been used for the packet loss measurements.

MANAGEMENT VS. SIGNALING BASED

The tunnel-setup times, as obtained for several commercial switches, are shown in Fig. 6a for both the management- and signaling-based approaches. The advantage of the management-based solution are the very fast setup times, independent of the tunnel length, which are indicated here as the depth of the aggregation network. The main reason for this behavior is that the switch configuration is performed in a parallel way using SNMP. The disadvantage of this solution is the necessary knowledge of the positions of the trains, in order to know which tunnel is needed for a train. This is based on the GPS information sent by the train to the management system. Besides the delay of the reception of this information, and taking into account the limited accuracy of the GPS signals, the exact positioning of the train is not known and thus the tunnel switching triggers suffer from incorrectness. This leads to packet loss, as discussed in the next section. The signaling-based approach, on the other hand, does vary with the tunnel length. From Fig. 6b it is clear that the tunnel-setup times linearly increase with the tunnel length. This makes the signaling-based approach difficult to use in the overall aggregation network.

HYBRID APPROACH

Measurements on the management-based solution [10] have proven that this approach is not usable in access networks, nor in aggregation network parts that are nearby the railroad, due to the fast moving behavior of the tunnels in that part of the network, thus leading to an inaccurate knowledge of the position of the

Tunnel setup and packet loss measurements indeed show that hierarchical Ethernet, together with the presented hybrid tunnel-setup approach, allows for flexible management of broadband aggregation networks for fast moving users.

train. It is also clear that a pure signaling-based solution is not an option, because the fast growing setup times of the tunnels as function of the length of the tunnel. For the management-based approach, the accuracy of the knowledge of the positions play a crucial role. Therefore, this approach is not recommended to be used in the lower part of the aggregation network, where the positions of the trains are not well known. In case of signaling-based tunnel setup, the length of the tunnel is determinative and not the knowledge of the positions of the trains. Hence, the signaling approach is advised to be used in the lower parts of the aggregation network. An optimal solution is found when combining both approaches in a hybrid approach, which perfectly fits in the proposed hierarchical aggregation network architecture. In the next section packet-loss values are measured for different hybrid solutions, leading to an optimal solution.

PACKET LOSS

The packet-loss percentages are measured when a train is moving at a specific speed and tunnels are moving in the network, following this train. The results, as measured on our complete testbed (Fig. 5), are shown in Fig. 6b for train speeds of 100 and 200 km/h. In the figure, the packet-loss percentages are measured in each part of the aggregation network. For this case, we used two levels in the aggregation network. In the upper part the management-based approach is used to set up the tunnel, while in the lower part the signaling-based approach is used. On the X-axis, the number of ABS switches in the highest part of the aggregation network is given. If each highest level network consists only of one ABS switch, the total packet loss (denoted by the thick line) is mainly due to the packets lost in the upper part of the network where the management-based approach is used. The main reason for this packet loss is the inaccuracy of the knowledge of the position of the train. If seven ABS switches are taken together in the lower network part, the total packet loss due to GVRP dominates because the length of the tunnel in the lower parts of the network leads to high tunnel-setup times and high packet losses. From the figure, it is clear that a minimum total packet loss is found. The total packet loss due to the tunnel movement in the aggregation network, stays low (approximately 0.1 percent) and this loss ratio does not jeopardize multimedia services for the fast moving users in trains.

DEPLOYING AN ETHERNET AGGREGATION NETWORK FOR FAST MOVING USERS

This section gives an overview of actions that need to be undertaken in order to set up and maintain an Ethernet aggregation network for fast moving users.

BSw_n Selection — Suppose Ethernet switches are installed and connected to each other. First, the aggregation network must be divided into different smaller parts. The maximum number of ABS switches in the highest-level aggregation networks (i.e., the network near the railroad), might not exceed three switches; otherwise, the total packet loss will not be minimal anymore. It is preferable to take two BSw_n values at the upper side in each part of the aggregation network, so that single-node failure of an BSw_n is covered. The rest of the aggregation network is divided into other different parts, so that no loops are found in the different parts of the aggregation network.

Spanning-Tree Configuration — The MSTP sets up one instance of a spanning tree in each part of the network by setting the ports of each Ethernet switch to the correct spanning tree instance. If certain links that are needed for the tunnels are not part of the spanning tree, the costs for that links must be set to a lower value. This is easily achieved by using a management tool.

BSw_n VLAN Configuration — Once the Spanning Trees are stable, each BSwn is associated to one dedicated VLAN. This limits the size of the parts of the aggregation network: only 4094 BSw_ns can be supported at the lower side of each part. This VLAN is used for the tunnel from the BSw_n node toward the uplink to the Internet.

Failure Detection — By monitoring the Ethernet switches — more precisely, by examining the STP parameters — an Ethernet management system can display failures in the network. In the lower part of the aggregation network, in which GVRP is responsible for the tunnel setup, the failures will be fixed automatically by means of the reconfiguration of the spanning trees. This is a first step toward a self-managing Ethernet-based aggregation network for fast moving users.

CONCLUSION

In this article we have argued that the use of moving tunnels in a hierarchical Ethernet aggregation network in combination with Ethernet-based access networks is an interesting approach for realizing broadband access to fast moving users. The concept of a hierarchical Ethernet aggregation network was described in detail. It has been demonstrated that neither a fully signaling-based nor a fully management-based aggregation network is an option. It was shown that tunnel management in the Ethernet aggregation network is best realized by a hybrid approach. The partly signaling-based tunnel management approach is a first step toward a fully self-managing Ethernet-based aggregation network. This hybrid approach allows packet loss to be minimized and provides accurate tunnel-setup triggers. Tunnel-setup and packet-loss measurements indeed show that hierarchical Ethernet, together with the presented hybrid tunnel-setup approach, allows for flexible management of broadband aggregation networks for fast moving users.

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