Broadband Aggregation Networks for Fast Moving Users through Hierarchical Ethernet

Frederic Van Quickenborne, Filip De Greve,
Filip De Turck, Ingrid Moerman, Piet Demeester

Department of Information Technology (INTEC)
Ghent University - IBBT
Gaston Crommenlaan 8, bus 201, B-9050 Gent, Belgium.
Tel.: +32 9 33 14974, Fax: +32 9 33 14899
{frederic.vanquickenborne|filip.degreve}@intec.ugent.be

Abstract. Delivering broadband services to fast moving users (e.g. in trains or cars) involves both wired and wireless networks. In this paper, we motivate that 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 focus is on the tunnel management in the Ethernet aggregation network for providing broadband services to trains. A hybrid approach is presented, which allows to minimize tunnel setup times and provides accurate tunnel setup triggers. The hybrid approach is described in detail, together with performance measurements on commercially available switches. The achieved tunnel setup times and measured packet loss are presented.

Keywords Convergence wireless and wired networks, trains, VLAN, automated tunnel management.

1 Introduction

Seamless broadband end-to-end mobile networking implies convergence of different types of networks: access networks, aggregation networks and core networks. Examples of current access networks are wireless networks (such as IEEE 802.11e Wireless LAN, 802.16 Wireless MAN and 3G/4G wireless cellular networks), whereas the aggregation and the core networks are generally broadband wired networks (such as Ethernet networks or IP/MPLS with WDM optical networks). Each type of network defines its own way of resource allocation and of routing, in combination with mobility aspects. Generally two types of mobility ([1]) are considered in order to maintain the overall session mobility: the macro- and micro-mobility. Problems with macro-mobility are addressed by mobile IP, whereas cellular IP is used to tackle the problems that come with the micro-mobility. 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 [2]. In the European project IST-Magnet, another solution for mobility in IP is worked out [3]. All mentioned solutions are considered as solutions for use in the access networks because they handle every user separately. They are all constructed from a client-perspective view. When regarding to the 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.

As will be motivated in section 2, Ethernet is a strong candidate for delivering broadband services to fast moving users. This paper 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 focused 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 paper introduces a new concept of mobility in Ethernet based networks by introducing a hierarchical Ethernet aggregation network in section 3. The management of this network is discussed in section 4. Section 5 details the evaluation results of the solution and in section 6 the conclusions are summed up.

2 Considered Architecture

2.1 Aggregation Network

This choice for *Ethernet* in the aggregation network is motivated by the fact that telecom operators tend mainly for economical reasons towards networks

Fig. 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 [4]. We use Ethernet in the aggregation network. For the access networks, there are two options: WiFi and WiMAX.

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consisting of standard QoS-aware Ethernet switches. Ethernet networks [5] use a spanning tree protocol to maintain a loop free active topology. The legacy IEEE 802.1D Spanning Tree Protocol (STP) and the IEEE 802.1w Rapid Spanning Tree Protocol (RSTP), both use only $N-1$ links in a network of N nodes. This limits the amount of links that can be used in these networks but 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. Almost every commercial switch is IEEE 802.1q & p compliant: i.e., they all support the 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. The configuration of VLANs can be performed automatically by means of the standardized GVRP (GARP VLAN Registration Protocol) or can be done in a management based way by contacting every network device separately, e.g. by using Simple Network Management Protocol (SNMP). In each access network an independent Multiple Spanning Tree Instance (MSTI) must be defined. The configuration of the spanning trees is done by setting the costs of the ports of the Ethernet switches. This is realised by accessing all the Ethernet switches and setting the costs via e.g. SNMP (Simple Network Management Protocol), as described in RFC 1493 [6]. 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 in section 3.1.

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 the IP infrastructure on the train, we observe a moving IP behavior while the IP addresses of the users on the trains remain equal 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.

At the top of the aggregation network, a Service Gateway (SGW) is installed. This device acts as the uplink towards the Internet. At the lower side of the aggregation network, different Access Border Switches (ABS) are installed. They establish the connection between the aggregation network and the different access networks.

2.2 Access Networks

Considering the last wired networks before the wireless connections between the moving trains and the antennas near the railroad, we have two options: WiFi and WiMAX. In case the WiFi technology is chosen, each access network will consist of different antennas, so it will be possible that multiple trains will be connected

Fig. 2. Layer 3 and Layer 2 tunnels through the network.

to one access network. Therefore, VLAN tunnels will be needed in the access networks too. In case of WiMAX technology, there will be only one antenna per access network, so no further tunneling is necessary in the access networks, when using WiMAX. Both cases are also depicted in the network architecture Figure 1.

2.3 End-to-End Tunnel Scenario

While commuters on the train are moving along the railroad trajectory, their attachment point to the aggregation network will hop from one ABS to another. In order to preserve the connection between the train and the core network, tunnels in the network must move with the trains (also for the sake of resource efficiency). Due to the moving tunnel concept, seamless connectivity is not assured. However, service guarantees can be assured by making on-time resource reservations in the aggregation network. This prevents high congestion levels which are inherently harmful for the network performance during tunnel switching. In this paper we assume that every train has one or more antennas on its roof and that each antenna it is using a single associated tunnel in the aggregation network. By using multiple tunnels per train, a continuous connection can be achieved, even during the hand-over 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 ABS in the aggregation network.

An overview of the overall end-to-end scenario is depicted in Figure 2. Between the core router (placed in the service provider domain) and the train router (placed on every train) an IP-connection is established by means of an MIPv6 tunnel. IP-packets going from the core router to the train router, use the IP-address of the user as destination IP-address and are encapsulated in Ethernet packets with the MAC-address of the train antenna as destination address. In the other direction, packets are always sent to the core router except for the packets to other users in the same train. The Layer 3 connection consists of different Layer 2 VLAN tunnels. The VLANs are end-to-end tunnels, through all the different networks between the Internet and the user on the train, au-

tomatically installed by the management system or by a signaling protocol. At their due time, tunnel setups are automatically done for every connection, but only when the connection will be effectively used. When the train is no longer connected to the ABS and the tunnel is no longer required, it is released. In this way the system always guarantees that the current and the next hop tunnel will be able to maintain the service level and that useless reservations are prevented.

3 Hierarchical Ethernet Aggregation Network

3.1 Motivation

Different scalability issues make Ethernet hard to use in large aggregation networks. First, the use of spanning trees is inevitable and next, routing in Ethernet networks is based on the non-scalable 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

Fig. 3. Hierarchical Ethernet Aggregation Network example. On the top, one Service Gateway (SGW) is depicted, at the bottom, different Access Border Switches (ABS). 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.

through a VLAN tunnel, without learning and/or using 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 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 s at the upper part (towards the uplink) and ABSs or BSw_n at the lower side (towards the trains), as depicted in Figure 3. The needed 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 management and configuration of those nodes are discussed in further detail below.

3.2 The Border Switches Level n

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, continuation of a tunnel in an aggregation network to another tunnel in the next aggregation network is needed. This is done in the BSw_n nodes and managed by the management platform. For instance, they must be aware of the different MSTIs used in the adjacent aggregation networks.

3.3 Multicast Services

Besides the mentioned advantage of making Ethernet scalable enough to use it in an aggregation network for fast moving mobile users, another interesting advantage of the hierarchical approach is the support for multicasting. For instance if a train company wants to distribute video streams to a specific group of trains. In that case a VLAN tree will be configured between the source of the multicast and all the involved trains. Because the branches of this VLAN tree are handled in each part of the aggregation network separately, the management of such a VLAN tree becomes easy in comparison with the IP multicasting approach.

4 Tunnel Management

We need an automatic tunnel configuration so the tunnels automatically follow the appropriate trains. Two different moving tunnels are involved: (i.) the tunnels in the aggregation network and (ii.) the tunnels in the access networks. In the aggregation network, we opt for Layer 2 tunnels, by means of VLAN tunnels. As in the access networks, where Layer 2 tunnels are also preferred.

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Fig. 4. 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 Access Border Switches. As the depicted network could be also in the middle of the overall aggregation network. The thicker tunnels are used for the data packets, the thinner ones for the management traffic.

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. In order to decide which user is using which tunnel in the management based case, tables must be kept up to date, holding information about the trains and the users on the trains. This has been published by the authors in [7]. The mentioned information of the trains consists of their positions and their needed bandwidth and QoS. First three possible ways of tunnel management are detailed, followed by their application in the hierarchical structure of the aggregation network and in the access networks.

4.1 Tunnel Setup Approaches

Management Based - This is based on the location information of the trains by means of the GPS information of each train. Dependent of the position of the train, the appropriate tunnel is used. This is depicted in Figure 4. 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. In the evaluation section 5, the performance of the method is evaluated. The deprecated tunnel is later removed by the management platform. It is important to mention that the tunnels do not move in time, they are installed

Fig. 5. 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.

before the trains are using the tunnel. It is the responsibility of the management platform to set up the tunnel, so it is usable when needed. It has been proven that a tunnel management approach is affordable if the time between tunnel switches is not too small. As this is the case in the upper part of the aggregation network (each train is approximately 1 minute connected to an access network of an ABS), it might be advisable to use this approach to set up and tear down the tunnels in the upper part of the aggregation network.

Signaling Based - If the time between successive tunnel movements becomes too small, a management based approach will suffer from a bad performance. In that case, a signaling based solution will be better. This is achieved by installing GVRP-aware switches on the trains. The train will signal its presence at a certain 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, a complex traffic engineering is inevitable, in comparison with the signaling based dynamic tunnel management. They are not static but move with the trains and they are automatically set up and teared down by the signaling protocol. This approach is depicted in Figure 5. The train sends GVRP messages, so one half of the tunnel is set up. The other half is set up by the GVRP messages sent by the upper BSw_n towards the trains. Again, the performance is discussed in the evaluation section.

Hybrid Approach - A final approach is the hybrid approach, consisting of both management and signaling based tunnel setup and teardown. This is more detailed in the next section.

4.2 Hierarchical Ethernet Aggregation Network Tunnel Management

As mentioned before, the management based tunnel management looks like the best choice to use when the time between the tunnel setup and teardown is not too small, like this is the case in the upper part of the aggregation network. However, by introducing the hierarchical structure in the aggregation network, the aggregation networks close to the railroad, will experience a faster tunnel movement. In that case, a signaling based tunnel management can provide a better performance. For the aggregation networks close the upper SGW, the management platform will set up the needed tunnels. Dependent on the position of a specific train, one of the tunnels is used to communicate with that train. The management platform must be aware of the exact position of the train, more specifically they must know to which antenna the train is connected. This information is sent from the train, through the ABS to the SGW over the management tunnel. The management tunnel is always active and the Common Spanning Tree (CST) is used to route the position information through the overall aggregation network, as this is the only spanning tree instance for the entire bridged network.

In the lower aggregation networks, a signaling based tunnel management will be used, because the time between successive tunnel movements is too small. This is very similar to the tunnel management in the access networks, detailed in the next section.

4.3 Access Network Tunnel Management

It has been proven that GPS information is not workable in access network environments, because the distance between successive antennas is too small. A signaled based solution will be better. Especially if the trains have multiple tunnels towards the ABS, e.g. if the train is connected to two antennas simultaneously. Multiple tunnels per train must be supported in that case, leading to a VLAN tree in the access network, instead of a VLAN tunnel. The management of a VLAN tree is very complex. The branches of the different trees in the access networks must be set up when needed and teared down when not needed anymore, leading to a complex resource allocation. Moreover, they must follow the trajet of the train, leading to dynamical routing. However, in our proposed solution, this is easily achieved by installing GVRP-aware switches on the trains. The trains will send a GVRP message to the ABS, this automatically sets up the trees for the train between the ABS and the train. As tunnels are set up automatically per train by means of GVRP, the nodes in the network do not have to know the location (i.e. the position of the train in which the user is traveling) of each user, as the tunnels go directly from the ABS of the particular access network to the antenna on the roof of the train. The tunnels in the access networks follow the trains automatically (because the tunnels are set up by means of GVRP). As mentioned before, the tunnel management in the aggregation networks close to the railroad, is done in a similar way.

5 Evaluation

5.1 Management versus Signaling Based

The advantage of the management based solution are the very fast setup times, because the switch configuration is performed in a parallel way using SNMP. The setup times, as obtained for several commercial switches, are shown in Figure 6(a). The disadvantage of this solution is the necessary knowledge of the positions of the trains. This is in contrast with the signaling based solution, as in this case the tunnel automatically follows the train. On the other hand, the tunnel setup in that case is done sequentially and the total setup times are higher compared to the management based solution (shown in Figure 6(a)), if the tunnel is longer than 2 hops.

5.2 Hybrid approach

Measurements on the management based solutions ([8]) have proven that the management based solution is not usable in access networks, nor in aggregation network parts nearby the railroad, because the fast moving behavior of the tunnels in that part of the network. However from Figure 6(a), it is clear that a pure signaling based solution neither is an option, because the fast growing setup times of the tunnels as function of the length of the tunnel, here indicated as the depth 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.

5.3 Packet loss

Besides the setup time measurements, the packet loss percentages are measured when a train is moving at an average speed of 200 km/h and tunnels are moving in the network, following this train. The results are shown in Figure 6(b), and the packet loss ratio behaves linearly with the speed of the train. From the Figure, it is clear that also the time between position updates sent by the trains must be taken into account. The conclusion is that not only the fast setup times are important but also the times between the position updates in case of the management based tunnel setup. In case of signaling based tunnel setup, the length of the tunnel is determinative.

6 Conclusion

In this paper, we motivated that 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 was shown that tunnel management in the Ethernet aggregation network is best realized by a hybrid

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Fig. 6. Management based versus signaling based tunnel setup times and packet loss (as obtained through measurements on several commercial switches).

approach. This hybrid approach allows to minimize tunnel setup times 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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