On the Management of Aggregation Networks with Rapidly Moving Traffic Demands

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Abstract

In this paper, the focus is on the management aspects for delivery of multimedia services to fast moving users (e.g., users in trains, cars or airplanes). The considered network architecture consists of two parts: an aggregation network part and an access network part. We designed a management system for the aggregation network. The main functionalities of this management system are: (i) pre-configuration of the QoS (Quality of Service) tunnels, based on the results of the network capacity planning process, (ii) activation of the QoS tunnels when required and (iii) tunnel reconfiguration when the activated tunnels are unsufficient to carry the instantaneous demand or in case of other failures. The main difference with existing management systems is that it is designed to deal with the rapidly moving nature of the traffic conditions and the generation of triggers for tunnel activations or reconfigurations. The management system focuses on multimedia service delivery to trains through high speed Ethernet aggregation networks. An extended GVRP (GARP (Generic Attribute Registration Protocol) VLAN Registration Protocol) and a new GARP protocol (G2RP) were designed and implemented as protocols for the automatic tunnel pre-configuration and activation, respectively. The management system makes use of optimization algorithms for network dimensioning and tunnel path determination. These algorithms will be described in detail and their evaluation results will be compared for a basic train scenario. Finally, measurement results on the performance of the designed protocols for tunnel pre-configuration and activation, are presented in detail.

Keywords

Multimedia traffic, dimensioning, optimization, tunnel management, GVRP, G2RP

1. Introduction

Nowadays, a lot of multimedia applications are taken for granted in fixed networks. These applications, such as managed home networking, multimedia content delivery, video phoning and on-line gaming require a high level of Quality of Service and are generally characterized by high bandwidth requirements. Current telecom-operators have mainly designed their broadband networks to cope with rather static or slowly moving traffic demands while fast moving traffic conditions have never been taken into account. The challenge is to design telecom networks in such a way that high bandwidth services can be provided to fast moving users. These networks can typically be deployed in metropoli-

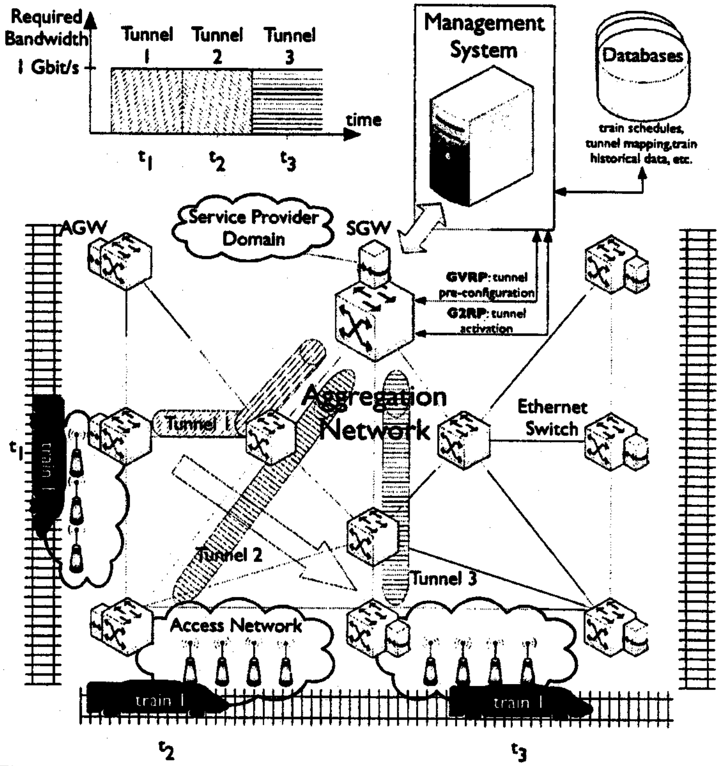


Figure 1: Schematic representation of considered network architecture.

tan areas, along railroad tracks or along highways. For an example of such a network, the reader is referred to [8]. The considered network architecture in this paper is depicted in figure 1. As can be seen in this figure, the architecture is divided in an access network part and an aggregation network part. The main difference between these two parts is that in the access network part, traffic demands from separate users are considered, whereas in the aggregation network part, groups of users are aggregated together. We define one or more groups of users per train. The traffic of each group of moving users is multiplexed in the Access Gateways (AGWs) into a tunnel. These AGWs provide the connections between the access network and the aggregation network. The aggregation of the groups is done by taking the users together in tunnels in the aggregation network, as depicted in figure 1. In this figure we consider three time-events: t_1, t_2 and t_3 on which the train is connected to three different access networks. The total required bandwidth for the train is 1 Gbit/s, based on a calculation made in [9]. On t_1, Tunnel 1 is used to meet the traffic demand of the train. On t_2, Tunnel 2 is used, and on t_3, Tunnel 3.

The aggregation network is responsible for the transport of aggregated data traffic, by means of high bandwidth tunnels moving at high speed, between different access networks and the service provider (SP) domain such as Internet service providers (ISPs).

content providers and telephony operators. The connection between the SPs and the aggregation network is realized by Service Gateways (SGWs). The fast moving aspect of the traffic demands (leading to rapidly moving tunnels) has not been extensively studied for aggregation networks. E.g., a detailed description of the UMTS (Universal Mobile Telecommunications System) technology in [14] gives only a brief description of the used protocols for interaction with the fixed network.

The main problem, tackled in the paper, can be described as follows: how to calculate and manage dynamic tunnels between the AGWs and the SGW in the aggregation network to meet the traffic demand of requests while achieving low congestion and optimizing the utilization of the network resources. As seen from figure 1, the dynamic tunnels have a fixed source but a rapidly changing destination: this leads to the concept of rapidly moving tunnels to fulfill the rapidly moving traffic demands of the trains. In order to automatically invoke the setup of the required tunnels and activate the tunnels at their due time, a dedicated management system is required. The designed management system differs from existing management systems in that it is designed for (i) handling the tunnel pre-configuration and activation requests and (ii) the generation of triggers based on information such as train schedules, train delays, predictions about increase in amount of traffic demand, etc. A critical part of the management system is the theoretical network dimensioning model that optimizes the use of resources under rapidly moving but quite predictable traffic conditions e.g., users on a predetermined route, as users on trains or in airplanes (connected to antennas on the ground, as airplanes also follow highways). For users in cars, we need a slightly different approach: generally tunnels are needed to all roads, sometimes with supplementary tunnels during special events which are more predictable e.g., during rush-hours. Due to the complexity of the model, rigorous optimization by means of ILP (Integer Linear Programming [11]) techniques only delivers solutions in a reasonable calculation times for limited network sizes. The model also includes a path calculation algorithm that is specifically designed for fast moving user conditions.

Mainly for economical reasons telecom operators [4] tend towards networks consisting of standard QoS-aware Ethernet switches (IEEE 802.1d [1], IEEE 802.1q [2] & p, IEEE 802.1s [3] compliant). We do not consider satellite or UMTS technology, due to their respective limitations of latency and bandwidth for fast moving users. The network interfacing of the management system has been implemented for Ethernet aggregation networks. An adaptation layer has been developed which allows the end-to-end Ethernet tunnel setup. This adaptation layer allows for easy plugin of the other management components. The management system allows to make optimal use of VLANs (Virtual LANs [2]) to support Multiple Spanning Trees in the Switched Ethernet networks. In this way network resources are optimally used. The remainder of this paper is structured as follows: section 2 details the management system, whereas section 3 details the model for the optimal network capacity planning and tunnel path determination. Section 4 describes the self designed and implemented protocols for tunnel pre-configuration and tunnel activation and section 5 considers the evaluation results. In the final part of the paper in section 6, the results are summed up in the conclusion.

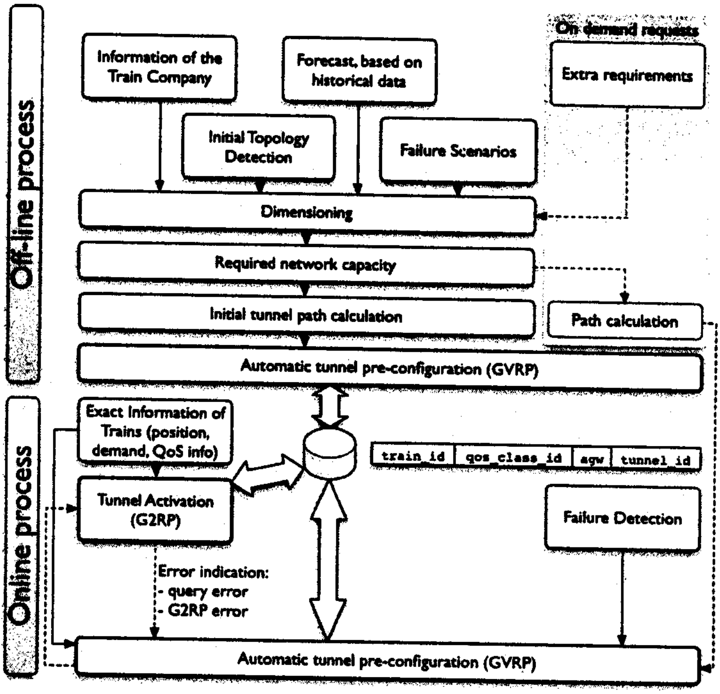


Figure 2: Flow diagram of the off-line tunnel pre-configuration process (upper part) and flow diagram of the online tunnel activation and reconfiguration process (lower part)

2. Management System

Each train defines two traffic demand classes: a basic and an extra traffic demand class. The last one is needed to fulfill the foreseen extra requests. Unscheduled trains do not have any basic traffic demand but only extra traffic demand. After the dimensioning and path calculation processes, the basic tunnels will be pre-configured. Remark that at this point, no bandwidth will be reserved. When a train approaches a network connected to an AGW, the appropriate tunnel will be activated, by reserving the needed bandwidth. When necessary, the foreseen extra tunnels can be pre-configured and activated very quickly. The tunnel pre-configuration process is an off-line process, whereas tunnel activation and reconfiguration are online processes, that need to be performed in real time. An schematic overview of all processes is depicted in figure 2.

2.1 Tunnel pre-configuration

The tunnel pre-configuration is based on the results of the network dimensioning process. The implemented network dimensioning module takes the following input parameters into account: (i) information from the train company about the trains schedules, the train capacity in terms of passengers and their QoS requirements, (ii) forecast of deviations from the train schedule and train capacity parameters (based on historical data), e.g., expected train-delays, extra trains due to special events and increase of user multimedia traffic, (iii) initial topology information, i.e. the positions of the core switches, the Service Gateways (SGWs) and the Access Gateways (AGWs), and the existing fibres between the different nodes, (iv) network element failure scenarios, the system needs to be resilient to. Since the dimensioning process takes into account possible train-delays, extra trains and resilience requirements, the dimensioned network capacity will be higher than strictly needed during normal system operation.

Based on the output of the network dimensioning, the path for each required tunnel is calculated. The path calculation aims at minimizing the total resource usage by applying optimization algorithms, which are detailed in the next section. Based on the determined path for each tunnel, these tunnel are pre-configured in the network by means of GVRP [2] (GARP [1] (Generic Attribute Registration Protocol) VLAN Registration Protocol). This protocol automatically establishes the tunnel path, without reserving the required resources. At activation time, the management system will invoke the resource reservation by means of the G2RP (GARP Reservation Parameters Registration Protocol) protocol. For an operation description of GVRP and G2RP, the reader is referred to section 4. An experimental performance evaluation of both protocols is described in subsections 5.2 and 5.3.

Each train is assigned an unique `train_id` and each requested QoS class per train an unique `qos_class_id`. Per `train_id` and `qos_class_id`-pair, several records are stored in the database, dependent on the number of AGWs the particular train passes by. A query on a `train_id`, `qos_class_id` and `agw` will reveal a `tunnel_id` on which the traffic has to be mapped, for the considered train, QoS class and between the SGW and the considered AGW. In our implementation, we have a many-to-1 mapping betweens tunnels and VLANs. In order to reduce the total number of required VLANs and to avoid scalability problems, different `tunnel_ids` can be mapped onto one `VLAN_id` since VLANs support multiple QoS tunnels. So trains with two different `qos_class_ids` will define two `tunnel_ids` per AGW. However, tunnels with the same path will have the same `tunnel_id`. To tackle the problem with the limited number of Spanning Trees, the Per VLAN Spanning Tree [12] solution can be used.

For solving the described design problem, several algorithms have been developed and are described in the next section. The lower part of figure 2 depicts the flow diagram of the online functionality of the management system. This online functionality is described in the next subsections.

2.2 Tunnel activation

The main purpose of this part is to activate the pre-configured tunnels at their due time. Based on data provided by the train company the exact train positions, the traffic demands and their QoS requirements are known, the tunnel activation is invoked. The management system will trigger the SGW and the AGWs to activate the tunnels when needed. This tunnel activation might fail, due to two reasons: (i) the activated tunnel is insufficient (e.g., due to an increase in the traffic demands) or (ii) no tunnel was pre-configured for the requested flow (e.g., in case of an extra train). When either of the two conditions occurs, the management system will invoke the tunnel reconfiguration module.

2.3 Tunnel reconfiguration

Besides the basic traffic demands for each train, all extra requests (e.g., predictable increase in traffic demand and extra trains) must be provided before the tunnel path determination process is started. After this process, the basic tunnels will be pre-configured. Only when necessary, the extra tunnels will be pre-configured and activated very quickly, as will be shown in the evaluation section of the paper. Unanticipated extra requests will be dealt with in a best effort way.

The off-line on demand requests (e.g., sudden increase in traffic demands, an extra train) are also shown in figure 2 for the sake of completeness.

3. Network capacity planning and tunnel path determination

In subsections 3.1 and 3.2 the assumptions concerning the considered network and traffic parameters will be detailed. A formal definition of the aggregation network capacity planning and related tunnel path determination will be presented in subsection 3.3. Subsection 3.4 details the developed solution technique.

3.1 Network model

For now, we assume a single service gateway and we assume that successive access gateways are positioned along the railroad track. Passing trains will connect to the closest access network and will hop from one AGW to another. The SGWs are constantly updated with the current position (and future positions) of the train, based on the information provided by the train company. To optimize the cost of the network we assume the links to be already installed and we only take the node cost into account. We distinguish between different line card types of different speeds and with different port ranges. The model will ensure that link and node capacities are adjusted appropriately. The model allows a large flexibility: removing certain card ranges on nodes, different prices of different hardware vendors can be taken into account. We assume that for every traffic class a single path is used for routing for every AGW-SGW pair at a certain moment. This path may vary in time but it will always be the same for a traffic class. In other words, this supports that different traffic classes of one train may be routed differently. Traffic demands vary depending on wether the application is symmetric (video conference) or asymmetric (video broadcasting). Both symmetric and asymmetric demands can be taken into account in the proposed model. We define a set of access gateways: $AGW = \{agw_i\}$, with index i indicating the different access gateways and a set of service gateways: $SGW = \{sgw_k\}$, with index k indicating the different service gateways. To characterize the network, we define a given set of unidirectional edges: $E = \{e\}$ and a given set of nodes: $N = \{n\}$. In addition we define a set of links: $L = \{l\}$ with every (bi-directional) link consisting of two unidirectional edges given by set $E_l = \{e_l, e_l'\}$ with same source-destination node pair as link l. We like to remark that $\forall l : |E_l| = 2$. Each node is characterized by the speed of every interface and the number of interfaces, possibly grouped together on one card (e.g., one card with two Gigabit interfaces):

$$C_v = \text{e.g.}, \{100|1000|10000\}, v = 1 \ldots |V|; \tag{1}$$

$$\forall v : O_{vw} = \text{e.g.}, \{1|2|4\}, w = 1 \ldots |O_v| . \tag{2}$$

V gives the set of strings, each describing a different type of card which are present on a node; C_v defines the different speed of every type of the set *V* (where *v* is used to distinguish the different types of cards): in this example speeds from 100 Mbit/s to 10 Gbit/s are considered; O_v gives the set of possible configurations of the cards of a certain type (the type is indicated by index *v*); more specific, O_{vw} gives the number of interfaces present on a card for every type of card.

3.2 Traffic model

In order to describe the traffic demands, we define flows *j* as being the basic routing unit: this allows different levels of abstraction. We can define one flow per train, one flow for every QoS class per train, etc. Traffic loads per AGW are associated with the flows as they move along the AGWs. It is important to notice that flows are associated with a moving train, so flows are not directly connected to one specific AGW nor SGW. Each train that passes the antennas connected to an AGW results in a certain demand for the specific *agw* from a specific server: $D_{ik} = \{d_{ijk}(t)\}$ with index *i* indicating the AGW, *k* indicating the SGW and *j* is used to make a difference between the different flows, in order to distinguish the different trains and/or QoS classes. To indicate if the demand at a certain *agw* is above zero and thus active, we introduce

$$a_{ij} = \begin{cases} 1, \text{if} \sum\limits_{t} \sum\limits_{k} d_{ijk}(t) > 0 \\ 0, \text{otherwise} \end{cases} . \tag{3}$$

Due to the moving aspect of trains, the traffic demands are time dependent. However, the dimensioning problem is not continuous and can be solved for a limited set of discrete events. Therefore, we define a set of events that are critical for the dimensioning. These events are all the discrete time points when the traffic conditions change. However, this set contains a lot of events which are redundant for the dimensioning problem. In order to minimize the amount of constraints for the dimensioning problem, the set of events is reduced: e.g., for a single AGW scenario, if the network must be able to support a certain demand to this AGW, all the events with lower demands for the AGW (under same other circumstances) are already covered and are removed from the set of events. The set of reduced time events is given by $T' = \{t'\}$.

3.3 Problem formulation: network capacity planning and tunnel path determination

1. Variables

   First of all, the variables of the ILP-problem are defined. The first one represents the number of line cards available in each node:

   $$z_n^{vw} = \# \text{ of cards with } O_{vw} \text{ interfaces of speed } C_v \text{ on node } n. \tag{4}$$

   Each card has a specific cost, c_{vw}, depending on the speed of the interfaces on the card (C_v) and the number of interfaces installed on the card (O_{vw}). The following parameter gives information about the number of fibres on every link:

   $$x_l^v = \# \text{ of fibres with speed } C_v \text{ on link } l. \tag{5}$$

With this information, one can calculate the capacity of every link in the network:

$$C_l = \sum_v x_l^v \cdot C_v. \tag{6}$$

Besides the previous defined variables, we also need a variable to indicate if a certain edge *e* is used for a certain flow *j*:

$$y_{eijk} = \begin{cases} 1, \text{ if edge } e \text{ is used between } i \text{ and } k \text{ for flow } j \\ 0, \text{ otherwise} \end{cases}. \tag{7}$$

2. Node capacity constraint

   Every node needs enough interfaces with appropriate specifications (given by indices *v* and *w*) to provide the links that are connected to it:

$$\forall n, \forall v : \sum_{w=1}^{|O_v|} z_n^{vw} \cdot O_{vw} \geq \sum_{l \text{ incident to node } n} x_l^v. \tag{8}$$

3. Link Capacity constraint

   This constraint imposes that the traffic that is transported over a link does not exceed the capacity of that particular link:

$$\forall l, \forall t \in T' : \begin{cases} \sum_k \sum_i \sum_j y_{e_l ijk \cdot d_{ijk}(t)} \leq \sum_v x_l^v \cdot C_v, \\ \sum_k \sum_i \sum_j y_{e_l' ijk \cdot d_{ijk}(t)} \leq \sum_v x_l^v \cdot C_v. \end{cases} \tag{9}$$

4. Flow Conservation constraint

   The last constraint imposes that a flow is not interrupted in the network:

$$\forall n, \forall k, \forall i, \forall j : \sum_{e \in \text{out}(n)} y_{eijk} - \sum_{e \in \text{in}(n)} y_{eijk} = \begin{cases} a_{nj}, \text{ if node } n \text{ is the source for the flow} \\ -a_{in}, \text{ if node } n \text{ is the desired } agw \\ 0, \text{ otherwise} \end{cases}. \tag{10}$$

5. Objective function o

$$o = \sum_n \sum_v \sum_{w=1}^{|O_v|} z_n^{vw} \cdot c_{vw} + \sum_k \sum_i \sum_j \sum_e y_{eijk} \cdot c_l \cdot C_j. \tag{11}$$

   The first part is the cost for the network devices in the network while the second part is the routing cost in the network, in which c_l gives us the cost for every link and C_j represents the bandwidth of each flow. The aim of the optimization algorithm is to minimize *o*.

3.4 Solution Technique: Integer Linear Programming

- Network and traffic model - The network topology, node- and link-related parameters were modeled by using the TRS (Telecom Research Software) library. TRS is a Java-library, developed by our research group, intended to be used in the telecom-research to speed up the development of tools and applications. For more information about TRS, the reader is referred to [5].

- ILP solution technique - Based on (i) the input variables D_{ik}, C_v, O_{vw}, c_{vw}, C_j and c_l, on (ii) the constraints (8), (9), (10) and on (iii) the objective function (11) the requested matrices for ILP are constructed. The optimal values for the decision variables z_n^{vw}, x_l^v and y_{eijk} are then calculated, using a Branch and Bound based ILP solution approach [11]. From the obtained values of the decision variables, the optimal path required capacity for the considered problem instance can be easily deduced.

4. Tunnel pre-configuration and tunnel activation

Based on the determined optimal path for each tunnel, found by the solution method described in the previous section, the VLAN tunnels are pre-configured in the network by means of GVRP. At activation time, extensively described in subsection 2.2, the management system will invoke the resource reservation by means of the G2RP protocol. This section gives an operational description of both protocols.

4.1 GVRP

GARP-based protocols are providing all the necessary capabilities for dynamic VLAN tunnel set-up. Therefore, the best approach is to make intelligently use of a standardized Ethernet broadcasting protocol instead of developing a brand new protocol. GVRP removes the burden of manually installing and maintaining VLANs from the network administrator's hands. The automatic VLAN registration is performed in a more consistent and reliable way compared to the laborious manual VLAN configuration on every switch in the network. GVRP not only reduces the chance of incorrect VLAN configurations but also makes the VLANs resilient to Layer 2 network failures because it works in conjunction with the spanning tree protocol (STP). After the STP has converged, the VLANs are automatically remapped to the new topology induced by the new spanning tree.

However, GVRP was never designed to set up point-to-point VLAN tunnels but the VLAN topologies would rather resemble a sub-tree of the spanning tree topology. The redundant propagation of GVRP messages can be resolved by removing the overhead registrations and therefore, we developed the "Scoped Refresh" extension of GVRP. A more detailed description of the protocol with the extension can be found in [7].

4.2 G2RP

The extended GVRP resolved pre-configuration of a physical point-to-point tunnel but is still lacking means to configure the switch hardware according to the QoS-related parameters associated with each tunnel. Instead of extending GVRP to support attribute types to propagate reservation parameters and activate the tunnel, a new GARP protocol is designed. This protocol is called GARP Reservation Parameters Registration Protocol (G2RP). By separating the distribution of reservation parameters and `VLAN_ids`, G2RP remains independent of the applied tunnel set-up mechanism. G2RP is designed according to the GARP standard. Just like GVRP, a single run of G2RP is responsible for configuring a single direction of the tunnel but in contrast to the GVRP, a G2RP reservation session can fail due to interference of the admission control. In contrast with GVRP, a single trigger is sufficient to configure the entire tunnel: at the opposite end of the VLAN tunnel, the G2RP PDUs are reversed and sent back to the originating end of the tunnel. G2RP PDUs will always follow the VLAN tunnel, even in conditions of VLAN tunnel reconfiguration, due to change of the ST. If at the originating switch the reversed PDUs do not arrive in time, the reservation session will have failed due to insufficient network resources. Again, we refer to [7] for a more detailed description of the protocol.

4.3 Implementation aspects

The extended GVRP and the novel G2RP application are implemented in platform independent C code and both applications are tested on a Linux test bed. The Data Plane is emulated using the Click Modular Router Toolkit [10]. Click is a software architecture for building flexible and configurable routers. We designed the necessary extra elements, in order to configure the Click Router as a fully VLAN compliant Ethernet switch. They will be made public available through open source software license. The platform independent code is extended with an Adaptation Layer containing Linux-related code for sending Ethernet frames towards the physical interfaces, code for receiving Ethernet frames from the Data Plane and the remaining code supports the interaction with Click: editing the VLAN Filter Databases, modifying the configurable switching hardware and accessing the STP port states. For further details concerning the Click Router, the protocol development or other implementation aspects, we refer to the Linux Kongress paper [13].

5. Evaluation results

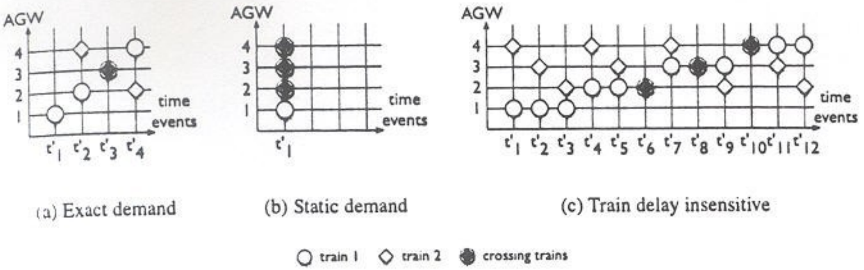
5.1 Optimal network capacity planning and tunnel path determination

We consider a network (shown in figure 1) consisting of 11 nodes, which positions are fixed. One of the 11 nodes is connected to a Service Gateway (SGW) and 7 others are connected to one of the 7 Access Gateways (AGWs), positioned every 7,5 kilometres along the railroad track, based on a calculation made in [9]. The last 3 nodes are core switch devices installed between the node connected to the SGW and the nodes connected to the AGWs. We assume the core switch devices are Layer 2 devices while the AGWs and SGW are Layer 3-aware devices. All the available links are also indicated in figure 1.

For the evaluation of the network capacity planning process, we consider three trains running on the railroad tracks. Two trains, each demanding a total traffic of 0.8 Gbit/s, are going from the upper left to the upper right AGW via all the indicated AGWs in figure 1. The third train goes in the opposite direction: from the middle right AGW to the middle left one, via the AGWs on the bottom. The bandwidth requirement for this train is slightly lower than the other one: we consider a bitrate of 0.6 Gbit/s.

Demand Cases

The considered input cases for this problem will be detailed in this paragraph. A schematic overview is given in figure 3. This overview shows the considered time events on the X-axis and the positions of the trains are indicated on the Y-axis. The shown scenario is one of two crossing trains, the first one is going from AGW 1 to 4, while the other train goes from AGW 4 to AGW 2. The two trains cross each other at AGW 3.



(a) Exact demand (b) Static demand (c) Train delay insensitive

Figure 3: The three traffic demand cases

1. Exact demand (figure 3(a)) - In this case we take the exact traffic demands into account. For the crossing trains scenario, this implies that we optimize the network resources with knowledge of the exact point (= the exact AGW) where the two trains cross each other and of the exact moment in time when the two trains cross each other. However, should one train experience a delay and the point where the two trains pass each other changes to another AGW, the network could suffer from inability to provide the requested resources to meet demand.
2. Static demand (figure 3(b)) - This case translates the dynamic traffic demands of the exact demand case into a static demand (and hence neglecting the time-related aspects of the demands). This is done by adding all the demands that are requested for a particular AGW, and this for every AGW separately. This results in a time-independent demand from the SGW to each AGW. For the shown scenario in figure 3, this implies that we assume that both trains could cross in every AGW simultaneously, except for AGW number 1. This dimensioning case is required if the network is lacking a dynamic reservation mechanism. This results in a new definition of the traffic demand:

$$\forall i, \forall j, \forall k : d_{ijk} = \sum_{t \in T'} d_{ijk}(t); \tag{12}$$

   and the capacity constraint (9) is only evaluated for a static, time-independent demand d_{ijk}.
3. Train delay insensitive demand (figure 3(c)) - To tackle the problem of loss of information in case of train delays, a new approach has been developed. In this case we re-interpret the traffic demands by neglecting the exact time-position relation between multiple trains. For the crossing trains scenario this implies that we assume that single trains are not connected to all the AGWs at the same time but we neglect the information of when or where the trains will cross each other exactly. In other words, the network is dimensioned to support that the trains will cross each other in any AGW along their track. This results in a new definition for the demand, and more time events need to be considered.

Three traffic demand cases compared

Table 1 shows the comparison between the three considered demand cases found by the ILP solution technique for the three trains scenario, as described in the beginning of this subsection. From the difference between the static demand case and the two other, we can conclude that the static demand case is not advisable to use in the considered scenario, nor is it for every other scenario with rapidly moving traffic conditions. The cost for the static solution is almost the double. These results show that for rapidly changing traffic demands, a dynamic tunnel management is indispensable.

The very cheap solution found for the exact demand case looks very attractive to use, but several drawbacks makes the solution less useful in real situations. The example of a train with little delay is already mentioned. Therefore a new traffic demand has been taken into account that deals with train delays: the train delay insensitive traffic demand. As shown in table 1, the cost for the network capacity planning found for this traffic demand is a little more expensive than the cheapest solution, but the benefits are huge: trains with delay will still receive their requested bandwidth. But also other unexpected problems can occur: increased traffic due to an increased number of users or a suddenly higher ask for bandwidth, an extra train, etc. To deal with these situations, extra tunnels must be pre-configured and activated at their due time (as shown in figure 2).

Tunnel path determination

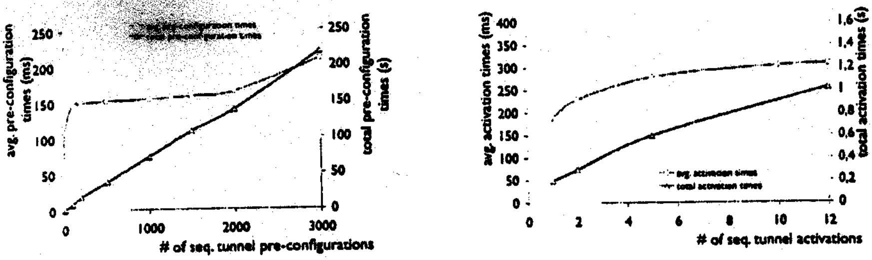
Besides the cost of the network capacity planning, the routing is also calculated with the solution technique. A rule of thumb can be derived from the found solution: the optimal path is nearly a ring. Indeed, all the links that are located along the railroad are part of the design. Together with the links between the middle left and middle right AGW and the SGW. Indeed, only the upper left and upper right AGWs are not included in the ring.

5.2 GVRP test results

Once the optimal tunnels are determined by the dimensioning model, GVRP has to pre-configure all those tunnels. On our test bed we measured the time it takes to perform a burst of sequential tunnel pre-configurations. Measurements for the pre-configuration and activation times are done for tunnels like depicted in figure 1, i.e., for tunnels with one intermediate hop. The pre-configuration times are measured at one end device of the tunnel (called switch A). This end device (A) sends a trigger towards a specific UDP port of the device at the other end of the tunnel (switch B). This trigger for `VLAN_X` is sent via a separate control network to switch B. Switch A waits for incoming GVRP registration messages for `VLAN_X`. If the `VLAN_X`-value gets registered on a non-blocked port of switch A, this indicates completion of a (half) VLAN tunnel. Both these times are logged using the PC clock with a precision of 1 ms. We measured the pre-configuration times of every VLAN-tunnel of the burst individually and measured the duration of the entire pre-configuration procedure. The results (averages of 20 tests) are presented for a

Table 1 Required cost for the three demand cases

Traffic demand case	Required cost (%)
Static demand	100
Train delay insensitive demand	49
Exact demand	48



(a) Average and total times for simultaneous pre-configuration of large number of tunnels

(b) Average and total activation times

Figure 4: Pre-configuration and activation times

growing number of VLANs in figure 4(a). Note that, as all Spanning Trees are set up before pre-configuration, the STP convergence time does not influence the operational performance.

5.3 G2RP test results

Figure 4(b) represents the activation times of different tunnels, done by G2RP. The activation times are shown for a maximum of 12 tunnels. For example, it takes 1033 ms for activating all 12 pre-configured tunnels while the average activation time measures 310 ms. From various example numbers (distance between AGWs: 7.5 kilometres, speed of trains: 200km/h), we can calculate for the numerical example that a tunnel between the SGW and one AGW is active for about 135 seconds. Times to activate the tunnels are clearly lower than this time.

5.4 Comparison with other tunnel set-up mechanisms

As concurrent implementation we take a Linux implementation of RSVP-TE [6]. The set-up times, presented in table 2, are the total set-up times for a single direction of the LSP tunnel in a test network with one intermediate hop. The LSP (Label Switched Path) times were measured without configuring the switching hardware or without admission control. In these circumstances we can compare these times with the GVRP pre-configuration times of our implementation. Because RSVP-TE was suffering from an non-linear function in assigning LSP labels, our implementation is a lot faster.

6. Conclusion

In this paper, we focused on the management aspects for delivery of multimedia services to fast moving users. More specifically, we designed a management system for the aggregation network, the core part of the considered network architecture. The proposed method includes an optimal network capacity planning and determines the paths of the

Table 2 Total times (ms) versus Number of tunnels

Number of tunnels	LSP	GVRP
10	510	776
50	17350	3849.5
100	63000	7000

required dynamic tunnels. Several optimization algorithms have been presented and it has been proven that using dynamical tunnel management strongly reduces the cost of the network capacity planning. Also, the interaction between the management system and the aggregation network, supported by GVRP and G2RP, was detailed in the paper. For the pre-configuration of the VLAN-based tunnels, a "Scoped Refresh" extension of the GVRP standard has been implemented. For the activation of the tunnels, a new GARP-based protocol (G2RP) has been developed. Finally, the performance of the designed protocols for pre-configuration and activation, have been demonstrated.

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