

Aggregation Network Design for Offering Multimedia Services to Fast Moving Users

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Abstract. Nowadays, passengers in fast moving vehicles can consume narrow-bandwidth services such as voice telephony or email but there is no widely deployed platform to support broadband multimedia services. In this paper, an aggregation network architecture for the delivery of multimedia services to train passengers is presented. For the topology design and capacity assignment of this network, a novel method is presented that calculates the required dynamic tunnels to meet the traffic demands of the fast moving users while achieving low congestion and optimizing the utilization of the network resources. The method enables that under conditions of train delay the Quality of Service (QoS) requirements of the traffic flows are guaranteed. The capacity assignment efficiency is demonstrated for different network scenarios and due to the time-dependent complexity of the problem, heuristic approaches are designed to solve problems of realistic size.

1 Introduction

1.1 Motivation

By 2007 the national railroad company of Belgium (NMBS) would like to build its own digital communication network "GSM-R" (GSM for Railways) in replacement of their currently out-dated network [1]. Therefore the NMBS is investing in the construction of 450 new antennas. These antennas will also be shared with some major telecom-operators in order to improve the (narrow-bandwidth) voice service of train passengers. However, current applications such as multimedia content delivery, video phoning and on-line gaming require a high level of QoS and are generally characterized by high bandwidth requirements. They cannot be offered to the passengers with this kind of network.

The lack of broadband services in fast moving vehicles such as trains, busses and vessels is stated in [2] and while trials are on the way to find out whether commuters will ultimately pay for broadband services, the aggregation part of the broadband network (see Fig. 1) is not optimally designed to cope with fast moving users; it is typically designed to cope with traffic demands of fixed users. Such a design (even with addition of an admission control system to limit the

impact of unexceptional circumstances) won't be sufficient to maintain the QoS guarantees of the passenger data traffic at all times without overdimensioning the network. In this paper we present a cost effective design method that calculates the required dynamic tunnels to meet the traffic demands of fast moving users while achieving low congestion and optimizing the utilization of the network resources. It is no goal to elaborate on the operation of the enabling platform or specific service realization issues (such as handovers or roaming issues).

We can state that multimedia services are taken for granted in fixed networks and narrow-bandwidth services are being deployed for fast moving users but to our knowledge the network resource optimization and routing have never been studied for fast moving users. The environment is characterized by groups of users moving at equal speed along a (predictable) trajectory, causing dynamically changing traffic conditions. Without loss of generality we will focus on train scenarios and take into account that in many cases installed optical fibers are already present along the railroad tracks. For example, the NMBS has its own telecom division that exploits a fiber optic network covering almost the entire Belgian railroad track [1]. In many other cases train companies (such as North America's largest railroad company [3]) have given permission to telecommunication companies to install fibers along their railroads. Enabling these fibers is cheaper than digging, renting or activating additional fibers.

The considered network architecture is represented in Fig. 1. While passengers are connected to the internal train network, the train remains connected to the closest wireless station near the railroad track. These wireless stations are bundled in access networks. While trains are moving on the railroad track, the train's connection hops from access network to access network. The passenger traffic is gathered in aggregated traffic flows per train and per QoS class on the Access Gateway (AGW). The aggregation network has AGWs connecting to the access networks and Service Gateways (SGWs) connecting to the provider's domain. The connectivity in the aggregation network is achieved by setting up dynamic tunnels between the AGWs and the SGW in which the aggregated traffic flows are mapped. The SGW is constantly updated with information about the current (and future) positions of the trains and every turn the next hop gateway towards the moving users gets updated. The set-up protocol for the dynamic tunnels and the admission control mechanism for QoS-aware aggregation networks are described in [4]. Mainly due to economical reasons a network is preferred consisting of standard QoS-aware Ethernet switches (IEEE 802.1s, IEEE 802.1q&p compliant) with separated hardware queues per QoS class. We assume that the AGWs and SGW have a fixed position, successively placed along the railroad track (e.g. every 5 or 10 km). The presented method will calculate the network equipment that needs to be installed, where to place fibers between the network nodes, how to set up and adjust the AGW-SGW tunnels and how to route the traffic flows at every moment in time.

This paper is organized as follows. The introduction is completed with related work on the topics of network design for fast moving users. In the next section the theoretical model for the dimensioning problem is presented and the model

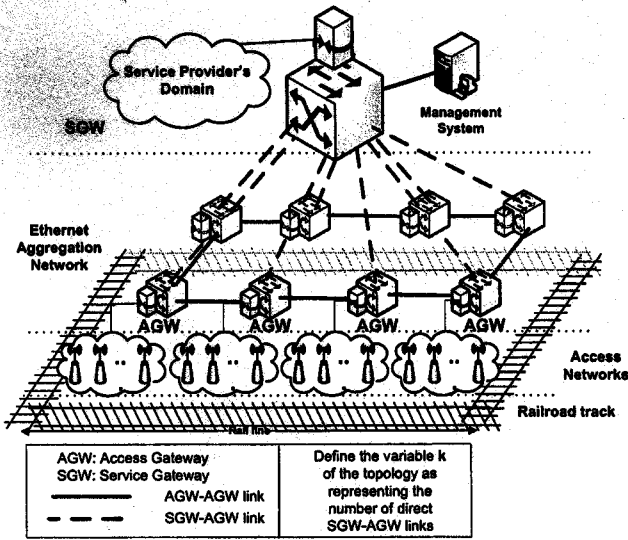


Fig. 1. Schematic representation of the network architecture.

is illustrated for linear railroad tracks. In Section 4 heuristic solution techniques are described and the performance will be evaluated by gradually increasing the railroad complexity towards ring-shaped (Section 5) and grid-like (Section 6) railroad tracks. The influence of larger scale topologies, variations on the cost parameters and different traffic patterns will be discussed.

1.2 Related Work

Today, organizations such as IEEE and 3GPP are establishing wireless specifications for new wireless technologies which have to meet the bandwidth requirements of tomorrow, e.g. the cellular UMTS, integrated Beyond 3G solutions or the future WiMAX standard for limited mobility (IEEE 802.16e). Broad-band network design and dimensioning studies mainly assume traffic of fixed users [5, 6]. Unfortunately fast moving users have not been taken into account. Related solutions for moving vehicles are proposed in [7] (with focus on the wireless part) and in [8] (application-based approach for disconnection tolerant networking). In [9] the routing and dimensioning issues of time-scheduled connections in QoS networks are addressed.

2 Theoretical Model

A path flow based Integer Linear Programming (ILP [10]) formulation of the theoretical model [11] is used to calculate the exact dimensioning and tunnel path determination. This formulation is introduced by means of different variables and the objective function (subsection 2.1). The ILP constraints such as link capacity

constraints, flow conservation constraints and node capacity constraints are not discussed in this paper. For a more mathematical detailed overview the reader is kindly referred to [11]. However, for scenarios of realistic size only heuristic approaches will be suitable to calculate a feasible solution. The solving time of the exact solution increases rapidly with the network size and the number of trains, mainly due to the strong time-dependent problem formulation. Subsections 2.2 and 2.3 describe the assumptions concerning the network and traffic parameters. Subsection 2.4 details the developed solution techniques.

2.1 The Variables and the Objective Function

The variables of the dimensioning problem:

$$u_l = \begin{cases} 1 & \text{if link } l \text{ is used} \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

$$x_l^v = \# \text{ of fibres with speed } C_v \text{ on link } l. \quad (2)$$

$$y_{pijk} = \begin{cases} 1 & \text{if path } p \text{ is used between AGW } i \text{ and SGW } k \text{ for flow } j \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

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

and their vector representations:

$$U = [u_l], X = [x_l^v], Y = [y_{pijk}], Z = [z_n^{vw}] \quad (5)$$

Each card has a specific cost depending on the speed of the Ethernet interfaces (C_v) and the number of interfaces (O_{vw}) installed on the card. Each required link has a specific cost depending on the installation cost of the link. The cost function of the dimensioning problem is represented in a simplified form (6) depending on the parameters α , β and γ . We will focus on three different parts of the cost function: the topology cost, the node cost and the routing cost.

$$c = f_0(U) + \alpha f_1(U) + \beta f_2(Z) + \gamma f_3(Y) \quad (6)$$

The term $f_0(U)$ represents the cost to install and start using the fibers that are placed along the railroad track (links represented as full lines in Fig. 1). The term $\alpha f_1(U)$ represents the cost to install and start using the fibers that connect the AGWs to the SGWs if these fibers are not placed along the railroad track (links represented as dotted lines in Fig. 1). The topology cost is defined by their sum $f_0U + \alpha f_1(U)$. If α equals 1, there is no cost difference in exploiting fibers that are placed along or not along the railroad. The term $\beta f_2(Z)$ represents the cost to install network equipment with network interface cards with sufficient link capacity to handle the data traffic of the fast moving users (= the node cost). We distinguish between different line card types of different speeds and with

different port ranges. The parameter β enables to increase or decrease the node cost compared to the topology cost. The term $\gamma f_3(Y)$ represents the sum of the hop counts of all AGW-SGW tunnels that are required to maintain connectivity with the moving trains. We will tune γ in such a way that this term is negligible in the objective function. Because no actual cost is associated with this term, it will be used as a tiebreaker to prefer the network with the shortest average tunnel length. This γ -value can be made dependent on the specific QoS class of the flows that are transported in these tunnels. By adjusting γ according the QoS class a more expensive but QoS sensitive routing can be achieved. This can be used as online routing algorithm to optimize the real-time performance of the network.

We introduce scenarios based on 3 business models (with increasing node cost) without elaborating on the exact values. In all scenarios γ equals 0.00001.

- Scenario 1: $\alpha=100.0$; $\beta=0.01$

This corresponds to the case where the railroad company owns installed fibers along the railroad tracks (as for the Belgium railroad scenario) but they only need to be connected to the service provider.

- Scenario 2: $\alpha=1.0$; $\beta=0.01$

This corresponds to the case where a telecom operator with good connectivity along the railroad track, wants to design a network from scratch while the train company owns installed fibers along the track.

- Scenario 3: $\alpha=1.0$; $\beta=100.0$

This corresponds to the case where a railroad company wants to design a network from scratch while a network operator already has installed fibers along the track.

2.2 Network Model

The simulated networks in this paper will have increasing topology complexity: from linear and rings to grids. In our model the AGWs and SGWs have Layer 3 abilities (to connect to the access network and to the provider's network) but the data traffic is switched in Layer 2 Ethernet switches. In this paper we assume the presence of a single SGW in the network. In these circumstances the use of additional core nodes would only increase the total network cost. Therefore no extra Ethernet core switches are added and all AGWs have direct candidate links to the SGW as presented in Fig. 1. For the simulations we assumed the following range of Ethernet speeds: 100 Mb/s, 1 Gb/s and 10 Gb/s and the following port ranges: 1-port, 2-port and 4-port line cards.

2.3 Traffic Model

On the railroad track, rail lines are defined. The time schedules of these lines will be used as input to define time-dependent traffic flows in the network. In this paper the assumption of two crossing trains per line is made without loss of generality. For simplicity we assume that the traffic profile of the users itself

doesn't change and we assume constant unidirectional traffic demands to focus on the rapidly moving aspect of the user. We assume traffic loads of approximately 1 Gb/s per train based on [12]. The user traffic will be gathered per train and per QoS class in basic routing units, named flows. We will define three traffic demand types: exact demands, static demands and train delay insensitive demands.

Exact Demands. Exact traffic demands imply optimization of 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, if one train suffers from delay and the place where the crossing of two trains occurs, moves to another AGW, the network could suffer from insufficient resources to deliver the requested demand to the crossing trains and loss of information would occur.

Static Demands. By neglecting all time-related aspects of the traffic demands, exact demands can be transformed into static demands. This is done by adding all 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 and implies that both trains could cross in every AGW simultaneously. Static demands are required if the network is lacking a dynamic reservation mechanism and results in overdimensioning of the network resources.

Train Delay Insensitive (TDI) Demands. 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. This implies that single trains are not connected to all the AGWs at the same time but we neglect the information of when and where trains will cross each other exactly. In other words, the network is dimensioned to support that trains could cross in any AGW along their track.

2.4 Solution Techniques: Integer Linear Programming

The network topology, node- and link-related parameters are modelled by using the in-house developed TRS (Telecom Research Software) library [13]. Based on these model parameters and the constraints, the objective function (6) is minimized by using a Branch and Bound based ILP solution technique [10]. From the optimized variables z_n^{vw} , u_l , x_l^v and y_{pijk} the minimal network cost and the dynamic traffic routing can be derived.

3 Dimensioning Linear Railroad Tracks

The first test network is a linear railroad track with a single rail line of varying length: ranging from 2 up to 10 successive AGWs. The dimensioning of this rather simple network topology results in some interesting guidelines.

3.1 Evaluation Results

The three scenarios introduced in Section 2.2 are evaluated for two traffic profiles: profile A (2 opposing trains, load of 700 Mb/s and load of 800 Mb/s in the opposite direction) and profile B (doubled loads compared to profile A, respectively 1400 and 1600 Mb/s).

First we examine the network cost of the static demands with respect to the exact demands. The absolute value of the additional cost for profile B will always be larger than for profile A. Because of the self-evidence of the profile-dependent cost difference, the results are a representation of the average of both profiles (unless mentioned otherwise). The additional network cost in case of static demands is represented on Fig. 2 for the defined scenarios and profiles.

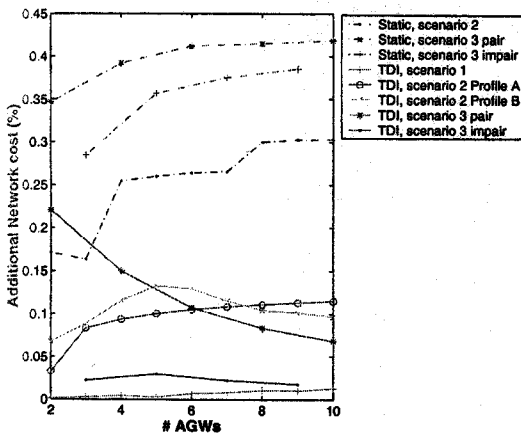


Fig. 2. Network cost for linear tracks with 2 up to 10 AGWs.

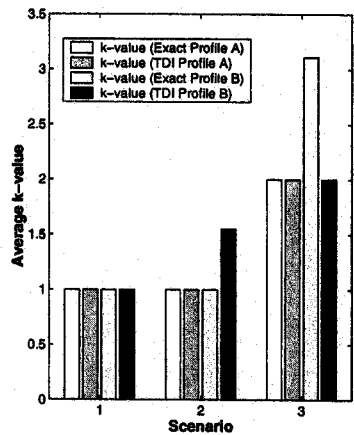


Fig. 3. Optimal k-value for linear tracks with 2 up to 10 AGWs.

Because scenario 1 (not depicted on the figure) has a dominant topology cost, the static dimensioning is not significantly bigger however the routing cost increases a lot. For the other two scenarios the static demand case creates a network overdimensioning (up to 42%) that increases with increasing influence of the routing cost and that is not scalable with the network size. This leads to increasing additional network costs with increasing number of AGWs.

Secondly, we examine the network cost of the TDI demands with respect to the exact demands. The additional network cost is also represented on Fig. 2. We define the k-value of an optimized network topology as being the amount of required links originating from the SGW towards the AGWs. This is represented in Fig. 3. For scenario 1 the additional costs are very low because the topology cost has a major influence and the optimal topology only requires a single link originating from the SGW. This leads to increasing additional network costs with increasing number of AGWs for both profiles. For scenario 2 the profiles show a different behavior: profile A is similar to scenario 1. However, for profile

3 the optimal TDI topology changes by adding an additional SGW link and the additional cost starts decreasing with increasing amount of AGWs. Scenario 3 shows a similar behavior for both profiles (but significantly different in case of pair or impair number of AGWs): the optimal k is two (due to dominant topology cost) and the additional cost is decreasing with increasing number of AGWs. The optimal k increases for increasing influence of the node cost.

The additional cost is never bigger than 22% (in the rather theoretical 2 AGW case) but more important in case of dominant routing cost (scenario 2, profile B and scenario 3, both profiles) the additional cost decreases with the network size and in case of dominant topology cost (scenario 1, both profiles and scenario 2, profile A) the additional cost remains limited for realistic rail line lengths. Which train delays or train schedule changes can be supported by the exact dimensioning case? If the crossing trains are running 90 km/h on the average and if AGWs are positioned along the railroad every 10 km, the delay that can be covered, varies from 0 sec (worst case) to 3 min 20 sec. For bigger train schedule changes or larger train delays, the passengers will always experience loss of information along their journey.

3.2 Design Guidelines

The static dimensioning problem is easy to solve due to the lack of time dependency and it results in overdimensioning (non-scalable with the network size). With TDI demands the complexity of the problem increases drastically compared to the original problem. However, the additional network cost with TDI demands is kept limited, all kinds of delay scenarios are supported and the solution technique is scalable with the network size. The k -value for the TDI optimized topologies remains limited to one or two for all network sizes. If we examine this in further detail, the cheapest solutions can be found by considering only links towards edge points of the rail line. Links to intermediate AGWs are never used (except if the tiebreaker term of the objective function is decisive). The developed heuristic solutions in this paper will only consider candidate links towards the rail line edge points and will make use of TDI demands.

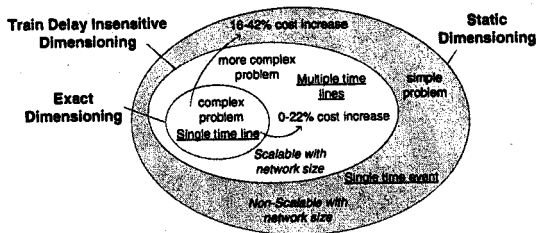


Fig. 4. Traffic models.

4 Design of the Heuristic Dimensioning Method

Two alternative solution techniques are implemented and they can be concisely described as follows:

1. Reduce the set of candidate SGW-AGW links
2. Redefine traffic demand profiles
3. (a) Solve the reduced ILP problem
(b) Use heuristic approach named "K-scanning"

First the set of candidate AGW-SGW links is reduced by solely maintaining links connecting the SGW to rail line edge points. After this topology reduction, the traffic demand profiles can be redefined towards more simple traffic demands concentrated in the rail line edge points with addition of minimum capacity constraints for the links along the railroad lines. Subsequently, the same ILP solution technique as presented in Section 2 can be used and will obviously have lower calculation times than previously. However, for larger network problems (e.g. 30 nodes, 10 rail lines and 20 trains would take several days or even weeks on a PC with a 1GHz CPU speed) a heuristic approach that approximates the solution of this reduced ILP formulation, is still desired.

Therefore, the heuristic scans the candidate k-values and starts by calculating the network cost for the minimum and maximum k-value. First of all, a ranking of optimal sets of k AGWs is created. Secondly, the heuristic selects a range of N solutions ($N \geq 1$) from the ranking. Thirdly, the minimal solution is calculated by solving the dimensioning problem in a heuristic manner for each of the N sets. The calculation times are reduced because the time dependency between the different rail lines is neglected and only a limited amount of possible paths to route the flows is explored. By increasing the N-value the amount of effort the heuristic spends in finding a suitable solution, increases. Finally, scanning of the solution space is continued by increasing or decreasing the temporary optimal k-value until no further improvement of the optimal network cost is found.

For the examples of Section 3, the "K-scanning" heuristic finds the idea solution for all scenarios, all profiles and all network sizes. In the remainder of the paper we will further examine the heuristic solution for more complex railroad topologies. Important to notice is that both methods utilize every single link along the railroad track, not depending on traffic profiles or network parameters

5 Evaluation Results for Ring-Shaped Railroad Tracks

In this section ring-shaped railroad tracks of different sizes (from 9 up to 2 AGWs) and with multiple rail lines (from 1 up to 6) are studied.

5.1 Performance Study of the Heuristics

In Fig. 5 the network cost calculated with the reduced TDI demands is represented in function of the ratio β/α for a ring with 9 AGWs and the traffic profil

Table 1. Traffic profiles for ring network with two crossing trains per rail line (see Fig. 6).

Rail lines (in 100 Mb/s)	Line 1	Line 2	Line 3
Profile A	4/5	6/7	8/9

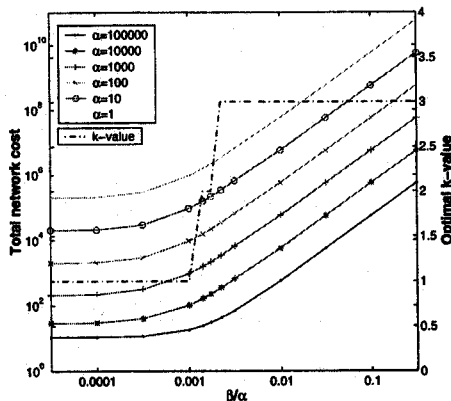


Fig. 5. Network cost and optimal k-value for ring with 9 AGWs and 3 rail lines.

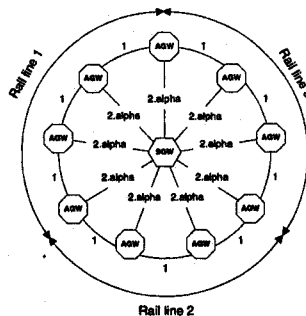


Fig. 6. Test network with 9 AGWs and 3 rail lines.

presented in Table 1. The performance is presented in Table 2 for $\alpha=1$. For high ratios, the solution for the reduced TDI demands has limited extra cost (3.4% for $\beta/\alpha=0.1$). This extra cost is caused by the fact that the heuristic utilizes every AGW-AGW link while this might not be the best choice for all traffic profiles. Take into account that with increasing rail line lengths the relative additional cost caused by this assumption will decrease. However, most important is the confirmation that only candidate SGW links to the rail line edge points are required to find the optimal solution. Based on the considered topology it can easily be proven that the additional cost for low β/α (where the topology cost becomes dominant) converges towards

$$1 - \frac{L_{st} + 2.\alpha}{L_r + 2.\alpha} \tag{7}$$

with L_r the link cost of the network along the railroad and L_{st} the link cost of its minimal spanning tree. For our test network (7) equals 9% for $\alpha=1$, 3% for $\alpha=10$ or 0.5% for $\alpha=100$. In Section 6 an alternative heuristic for low β/α ratios is presented, improving the global heuristic performance. The results of this method, named “Single-K” heuristic, are represented in the final column. Also represented in Fig. 5 is the k-value of the optimal solution. The k-curve is only depending on the ratio β/α and not on the individual α or β values. For higher ratios the k-value equals the maximum value (in this case 3) and for lower ratios it equals the minimum value (always 1). If the routing and topology

Table 2. Performance of reduced ILP, K-scanning and Single-K heuristic.

β/α	Exact solution Absolute value	Reduced ILP Add. cost (%)	K-scanning Add. cost (%)	Optimal k-value	Single-K Add. cost (%)
10	5624	1.2	1.2	3	46.5
1	567	2.7	2.7	3	45.7
0.1	69.3	3.4	3.4	3	40.4
0.0225	26.279	0	4.2	2	16.9
0.01	18.37	0	0.3	1	8.6
0.001	10.8501	7.6	7.6	1	2
0.0001	10.0895	8.9	8.9	1	0.2
0.00001	10.00895	9	9	1	0.02

cost are of similar magnitude, intermediate k-values may be found (only value 2 in this case). In any case this curve remains monotonically increasing for β/α . By applying the "K-scanning" heuristic identical solutions are found for low and high β/α ratios but near the k-slope (between 0.01 and 0.1) the heuristic approach finds an up to 4.5% more expensive solution (see Table 2).

5.2 Influence of Increasing Rail Line Lengths

If the length of the rail lines is increased without changing the traffic profiles, the slope in the k-curve moves to lower β/α ratios. This behavior is depicted in Fig. 7 for ring networks with 3 rail lines but increasing number of AGWs: from 9 to 24 AGWs. This behavior can easily be explained: for fixed α and for longer rail lines, the routing cost will become bigger if the rail lines become longer. This means that additional SGW links can be added on lower β values. The accuracy of the heuristic approach, compared to the optimal solution with reduced TDI demands, improves with the length of the rail lines: for a network with 24 AGWs the additional cost is below 2% near the k-slope. In other words, the performance of the heuristic is scalable with increasing rail line lengths.

5.3 Shape of the k-Curve

The specific shape of the k-value curve is dependent on the number of rail lines and the traffic profiles of these rail lines. We examine the influence of the traffic profiles on the k-curve for a ring of 24 AGWs and 6 rail lines. As can be seen on Fig. 8, the network costs for the 3 traffic profiles (see Table 3) are more or less the same but the k-curves are significantly different. This shape cannot be predicted and therefore the presented heuristic method scans the k-curve from bottom-to-top or top-to-bottom. The minimum k-value always equals one. However, not all intermediate k-values are present and even the maximum value is not necessary known in advance. While six might be expected, the maximum k-value remains five for traffic profile C due to light loaded network regions.

The curve for profile C is not monotonically increasing like the previously simulated curves (dotted line on Fig. 8). This is caused by using $N=1$ in the heuristic method. If $N=3$, the heuristic scans more solutions and the optimal

Table 3. Traffic profiles for ring with 24 AGWs, 6 rail lines and 2 crossing trains per rail line.

Rail lines (in 100 Mb/s)	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6
Profile A	4/5	6/7	8/9	6/7	8/9	4/5
Profile B	10/10	10/10	10/10	10/10	10/10	10/10
Profile C	4/5	4/5	4/5	12/14	16/18	8/10

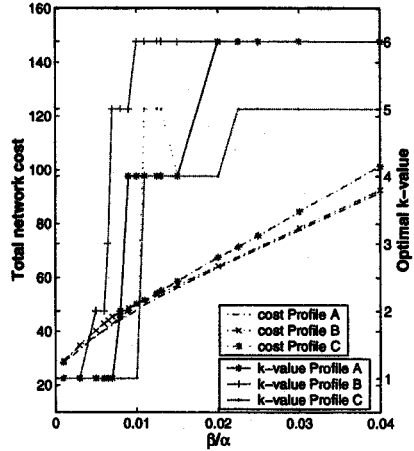
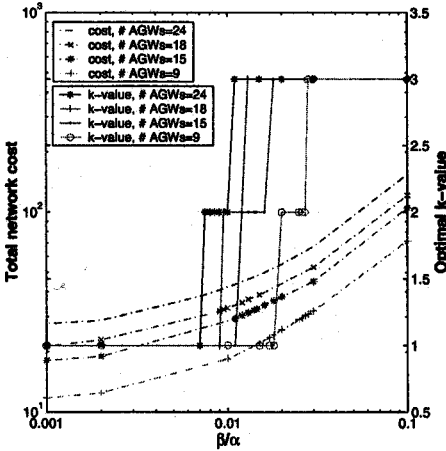


Fig. 7. Influence of increasing rail line length for ring with 9 AGWs, 3 rail lines and the traffic profiles of Table 1.

Fig. 8. Network cost and optimal k-value for ring with 24 AGWs, 6 rail lines and the traffic profiles of Table 3.

nondecreasing curve is found as depicted on the figure. The calculation time increases (from 155 sec to 598 sec on a PC with 1GHz CPU speed) but remains limited and the additional cost gain is at most 1.5% in the affected area. The ideal N-value is dependent on the desired precision and calculation time.

6 Evaluation Results for Grid-Shaped Railroad Tracks

In this final section we introduce a new heuristic and the results are presented on Fig. 9 for a grid example with 21 nodes, 8 rail lines and 16 trains. The new heuristic, named “Single-K”, improves scenarios where the optimal k-value equals one or in other words for β/α ratios with dominant topology cost. The previously designed heuristics won't be optimal because they are not designed to cope with an environment where the traffic profile of the fast moving users becomes obsolete. The K-scanning heuristic will always use every AGW-AGW link while the optimal solution will try to minimize the number of utilized links. The additional network cost will increase with the available amount of loops in the network and will also converge towards (7): 14% for $\alpha=1$, 9% for $\alpha=10$ and 2% for $\alpha=100$. Therefore the Single-K heuristic is developed and it can be summarized as follows:

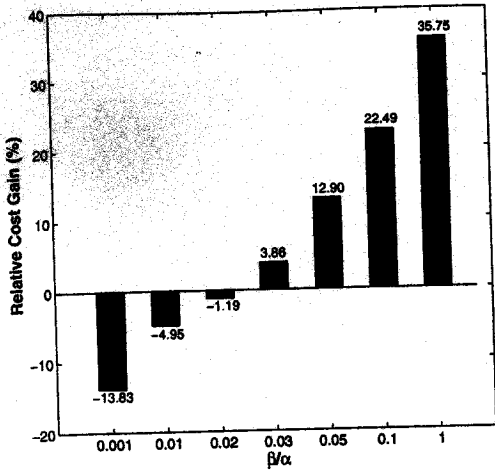


Fig. 9. Relative cost gain for Single-K heuristic with respect to the K-scanning heuristic.

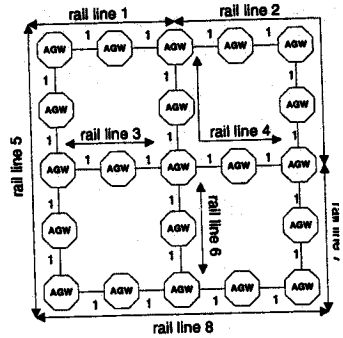


Fig. 10. Test network with 16 AGWs and 8 rail lines.

1. Calculate the center node based on the traffic demands and the topology
2. Connect the center node with the SGW and remove all other AGW-SGW links (i.e. $k=1$)
3. Calculate the minimum spanning tree originating from the center node
4. Calculate the dimensioning for this topology

For the network in Section 5 the performance for β/α ratios lower than 0.001 is improved drastically to 2% or less. For the grid network presented in this section the Single-K heuristic outperforms the K-scanning heuristic for values below 0.02: gaining 13.8% for $\beta=0.001$ and 5% for $\beta=0.01$.

7 Conclusion

In this paper we presented a design technique for aggregation networks with moving users: network topology design, resource optimization and path determination of the dynamic tunnels. Our approach reduces the capacity plan cost substantially. We found that traffic demands have to be defined as Delay Insensitive demands in order to be able to fulfill the QoS guarantee the passengers at all times. Based on the presented results we can conclude that for an optimal network design the candidate links that need to be considered for connecting the Service Gateway, are links towards rail line endpoints. This gives way to a reduced Integer Linear Programming formulation which is easier to solve. Due to the time-dependent complexity of the problem, we designed heuristic methods that are able to solve problems of realistic size. The performance of the heuristics is tested and results are promising. Moreover, the technique is scalable because the heuristic's performance doesn't degrade with increasing length of the rail lines.

Acknowledgment

Research is funded by PhD grant for Frederic Van Quickenborne (IWT Vlaanderen) and by postdoc grant for Filip De Turck (FWO-V).

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LNCS 3375

Quality of Service in Multiservice IP Networks

Third International Workshop, QoS-IP 2005
Catania, Italy, February 2005
Proceedings



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Library of Congress Control Number: 2004118330

CR Subject Classification (1998): C.2, D.2, H.4.3, K.6

ISSN 0302-9743

ISBN 3-540-24557-X Springer Berlin Heidelberg New York

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Printed in Germany

Typesetting: Camera-ready by author, data conversion by Olgun Computergrafik

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