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Designing Different Models of Robust IP/MPLS over DWDM Networks

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***Abstract*—Both IP/MPLS and DWDM layers can provide various resilient schemes to protect traffic from disruptions due to network failures. At the same time, both technologies provide the ability to realise virtual private networks. The aim of this article is to identify an optimal solution which provides a compromise between resilience time and network cost for different network models according to the network layer on which the different resilience schemes are implemented and the network layer on which virtual private networks are realised. Extended mathematical models for individual network layers for optimization are proposed to compare the different network models with the ASON network architecture. We prove that the optimal network topology applies hot standby path protection and virtual private networks on the IP/MPLS network layer. The DWDM network layer is in this case used as a pure transport platform.**

***Index Terms*—Backbone Networks Optimization, Resilience, Virtual Private Network, Traffic Demands and Traffic Flows**

I. INTRODUCTION

DUE to the explosive growth of telecommunications traffic, telecommunications operators must evolve their networks. Modern networks have to provide high capacities and also be reliable and scalable. Networks with high capacities must be able to operate 24 hours a day, 7 days a week without interruption. In the case of a lack of capacities, the network must be easily upgradable without great additional costs.

The number of network layers supported by different technologies is decreasing. The reasons for that are to simplify complex network design, avoid large overheads in transported signals and consequently achieve lower cost for more capacity. The trend in modern networks is to simplify the architecture from multi-layer networks, such as for instance IP over ATM over SDH over DWDM, to two-layer IP/MPLS over DWDM networks. Reducing the network architecture to two layers means better utilisation of network resources (CAPEX) and lower operating costs (OPEX). There are two possible architectures of a two-layer network, depending on which approach is taken for a control plane. One of them is based on ASON and the other on GMPLS frameworks. ASON evolved from ITU-T and represents a so-called overlay model of the control plane architecture. Each network layer plays a role as an independent layer and has its own transport, control and management planes. IEEE has developed a model of a multi-layer network which targets the so-called peer model of the control plane architecture. All layers in a network with the peer model are integrated into a single transport plane.

The network also has individual instances of control and management planes which are common for the whole network. In this article we consider the ASON network architecture [2]. We model and optimize each network layer independently of each other and later stack them into a network stack presented with different network models to find the optimal network from the cost and performance points of view.

On the upper traffic network layer we assume the IP/MPLS technology. This technology provides converged solutions that bridge TDM and IP networks for mobile and fix operators. It allows use of the existing legacy equipment and an evolution into a cost-effective converged network. This preserves 2G/3G investments while introducing 4G and seamlessly integrating fixed line services that are offered to customers. It is truly a bridge between both worlds by gradually migrating from TDM, over Hybrid Backhaul to all IP services. And since IP protocol is native in MPLS it can at the same time provide mobile and fixed services to customers using the same network. Beside TDM and IP convergence, implementing IP/MPLS technology on the upper network layer allows the network to assure traffic engineering, quality of service (QoS), L3VPN and fast resiliency [3].

On the lower transport network layer the DWDM technology is a natural choice. DWDM yields a cost-effective increase in optical fibre bandwidth by providing several independent wavelengths and consequently light paths over common optical fibres. A light path is an end-to-end path between two, not necessarily adjacent DWDM network elements. The advantage of the high bit rate and transparency provided by the DWDM technology must be accompanied by an adequately resilient mechanism [7].

In two-layer IP/MPLS over DWDM networks each layer can provide its own independent resilient scheme and enable the realization of virtual private networks. The question arises of which network layer enables a resilient mechanism and virtual private networks in order to ensure acceptable restoration times and low network costs.

The rest of the paper is organized as follows. In section II, we present various network schemes depending on which network layer resilient scheme and logical network topology is realized. Section III presents the most common resilient mechanisms and a formal definition of resilient mechanisms on the IP/MPLS network layer. In section IV, we set out the most common resilient mechanisms and a formal definition of resilient mechanisms on the DWDM network layer. Section V outlines the results for an example network and we conclude with a discussion in section VI and conclusion in section VII.

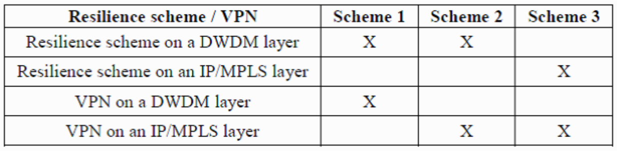
II. DIFFERENT NETWORK SCHEME

The design and implementation of a resilient scheme and virtual private networks is based on the following:

1. We consider two-layer, highly reliable IP/MPLS over DWDM networks.
2. Resilience mechanisms can be implemented on an IP/MPLS or DWDM network layer.
3. Virtual private networks can be realised on an IP/MPLS or DWDM network layer.
4. Virtual private networks on a DWDM network layer are realised with optical paths that interconnect network elements in an IP/MPLS network layer and usually belong to a particular customer [6].
5. Virtual private networks on an IP/MPLS network layer are realised with capacities created over cross-connect matrixes of network elements which reside on an IP/MPLS network layer.

Table 1 shows different network schemes according to selected network layers for implementation of the resilient scheme and virtual private networks.

TABLE 1
DIFFERENT NETWORK SCHEMES



Resilience scheme / VPN	Scheme 1	Scheme 2	Scheme 3
Resilience scheme on a DWDM layer	X	X	
Resilience scheme on an IP/MPLS layer			X
VPN on a DWDM layer	X		
VPN on an IP/MPLS layer		X	X

A network scheme with resilience on an IP/MPLS layer and created virtual private networks on a DWDM layer is not considered. For each protected logical path on an IP/MPLS network layer we have to create logical rings on a DWDM layer. This case has already been considered in schemes 1 and 2.

III. RESILIENT SCHEMES ON IP/MPLS NETWORK LAYER

Links, routers or both can fail in any network. Network operators have to consider this factor and have redundant links and routers at physical or logical locations. When such failure conditions occur, routers within the network might contain temporarily inconsistent routing information [4]. They might need to exchange routing updates and come up with a new, consistent picture of the network. This process is known as network convergence. The convergence time includes the amount of time for an adjacent router to detect the network failure and the amount of time for routers to distribute this information to all other routers and for all other routers to recalculate routes in the forwarding tables.

The first resilient scheme on the IP/MPLS layer belongs to the family of restoration schemes. With dynamic routing, all active adjacent routers exchange control messages in order to update router's routing tables. In an IP/MPLS network the labels are redistributed according to the new routing tables and packets are thus able to be dynamically rerouted beside link or node failures [4]. The goal is to realise the restoration scheme at the optimal network cost.

Consider a network with E links which connect R routers. Each link has its own capacity y_e and cost γ_e. On each link $e \in E$ a failure can occur. Each failure is described by failure situation s. We consider $s = 0$ representing a situation in which all the links are operational. Let D be a set of traffic demands. For each traffic demand, $d \in D$ is allowed, and can be realised over several paths p. The volumes of demands h_d are realised with traffic flows j_{dps} allocated to demand d over path p in network situation s. Coefficient $\delta_{edp} = 1$ if link e belongs to path p for demand d. The availability of particular link e is defined by coefficient $0 \le \alpha_{es} \le 1$. Let us assume that for all network situation $s \in S$ 100% realisation of all demand volumes is required. The optimisation problem is to realise the restoration scheme with the minimal network cost. The mathematical program (1)-(3) formulation is:

$$Minimize:$$

$$F = \sum_{e=1}^{E} y_e \gamma_e \tag{1}$$

$$subject\ to:$$

$$\sum_{p=1}^{P_d} j_{dps} = h_{ds};\ \forall\, d \in D, \forall s \in S \tag{2}$$

$$\sum_{d=1}^{D} \delta_{edp} j_{dps} \le \alpha_{es} y_e;\ \forall e \in E, \forall s \in S \tag{3}$$

Constraint (2) defines the total traffic flow allocated to demand d, and constraint (3) assures that the link load does not exceed the link capacity when the link is available.

The advantages of this restoration scheme are its simplicity and lower cost but it suffers from long convergence times in the case of a failure in the network.

The second resilient scheme we consider for the IP/MPLS layer belongs to the family of protection schemes.

Detecting a link failure requires physical and link layer mechanisms. IP/MPLS traffic engineering does not have an option to reduce the time to detect failures. It can reduce the time required to distribute the failure information and update the forwarding table by using MPLS traffic engineering’s fast rerouting capability. Before a failure, a fast reroute calculates and establishes a protection traffic engineering tunnel around the link or node that is deemed vulnerable. Upon detecting a failure, the backup tunnel takes over packet forwarding immediately or, more precisely in terms of time, in less than 50 ms. Before the fast reroute is enabled, there is a need to manually or automatically configure the primary IP/MPLS traffic engineering tunnel as the preferred path. At the ingress router which is the source of the primary traffic engineering tunnel, one can use the fast reroute option to configure a backup traffic engineering tunnel to protect the primary traffic engineering tunnel [3].

Assume again a network with E links, which connect R routers. Each link has its own capacity y_e and cost γ_e. Let D be a set of traffic demands. On each link $e \in E$ a failure can occur. We propose a protection scheme which protects different paths with a protection path in hot standby. $p = 1,2,\dots,P_d$ is a set of candidate paths for demands $d \in D$ and $q = 1,2,\dots,Q_{dp}$ is a set of candidate backup paths. The volumes of demands h_d are realised with traffic flows j_{dpq0} allocated to a pair (P_{dp}, Q_{dpq}) in a nominal network situation $s = 0$. Binary variable $u_{dpq} < 1$ limits the number of backup candidate paths to only one path. Coefficient $\delta_{edp} = 1$ if link e belongs to working path P_{dp} for demand d, otherwise it has a value of 0. Similarly, coefficient $\beta_{edpq} = 1$ if link e belongs to backup path Q_{dpq}, otherwise it has a value of 0. the availability of particular link e is defined by coefficient $0 \leq \alpha_{es} \leq 1$. The optimisation problem is to realise the restoration scheme at the optimal network cost. The mathematical program (4)-(8) formulation is [8]:

$$Minimize:$$

$$F = \sum_{e=1}^{E} \gamma_e y_e \tag{4}$$

$$subject\ to:$$

$$\sum_{p=1}^{P_d} \sum_{q=1}^{Q_{dp}} j_{dpq0} = h_d;\ \forall d \in D \tag{5}$$

$$\sum_{q=1}^{Q_{dp}} u_{dpq} \leq 1;\ \forall d \in D, \forall p \in P_d \tag{6}$$

$$j_{dpq0} \leq h_d u_{dpq};\ \forall d \in D, \forall p \in P_d, \forall q \in Q_{dp} \tag{7}$$

$$\sum_{d=1}^{D} \sum_{p=1}^{P_d} \sum_{q=1}^{Q_{dp}} (\delta_{edp} + \beta_{edpq}) j_{dpq0} \leq \alpha_{es} y_e;\ \forall e \in E, \forall s \in S \tag{8}$$

Constraint (5) defines the total traffic flow allocated to demand *d,* and constraint (8) assures that the link load does not exceed the link capacity when the link is available. Constraints (6) and (7) together assure that there is at most one traffic flow assigned to the set of routing pairs with the same normal path and that the flow assigned to the back-up path of the normal path equals $u_{dpq} j_{dpq0}$.

In summary we can confirm that restoration schemes are cheaper than protection schemes, but require longer convergence times.

IV. RESILIENT SCHEMES ON DWDM NETWORK LAYER

All sub-layers of the DWDM layer feature restoration and protection schemes. Like with higher layers, restoration schemes are more efficient from the capacity point of view but suffer from long convergence times. Protection schemes provide fast convergence but are greedier from the resources aspect [9].

The optical path restoration scheme requires that upon a network failure the working light path is replaced by a protection light path. We can simulate the restoration scheme on the DWDM layer with mathematical program (1)-(3).

Protection schemes on the DWDM layer are divided into path protection and link protection [9]. In both schemes, resources can be dedicated or shared. In the first case, protection resources are dedicated to a single working light path. In the second case, the same protection resources may be used to provide protection for multiple working light paths. Dedicated protection schemes are commonly referred to as 1+1 or 1:1 protection schemes. In the 1+1 case, both working and protection light paths are simultaneously active. The light path with better performances is chosen as a working one. In a 1:1 protection scheme transmission occurs on the working light path only, while the protection light path may be used to transport lower priority traffic. In the case of failure, the working and protection light path switch over the protection light path, pre-empting the low priority traffic. Shared protection schemes are referred to as 1:N. Such a protection scheme allows one protection light path to be shared by a number of working light paths. Once the spare light path is used to protect a particular working light path, it will not be available to protect another working light path until the original light path is re-established.

Path protection on the DWDM layer can be simulated with mathematical program (4)-(8). Let us consider two different link protection schemes. The first is hot standby dedicated link protection and the second one is link protection over a single protection path. A dedicated link protection scheme with hot standby reserves the protection optical path between the end nodes of each link used by the working light path. This protection scheme may require the allocation of more spare capacities than other schemes, but can provide very short convergence.

Assume a network with E links which connect W DWDM network elements. Each link has its own working capacity y_e and protection capacity y_e^*. Let us assume that the capacity unit cost for working and protection capacities are the same and are γ_e. Let D be a set of traffic demands. We consider a protection scheme which protects different links with protection path q in hot standby. $p = 1,2,\dots,P_d$ is a set of candidate paths for demands $d \in D$ and $q = 1,2,\dots,Q_e$ is a set of candidate backup paths. The volumes of demands h_d in the normal network state are realised with traffic flows j_{dp0} and, in the case of failure, with traffic flows z_{eq}. Coefficient $\delta_{edp} = 1$ if link e belongs to working path P_{dp} for demand d, otherwise it has a value of 0. Similarly, coefficient $\beta_{leq} = 1$ if link l belongs to backup path q restoring link e, otherwise it has a value of 0. The optimisation problem is to realise the restoration scheme at the optimal network cost.

Mathematical program (9)-(15) formulation is [8]:

$$Minimize:$$

$$F = \sum_{e=1}^{E} \gamma_e \left(y_e + y_e^* \right) \tag{9}$$

$$subject\ to:$$

$$\sum_{p=1}^{P_d} j_{dp0} = h_d;\ \forall d \in D \tag{10}$$

$$\sum_{d=1}^{D} \sum_{p=1}^{P_d} \delta_{edp} j_{dp0} \le y_e;\ \forall e \in E \tag{11}$$

$$\sum_{q=1}^{Q} z_{eq} = y_e;\ \forall e \in E \tag{12}$$

$$\sum_{q=1}^{Q} u_{eq} = 1;\ \forall e \in E \tag{13}$$

$$z_{eq} \le K_e u_{eq};\ \forall e \in E, \forall q \in Q_e \tag{14}$$

$$\sum_{e \ne l}^{E} \sum_{q=1}^{Q} \beta_{leq}\, z_{eq} \le y_e^*;\ \forall l \in E \tag{15}$$

Constraint (10) defines the total traffic flow allocated to demand *d,* while constraint (11) assures that the link load does not exceed the link capacity in the normal network state. Constraints (10) and (11) together assure that the normal demand volumes are carried using the normal link capacities only. Constraint (12) ensures that the traffic flow which is restoring the normal capacity of link *e* on restoration path *q* equals link capacity y_e, while constraint (15) assures enough capacities on link *l* to enable the restoration of all other links if they fail at the same time.

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If in the mathematical program we change replace constraint (15) with constraint (16):

$$\sum_{q=1}^{Q} \beta_{leq} z_{eq} \le y_e^*;\ \forall l \in E, \forall e \in E, l \ne e \tag{16}$$

then the model represents a network with a shared link shared protection scheme.

V. COMPUTATIONAL RESULTS

Let $G(V,E)$ be a graph representing the topology of a network with a set of vertices V and set of edges E, representing the network links on the DWDM network layer. Let the degree of vertex be $\Delta = 3$ and the graph diameter $D = 3$. The degree of vertex Δ is the number of intermodal links connected to the corresponding network node. Graph diameter D gives the longest distance between pairs of network nodes [9]. Assume that an IP/MPLS router is attached to each DWDM network element. The network has 8 nodes on the DWDM and IP/MPLS network layers. On the IP/MPLS network layer we assume 39 traffic demands and proportional fair capacity allocation [1], [8]. We assume bounded traffic flows and allow lower bounds h_d to be zero and the upper bounds H_d plus infinity. The assumed lower and upper bounds, assumed budgets B, expected revenues from unit of traffic demands w_d and calculated results for traffic flows are presented in Appendix A.

In DWDM network layer we assume the dissection of a mesh network topology in a set of self-healing rings [5]. The network used in the example is shown in Fig. 1.

The wavelengths which share a common link between two neighbouring self-healing rings may not use the same wavelength. The bundle of wavelengths used in a separate self-healing ring is denoted as SHr. Next to the labelled links in brackets are administratively appointed weights which are used to determine the shortest paths. We tested different network models and sub-models for different budgets available for link bandwidth realisation. All traffic flows are bounded by their lower and upper bounds [8]. All three mathematical programs we have considered are suitable for the study of one-layer networks. In the case where we stack individual layers into a multi-layer network, in our case a two-layer network, we must consider the fact that the unit cost of capacity in particular network schemes and models is a function of the number of links and in particular network schemes and models a function of the number of traffic demands. The possible network schemes are summarised in Table 1. Each scheme can be further divided into models according to a selected resilience scheme and are depicted in Table 2.

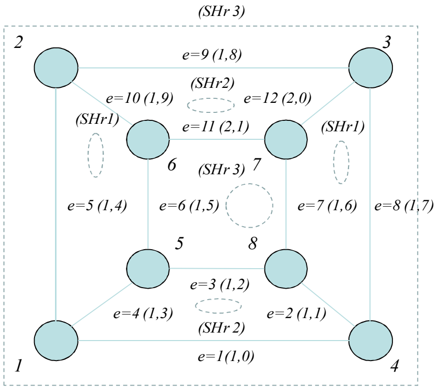


Fig. 1. The network model used in computational exercise

TABLE 2
DIFFERENT NETWORK SCHEMES AND MODELS

Scheme	Model	Resilience	VPN
Scheme 1	Model 1.1	Hot Standby Path Protection (DWDM)	DWDM
	Model 1.2	Hot Standby Link Protection (DWDM)	DWDM
	Model 1.3	Shared Link Protection (DWDM)	DWDM
Scheme 2	Model 2.1	Hot Standby Link Protection (DWDM)	IP/MPLS
Scheme 3	Model 3.1	Traffic Restoration (IP/MPLS)	IP/MPLS
	Model 3.2	Hot Standby Path Protection (IP/MPLS)	IP/MPLS

The unit costs of capacity are shown in Table 3.

TABLE 3
UNIT COSTS OF CAPACITY

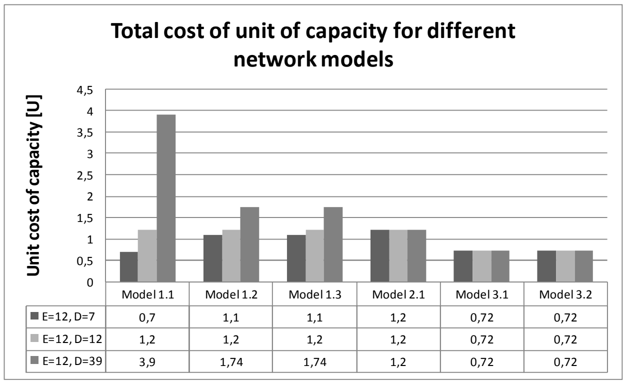
Model	DWDM layer	IP/MPLS layer
Model 1.1	$\rho(4D^{(T)}/\omega)$	$(2D/\omega)$
Model 1.2	$\rho(4E^{(T)}/\omega)$	$(2D/\omega)$
Model 1.3	$\rho(4E^{(T)}/\omega)$	$(2D/\omega)$
Model 2.1	$\rho(4E^{(T)}/\omega)$	$(2E/\omega)$
Model 3.1	$\rho(2E^{(T)}/\omega)$	$(2E/\omega)$
Model 3.2	$\rho(2E^{(T)}/\omega)$	$(2E/\omega)$

Coefficient ω represents conduction between the necessary interfaces on an individual network layer into the unit cost of capacity on an individual network layer. Coefficient ρ represents the ratio between the cost of DWDM and IP/MPLS interface. E represents the number of links in the network and D the number of traffic demands. Depending on the selected network model and inter-relationship between the number of links in the network and the number of traffic demands, we determine that the unit cost of capacity varies. This fact must always be taken into account when determining the unit cost of capacity. Fig.2 shows the total unit costs of capacity for different network models and different numbers of traffic demands. As a sample, one can see that in the case of network model 1.1 the unit cost of capacity may be the lowest, comparable with other models, or even the highest. Coefficients ρ and ω are set as $\rho = 2$ and $\omega = 100$.

The computational results for the test network are based on the following assumptions:

1. Ten different available budget B are considered for the construction of the two-layer IP/MPLS over DWDM network.

2. Proportional fairness for capacity allocation on the IP/MPLS network layer.



	Model 1.1	Model 1.2	Model 1.3	Model 2.1	Model 3.1	Model 3.2
■ E=12, D=7	0,7	1,1	1,1	1,2	0,72	0,72
■ E=12, D=12	1,2	1,2	1,2	1,2	0,72	0,72
■ E=12, D=39	3,9	1,74	1,74	1,2	0,72	0,72

Fig. 2. Total cost of unit of capacity for different network models

3. Network contains 12 links $e \in E$ as shown in Fig. 1 and there are 39 traffic demands $d \in D$ in the network.

4. A sequential approach is used, where calculated required capacities of the upper network layer represent the volume of traffic demands on the lower network layer.

The resulting costs per individual network layer $F(x), F(x)^T$, and total costs $\sum F$ in the different models of a two-layer IP/MPLS over DWDM network are given in Appendix B. Computational results were obtained by using the programming tool AIMMS 3.10 with LGO 1.0 to for solving non-linear programming problem (Appendix A) and CPLEX 12.2 for solving Mixed Integer Programming (Appendix B).

VI. DISCUSSION

The results shown in Appendix B reveal that the cheapest network model is model 3.1 with traffic restoration on the IP/MPLS network layer and realised VPN on the IP/MPLS network layer. On the DWDM network layer, point-to-point unprotected optical paths are realised. The deficiency of this network model is the possible long convergence time in the case of a network failure. Due to this limitation, this network model cannot apply to backbone networks. The most expensive network model is model 1.1 with a hot standby path protection scheme on the DWDM network layer and VPN on the DWDM network. This result is somewhat expected since it requires a lot of resources on the DWDM network layer, whereby network resources are more expensive than those on the IP/MPLS network layer. According to network model 1.1, the cost is significantly lower in models 1.2 and 1.3. In these two models, rather than the protection of an individual optical path the protection of an individual link is implemented. Virtual private networks are also realised at the DWDM network level. Model 1.3 is cheaper than model 1.2 since in model 1.3 a shared link protection scheme is implemented. A limitation of model 1.3 compared to model 1.2 is that in the case of multiple simultaneous failures in the network protection capacities only receive the connection that first discovers the failure. The most promising network model is 3.2. This model applies a hot standby path protection scheme and the realisation of virtual private networks on the IP/MPLS network layer. On the DWDM network layer point-to-point optical paths with no protection are realised. This network model provides fast resilience in the case of network failure at an acceptable network cost and simulates a two-layer IP/MPLS over DWDM network with a fast reroute protection scheme on the IP/MPLS network layer.

VII. CONCLUSION

In terms of cost and performances, for the optimal backbone network we propose a two-layer IP/MPLS over DWDM network with implemented virtual private networks and a fast reroute protection scheme on the IP/MPLS network. The DWDM network layer acts in this case as a pure transport layer which provides wide capacities with a configuration of optical paths between adjacent DWDM network elements. Such a network is modelled as Model 3.2.

VIII. APPENDICES

Appendix A

				B	***200***	***300***	***400***	***500***	***600***	***700***	***800***	***900***	***1979***	***4074***
d	***h***	***H***	w_d	Υ_d	x_d	x_d	x_d	x_d	x_d	x_d	x_d	x_d	x_d	x_d
1	10	300	0,3	0,5	10,00	10,00	20,64	29,24	33,01	35,27	40,43	46,29	102,84	300,00
2	10	150	0,3	0,4	10,00	10,00	25,18	37,08	41,10	44,02	51,11	57,33	127,60	150,00
3	10	200	0,3	0,3	10,00	10,00	33,90	51,05	56,19	60,65	69,19	74,25	169,44	200,00
4	10	800	0,3	0,375	10,00	29,78	30,00	39,80	44,10	47,01	54,66	60,72	138,02	215,32
5	5	400	0,3	0,45	5,00	26,88	23,75	32,65	36,52	39,24	45,20	51,67	114,64	400,00
6	10	540	0,3	0,425	10,00	10,00	24,10	34,70	38,65	43,76	48,03	54,35	120,90	540,00
7	10	900	0,3	0,25	10,00	10,00	34,20	56,50	63,98	69,24	78,53	92,73	204,59	113,63
8	10	700	0,3	0,35	10,00	31,02	29,54	43,00	47,50	50,55	58,75	63,93	146,50	327,72
9	10	230	0,3	0,475	10,00	10,00	21,72	30,77	34,67	37,02	42,78	49,29	108,40	10,44
10	10	120	0,3	0,535	10,00	10,00	19,23	29,20	30,96	32,85	37,85	44,33	96,02	120,00
11	5	120	0,3	0,275	6,09	38,96	32,75	52,90	59,39	120,00	74,00	71,71	120,00	120,00
12	10	340	0,3	0,325	10,00	33,26	31,52	46,80	51,28	54,75	63,54	69,28	158,06	147,59
13	10	670	0,3	0,6	10,00	10,00	16,97	25,64	27,74	29,49	33,74	39,87	84,91	121,83
14	10	460	0,3	0,675	10,00	10,00	14,95	10,00	24,67	26,17	30,35	35,46	76,38	106,21
15	10	250	0,3	0,675	10,00	10,00	14,95	10,00	24,50	26,18	30,30	35,46	76,39	250,00
16	5	430	0,3	0,7	5,00	17,38	15,48	22,24	23,67	25,16	29,39	34,11	73,73	98,54
17	10	700	0,3	0,975	10,00	10,00	10,00	10,00	10,00	17,62	20,64	22,62	50,38	700,00
18	10	670	0,3	0,7	10,00	10,00	14,41	10,00	23,70	25,78	29,63	34,11	72,86	98,85
19	10	680	0,3	0,575	10,00	10,00	17,78	27,16	28,90	30,94	35,21	41,50	88,78	75,70
20	5	320	0,3	0,7	5,00	17,22	15,48	22,24	23,67	25,16	29,39	34,11	73,81	320,00
21	10	320	0,3	0,6	10,00	10,00	16,97	24,84	27,74	29,49	33,79	39,87	84,91	76,96
22	10	340	0,3	0,675	10,00	10,00	15,77	10,00	24,50	26,27	30,34	35,48	76,38	178,29
23	5	560	0,3	0,875	5,00	14,23	12,89	17,74	18,60	19,43	24,04	26,06	58,31	63,50
24	10	800	0,3	1,000	10,00	10,00	10,00	10,00	10,00	17,82	20,03	22,40	51,32	66,65
25	10	200	0,3	0,95	10,00	10,00	10,00	10,00	10,00	18,85	21,92	24,21	54,19	65,76
26	5	320	0,3	0,925	5,00	12,49	11,66	16,02	18,06	18,24	22,71	24,26	55,66	67,17
27	10	300	0,3	0,675	10,00	10,00	14,95	10,00	24,46	26,29	30,30	35,45	75,12	84,78
28	10	340	0,3	0,525	10,00	10,00	19,62	27,98	31,51	33,58	38,58	45,09	96,80	10,00
29	5	400	0,3	0,675	5,00	16,69	15,77	22,83	24,61	26,17	30,32	35,46	76,51	400,00
30	10	540	0,3	0,925	10,00	10,00	11,49	10,00	10,00	19,37	22,70	24,18	55,61	289,56
31	10	700	0,3	0,4	10,00	10,00	25,17	37,02	41,20	43,95	51,11	57,33	129,37	479,51
32	10	500	0,3	0,675	10,00	10,00	14,95	10,00	24,41	26,46	30,34	35,43	76,42	148,91
33	5	450	0,3	0,3	5,00	33,14	36,14	49,58	55,14	45,02	69,75	74,19	171,22	118,55
34	10	340	0,3	0,275	10,00	10,00	34,95	52,93	59,44	64,78	74,97	75,14	185,36	340,00
35	10	200	0,3	0,7	10,00	10,00	14,41	10,00	10,00	22,96	29,53	34,17	72,86	10,00
36	10	100	0,3	0,875	10,00	10,00	11,97	10,00	10,00	20,40	24,01	25,72	58,32	10,00
37	10	120	0,3	0,525	10,00	10,00	19,62	28,05	31,35	33,62	38,46	45,09	98,22	120,00
38	10	120	0,3	0,4	10,00	10,00	25,37	37,04	41,21	44,00	51,11	57,33	120,00	120,00
39	5	900	0,3	0,3	5,00	39,08	34,56	50,25	55,82	59,60	69,36	74,19	171,24	108,30

Appendix B

B	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1979**	**4074**
Model 1.1										
F(x)	453,25	690,18	919,99	1157,35	1389,20	1620,42	1844,33	2072,42	4553,41	8431,46
F(x)$^{(T)}$	4709,2	7825,15	10.596,52	13.960,50	16.325,87	18.901,02	21.315,47	23.770,47	52.401,68	92.392,12
$\sum$ F	**5162,45**	**8515,33**	**11.516,51**	**15.117,85**	**17.715,07**	**20.521,44**	**23.159,80**	**25.842,89**	**56.955,09**	**100.823,58**
Model 1.2										
F(x)	453,25	690,18	919,99	1157,35	1389,20	1620,42	1844,33	2072,42	4553,41	8431,46
F(x)$^{(T)}$	2231,39	3397,86	4528,97	5697,6	6839,04	7977,02	9056,72	10.202,61	22.416,92	41.508,71
$\sum$ F	**2684,64**	**4088,04**	**5448,96**	**6854,95**	**8228,24**	**9597,44**	**10.901,05**	**12.275,03**	**26.970,33**	**49.940,17**
Model 1.3										
F(x)	453,25	690,18	919,99	1157,35	1389,20	1620,42	1844,33	2072,42	4553,41	8431,46
F(x)$^{(T)}$	1326,89	1899,84	2584,66	3267,88	3921,31	4681,76	5215,55	5836,41	12.787,38	21.897,20
$\sum$ **F**	**1780,14**	**2590,02**	**3504,65**	**4425,23**	**5310,51**	**6302,18**	**7059,88**	**7908,83**	**17.340,79**	**30.328,66**
Model 2.1										
F(x)	139,46	212,36	283,08	356,11	427,45	498,59	567,48	637,67	1401,05	2594,29
F(x)$^{(T)}$	2231,39	3397,86	4528,97	5697,6	6839,04	7977,02	9056,72	10.202,61	22.416,92	41.508,71
$\sum$ **F**	**2370,85**	**3610,22**	**4812,05**	**6053,71**	**7266,49**	**8475,61**	**9624,20**	**10.840,28**	**23.817,97**	**44.103,00**
Model 3.1										
F(x)	189,01	313,10	429,48	576,12	666,65	772,55	860,23	954,04	2097,67	3499,83
F(x)$^{(T)}$	378,02	626,19	858,97	1152,24	1333,29	1545,10	1720,47	1908,08	4195,35	6999,67
$\sum$ **F**	**567,04**	**939,29**	**1288,45**	**1728,37**	**1999,94**	**2317,64**	**2580,70**	**2862,12**	**6293,02**	**10.499,50**
Model 3.2										
F(x)	352,65	588,32	801,55	1058,58	1239,84	1431,19	1612,60	1799,06	3964,23	7041,55
F(x)$^{(T)}$	705,29	1176,64	862.335,74	2117,16	2479,68	2862,37	3225,20	3598,12	7928,45	14.083,09
$\sum$ **F**	**1057,94**	**1764,96**	**863.137,29**	**3175,75**	**3719,51**	**4293,56**	**4837,80**	**5397,18**	**11.892,68**	**21.124,64**

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