ON THE DEVELOPMENT OF METHODOLOGY FOR PLANNING AND COST-MODELING OF A WIDE AREA NETWORK

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ABSTRACT

The most important stages in designing a computer network in a wider geographical area include: definition of requirements, topological description, identification and calculation of relevant parameters (i.e. traffic matrix), determining the shortest path between nodes, quantification of the effect of various levels of technical and technological development of urban areas involved, the cost of technology, and the cost of services. These parameters differ for WAN networks in different regions – their calculation depends directly on the data "in the field": number of inhabitants, distance between populated areas, network traffic density, as well as available bandwidth. The main reason for identification and evaluation of these parameters is to develop a model that could meet the constraints imposed by potential beneficiaries. In this paper, we develop a methodology for planning and cost-modeling of a wide area network and validate it in a case study, under the supposition that behavioral interactions of individuals and groups play a significant role and have to be taken into consideration by employing either simple or composite indicators of socioeconomic status.

KEYWORDS

Wide Area Network, Traffic Matrix, Shortest Path Algorithm, Traffic Density, Network Bandwidth, Socioeconomic Indicators

1. INTRODUCTION

A Wide Area Network (WAN) is a computer network that covers a group of LAN networks that are administered separately and have different technology [1,2,3]. A network in a wider geographic area actually represents the infrastructure through which most ordinary services are carried out, all the way up to the most serious operations, such as monetary transactions. Creating an effective network that meets the needs of a particular region with minimal cost is still a challenge [4,5]. The end-user experience at the branch can be enhanced and the number of transactions across a WAN can be minimized by the use of WAN optimization/acceleration devices [6]. In 2009, computer academics at the University of California, Berkeley, asked whether it was more cost-effective to compute *locally* or reach across the network to powerful *remote* or distributed systems. It turned out the costs for storage and servers have fallen faster than that of network connections. Although WAN costs fell by a factor of 2.7x, computational equipment fell by a stunning 16 times. Ultimately, IT has to decide if the cloud makes economic sense. All the factors have to be considered when moving to cloud [7]: a company can write off

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all its assets and go to a fixed monthly cost – but, if the cloud environment is designed correctly, it should not see that much cost for bandwidth [8]. Nevertheless, WANs and the Internet were getting clogged long before the cloud: multimedia, Web and video conferencing, surfing, VoIP and unified communications already stress those networks that haven't been thoroughly boosted.

A WAN designer is required to possess a deep knowledge of technologies that will be encompassed in the process of building a WAN, their performance, price and connectivity. One also needs to consider the burden of network traffic and the distance of data transfer in certain areas and at certain times. A fundamental question that arises is *how to calculate (quantitatively) the traffic in these regional networks where the communication volume is variable*. Therefore, to construct an efficient WAN network, preceding calculations are required, such as identification and calculation of the traffic, the distances between cities, the number of participants in the traffic, the time of use of network infrastructure of participants, etc. Finally, it is also about the calculation of *carried traffic* (in Erlangs), as well as the *bandwidth* of the edges of the network graph.

In certain geographic areas, and at certain times, the traffic volume in a computer network is variable [9]. The *traffic matrix* describes the traffic map from one network location to all other locations, and it can be structured so that it represents the average value of the amount of traffic carried between locations – *nodes* of the network. Moreover, the introduction of either *simple* or *composite* indicators of *socioeconomic status* (i.e. *a socioeconomic indicator* – SEI), as a concrete contribution in this paper, helps obtaining more accurate information, needed in the development of methodology for planning and cost-modeling of a WAN network.

The remainder of this paper is organized as follows. Section 2 focuses on related work and identifies the main motivations. Section 3 discusses most of the necessary steps for effective construction of a WAN – calculation of traffic matrix, algorithms for finding the shortest path, as well as calculating traffic and bandwidth between nodes in a case-study network: we assume that 21 cities in the Republic of Macedonia are the graph nodes with 30 internode edges, and the weights of these edges are a measure for the distance between cities; in addition, to determine the shortest paths, *Dijkstra's* and *Floyd-Warshall* algorithms are applied. Prices of different technologies are evaluated in Section 4, where we shift our attention to cost-modeling. Finally, Section5 concludes the paper.

2. MOTIVATION AND RELATED WORK

Al-Wakeel's research report [9] is aimed towards cost study and analysis of WANs and Internetworks design. It focuses on the *economic* and *performance* characteristics of various network technologies and carrier service options, and evaluates the conditions in which each of these technologies is optimal. A top-down, step-by-step process has been developed and quantitative, business-oriented cost models for the network design have been built, in order to develop planning programs for constructing a WAN that is cost-effective for a large organization.

De Montis *et al.* [10] study the structure of a network representing the interurban *commuting traffic* of the Sardinia region, Italy, and use a *weighted network representation* where vertices correspond to towns and the edges to the actual commuting flows. However, they discuss the interplay between the topological and dynamical properties of the network, as well as their relation with *socio-demographic variables* such as *population* and *monthly income*. This analysis provides analytical tools for a wide spectrum of applications, and some of the principles laid out could easily be mapped to the problem of planning and cost-modeling of a wide area *computer network*, as well.

Taylor *et al.* [11] aim to identify associations between *demographic* and *socioeconomic factors* and *home Internet use patterns* in the Central Queensland region, Australia. This research hypothesizes that there are differences in Internet usage patterns between: young and old, male and female, people in urban and rural areas, married and unmarried, well-educated and less educated, rich and poor, and employed and unemployed. This paper examines differences in home Internet use across these parameters and the associations between home Internet consumption patterns and *demographic* and *socioeconomic factors*.

These are the main motivations for the introduction of *socioeconomic measures* (which are regularly used in official statistics to illustrate patterns of behavior and outcomes, and to support and develop policies) in the development of a model which will determine the exact cost of a wide area computer network that performs within the limits set by the demands of prospective users.

3. On the Development of Methodology for Planning of a Wide Area Network – a Case Study

3.1. Calculation of the Traffic Matrix

Calculation of the traffic matrix is based on the number of households in the cities, time of use of the networks and the number of service users over a network. The term “household” is considered a family or other community of people who declare that they are living together and spend their income. In other words, under the term household we consider so-called “collective household”, composed of persons living permanently in institutions for care of children and adults. In a city, there are two types of households: residential and commercial. The number of households in each node of the graph is calculated according to the following formula [9]:

$$\mathrm{T} = \frac{\boldsymbol{P}}{\boldsymbol{N}} \tag{1}$$

where:
T – number of households in the city
P – number of inhabitants in the city
N – number of inhabitants in a house (e.g.: this number in the Republic of Macedonia is 3.5) [9,12]

The total traffic in Erlangs (E) for any city (Table 2) is calculated as:

$$TF = \left(C \cdot \frac{P}{N} \cdot \frac{CC \cdot CL}{24} + R \cdot \frac{P}{N} \cdot \frac{CR \cdot RL}{24} \right) \cdot SEI \tag{2}$$

where:
C – commercial households (in percent)
CC – number of active on-line sessions per commercial household per day (24 hours)
CL – commercial session duration (in hours)
R – residential households (in percent)
CR – number of active on-line sessions per residential household per day (24 hours)
RL – residential session duration (in hours)
SEI – composite socioeconomic indicator.

The level of usage of a WAN network in a city depends not only on the population of that city, but also on their demographic structure and behavioral interactions of individuals and groups. It is quantified by a composite socioeconomic indicator (SEI), as a linear sum of products of weights

w_i, and several measures of labor status and education, a_i ($0 \le a_i \le 1$) (Table 1). The weights w_i are defined on the basis of statistical reports [12]:

$$SEI = \sum_{i=1}^{k} w_i a_i \quad (3)$$

where:
a_1 – percentage of public employees in that city;
a_2 – percentage of employees in enterprises in that city;
a_3 – percentage of pupils in that city;
a_4 – percentage of students in that city;
a_5 – percent of unemployed in that city;
a_6 – percent of the other inhabitants; i.e.:

$$a_1 = \frac{I_1}{P},\ a_2 = \frac{I_2}{P},\ a_3 = \frac{I_3}{P},\ a_4 = \frac{I_4}{P},\ a_5 = \frac{I_5}{P},\ a_6 = \frac{I_6}{P} \quad (4)$$

where:
I_1 – number of employees in the public sector in that city;
I_2 – number of employees in enterprises in that city;
I_3 – number of pupils in that city;
I_4 – number of students in that city;
I_5 – number of unemployed in that city;
I_6 – number of other population;
P – total population of the city.

w_1 – use of ICT and Internet in the public sector;
w_2 – use of ICT and Internet in enterprises;
w_3 – use of ICT and Internet by pupils;
w_4 – use of ICT and Internet by students;
w_5 – use of ICT by unemployed;
w_6 – use of ICT by others.

The traffic *between* cities A and B is calculated according to the formula:

$$T_{AB} = T_A \cdot \frac{P_B}{P_T} \quad (5)$$

where:
T_A – the traffic between city A and all other cities;
P_B – number of residents in city B;
P_T – number of all the inhabitants of 21 cities.

The SEI indicator has a significant impact in the calculation of the traffic between cities. The biggest users of computer networks in Macedonia are students and pupils (96.4%) and from here it turns out that the calculation of the traffic matrix between cities with SEI indicator included, traffic noticeably changes. If one carefully examines Table 3, there is a traffic increase between the nodes in the graph representing cities that have higher percentages of students, such as: Skopje– Bitola, Skopje–Tetovo, Skopje–Shtip, whereas there are no significant changes in traffic in Debar–Krusevo and Gevgelija–Kocani links, to name a few.

Table 1. Calculating the SEI.

	City	Households	Populationa	w1	w2	w3	w4	w5	w6	N	employees	I_1	$a_1 = \frac{I1}{N}$	I_2	$a_2 = \frac{I2}{N}$	I_3	$a_3 = \frac{I3}{N}$		I_4	$a_4 = \frac{I4}{N}$	I_5	$a_5 = \frac{I5}{N}$	I_6	$a_6 = \frac{I6}{N}$	$SEI = \sum_{i=1}^{6} w_i a_i$
				level of the republic								no. public sector (40%)		no.business sector (60%)		elementary students	High School students		no. students		no.unemployed		no.other		
1	Struga	14485	63376	0,720	0,360	0,964	0,964	0,25	0,25	63376	47811	19124,4	0,302	28686,6	0,453	6006	3229	0,146		0	3034	0,048	3296	0,052	0,546
2	Ohrid	16012	55749	0,720	0,360	0,964	0,964	0,25	0,25	55749	39074	15629,6	0,280	23444,4	0,421	4906	2605	0,135	1742	0,031	3809	0,068	3613	0,065	0,547
3	Bitola	28942	95385	0,720	0,360	0,964	0,964	0,25	0,25	95385	66955	26782	0,281	40173	0,421	7421	4604	0,126	2973	0,031	6838	0,072	6594	0,069	0,541
4	Debar	3917	19542	0,720	0,360	0,964	0,964	0,25	0,25	19542	13306	5322,4	0,272	7983,6	0,409	2306	713	0,154		0	1211	0,062	2006	0,103	0,533
5	Kicevo		47700	0,720	0,360	0,964	0,964	0,25	0,25	47700	34354	13741,6	0,288	20612,4	0,432	3997	2327	0,133	599	0,013	3238	0,068	3185	0,067	0,537
6	Krushevo	2706	9684	0,720	0,360	0,964	0,964	0,25	0,25	9684	7121	2848,4	0,294	4272,6	0,441	804	298	0,114		0	837	0,086	624	0,064	0,518
7	Prilep	24398	76768	0,720	0,360	0,964	0,964	0,25	0,25	76768	50641	20256,4	0,264	30384,6	0,396	6741	3977	0,140	1152	0,015	6760	0,088	7497	0,098	0,528
8	Gostivar	18091	81042	0,720	0,360	0,964	0,964	0,25	0,25	81042	60136	24054,4	0,297	36081,6	0,445	7083	4844	0,147		0	3546	0,044	5433	0,067	0,544
9	Тетово	20094	86580	0,720	0,360	0,964	0,964	0,25	0,25	86580	41528	16611,2	0,192	24916,8	0,288	10114	9795	0,230	6670	0,077	9761	0,113	8712	0,101	0,591
10	Skopje	146566	506926	0,720	0,360	0,964	0,964	0,25	0,25	506926	3E+05	138894,4	0,274	208341,6	0,411	53586	27692	0,160	32911	0,065	15874	0,031	29627	0,058	0,585
11	Kumanovo	27984	105484	0,720	0,360	0,964	0,964	0,25	0,25	105484	68606	27442,4	0,260	41163,6	0,390	11303	6514	0,169	1732	0,016	6472	0,061	10857	0,103	0,548
12	Kriva Palanka	6600	20820	0,720	0,360	0,964	0,964	0,25	0,25	20820	13503	5401,2	0,259	8101,8	0,389	1718	843	0,123		0	3154	0,151	1602	0,077	0,503
13	Sveti Nikole	5698	18497	0,720	0,360	0,964	0,964	0,25	0,25	18497	12767	5106,8	0,276	7660,2	0,414	1454	661	0,114	205	0,011	1843	0,100	1567	0,085	0,515
14	Shtip	15065	47796	0,720	0,360	0,964	0,964	0,25	0,25	47796	34171	13668,4	0,286	20502,6	0,429	4147	2794	0,145	1500	0,031	2434	0,051	2750	0,058	0,558
15	Veles	16959	55108	0,720	0,360	0,964	0,964	0,25	0,25	55108	38479	15391,6	0,279	23087,4	0,419	4579	2763	0,133	375	0,007	2995	0,054	5917	0,107	0,527
16	Kocani	11981	38092	0,720	0,360	0,964	0,964	0,25	0,25	38092	24041	9616,4	0,252	14424,6	0,379	3134	1719	0,127	2858	0,075	2884	0,076	3456	0,091	0,555
17	Radovish	8270	28244	0,720	0,360	0,964	0,964	0,25	0,25	28244	19009	7603,6	0,269	11405,4	0,404	2661	894	0,126	2119	0,075	1593	0,056	1968	0,070	0,564
18	Regotino	5898	19212	0,720	0,360	0,964	0,964	0,25	0,25	19212	14431	5772,4	0,300	8658,6	0,451	1817	775	0,135		0	1085	0,056	1104	0,057	0,537
19	Kavadaci	12026	38741	0,720	0,360	0,964	0,964	0,25	0,25	38741	27702	11080,8	0,286	16621,2	0,429	3438	1860	0,137		0	3513	0,091	2228	0,058	0,529
20	Strumica	15896	54676	0,720	0,360	0,964	0,964	0,25	0,25	54676	33452	13380,8	0,245	20071,2	0,367	5491	4018	0,174		0	2344	0,043	9371	0,171	0,530
21	Gevgelija	7221	22988	0,720	0,360	0,964	0,964	0,25	0,25	22988	15561	6224,4	0,271	9336,6	0,406	1869	991	0,124	2160	0,094	1459	0,063	948	0,041	0,578
	Σ	345453	1492410																						

Table 2. The total traffic from 21 cities with SEI included.

	City	population	Households N= 3,5 T	**CT**(15%)	**RT**(85%)	**TC** (CT*CL*4)/24, CL=1/2 h	**TR** (RT*RL*1)/24, RL=1/2 h	**TC+TR**	**SEI**	**(TC+TR)*SEI**
1	Struga	63376	18107,43	2716,11	15391,31	226,34	320,65	547,00	0,545661	298,474
2	Ohrid	55749	15928,29	2389,24	13539,04	199,10	282,06	481,17	0,546533	262,974
3	Bitola	95385	27252,86	4087,93	23164,93	340,66	482,60	823,26	0,540561	445,024
4	Debar	19542	5583,43	837,51	4745,91	69,79	98,87	168,67	0,533251	89,941
5	Kicevo	47700	13628,57	2044,29	11584,29	170,36	241,34	411,70	0,536561	220,900
6	Krushevo	9684	2766,86	415,03	2351,83	34,59	49,00	83,58	0,518026	43,298
7	Prilep	76768	21933,71	3290,06	18643,66	274,17	388,41	662,58	0,527954	349,812
8	Gostivar	81042	23154,86	3473,23	19681,63	289,44	410,03	699,47	0,543557	380,201
9	Тетово	86580	24737,14	3710,57	21026,57	309,21	438,05	747,27	0,59102	441,650
10	Skopje	506926	144836,00	21725,40	123110,60	1810,45	2564,80	4375,25	0,58482	2558,736
11	Kumanovo	105484	30138,29	4520,74	25617,54	376,73	533,70	910,43	0,547523	498,480
12	Kriva Palanka	20820	5948,57	892,29	5056,29	74,36	105,34	179,70	0,502561	90,308
13	Sveti Nikole	18497	5284,86	792,73	4492,13	66,06	93,59	159,65	0,51487	82,197
14	Shtip	47796	13656,00	2048,40	11607,60	170,70	241,83	412,53	0,557689	230,061
15	Veles	55108	15745,14	2361,77	13383,37	196,81	278,82	475,63	0,527339	250,821
16	Kocani	38092	10883,43	1632,51	9250,91	136,04	192,73	328,77	0,554843	182,416
17	Radovish	28244	8069,71	1210,46	6859,26	100,87	142,90	243,77	0,564386	137,582
18	Regotino	19212	5489,14	823,37	4665,77	68,61	97,20	165,82	0,537121	89,064
19	Kavadaci	38741	11068,86	1660,33	9408,53	138,36	196,01	334,37	0,529267	176,972
20	Strumica	54676	15621,71	2343,26	13278,46	195,27	276,63	471,91	0,529578	249,911
21	Gevgelija	22988	6568,00	985,20	5582,80	82,10	116,31	198,41	0,577857	114,652
	Σ	1492410								

Table 3. Traffic between cities with SEI included.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	City	Struga	Ohrid	Bitola	Debar	Kicevo	Krushevo	Prilep	Gostivar	Tetovo	Skopje	Kumanovo	Kriva Palanka	Sveti Nikole	Shtip	Veles	Kocani	Radovish	Negotino	Kavadarci	Strumica	Gevgelija
1	Struga		11,17	18,90	3,82	9,38	1,84	14,85	16,15	18,75	108,66	21,17	3,83	3,49	9,77	10,65	7,75	5,84	3,78	7,52	10,6	4,87
2	Ohrid	11,17		16,60	3,36	8,25	1,62	13,1	14,2	16,5	95,6	18,6	3,37	3,07	8,59	9,37	6,81	5,14	3,33	6,61	9,34	4,28
3	Bitola	18,90	16,62		5,75	14,12	2,77	22,36	24,30	28,23	163,54	31,86	5,77	5,25	14,70	16,03	11,66	8,79	5,69	11,31	15,97	7,33
4	Debar	3,82	3,36	5,75		2,89	0,57	4,58	4,98	5,78	33,5	6,53	1,18	1,08	3,01	3,28	2,39	1,8	1,17	2,32	3,27	1,50
5	Kicevo	9,38	8,25	14,12	2,89		1,38	11,18	12,15	14,12	81,78	15,93	2,89	2,63	7,35	8,02	5,83	4,4	2,85	5,66	7,99	3,66
6	Krushevo	1,84	1,62	2,77	0,57	1,38		2,27	2,47	2,87	16,6	3,23	0,59	0,53	1,49	1,63	1,18	0,89	0,58	1,15	1,62	0,74
7	Prilep	14,85	13,07	22,36	4,58	11,18	2,27		19,6	22,7	131,6	25,6	4,6	4,2	11,8	12,9	9,4	7,1	4,6	9,1	12,9	5,9
8	Gostivar	16,15	14,20	24,30	4,98	12,15	2,47	19,6		24	138,9	27,1	4,9	4,5	12,5	13,6	9,9	7,5	4,8	9,6	13,6	6,2
9	Тетово	18,75	16,50	28,23	5,78	14,12	2,87	22,7	24,0		148,4	28,92	5,239	4,769	13,35	14,55	10,58	7,98	5,16	10,27	14,50	6,65
10	Skopje	108,66	95,58	163,54	33,50	81,78	16,60	131,6	138,9	148,44		169,3	30,7	27,9	78	85,2	62	46,7	30,3	60,1	17,7	38,9
11	Kumanovo	21,17	18,62	31,86	6,53	15,93	3,23	25,6	27,1	28,92	169,32		6,38	5,81	16,26	17,73	12,89	9,72	6,3	12,51	17,66	8,1
12	Kriva Palanka	3,83	3,37	5,77	1,18	2,89	0,59	4,6	4,9	5,24	30,67	6,38		1,15	3,21	3,5	2,54	1,92	1,24	2,47	3,49	1,6
13	Sveti Nikole	3,49	3,07	5,25	1,08	2,63	0,53	4,2	4,5	4,77	27,92	5,81	1,15		2,85	3,11	2,26	1,71	1,10	2,19	3,10	1,42
14	Shtip	9,77	8,59	14,70	3,01	7,35	1,49	11,8	12,5	13,35	78,14	16,26	3,21	2,851		8,03	5,84	4,40	2,85	5,66	8,00	3,67
15	Veles	10,65	9,37	16,03	3,28	8,02	1,63	12,9	13,6	14,55	85,20	17,73	3,50	3,109	8,03		6,74	5,08	3,29	6,53	9,23	4,23
16	Kocani	7,75	6,81	11,66	2,39	5,83	1,18	9,4	9,9	10,58	61,96	12,89	2,54	2,261	5,84	6,74		3,51	2,27	4,51	6,37	2,92
17	Radovish	5,84	5,14	8,79	1,80	4,40	0,89	7,1	7,5	7,98	46,73	9,72	1,92	1,705	4,41	5,08	3,51		1,69	3,35	4,73	2,17
18	Regotino	3,78	3,33	5,69	1,17	2,85	0,58	4,6	4,8	5,17	30,25	6,30	1,24	1,10	2,85	3,29	2,27	1,69		2,28	3,22	1,48
19	Kavadaci	7,52	6,61	11,31	2,32	5,66	1,15	9,1	9,6	10,27	60,11	12,51	2,47	2,193	5,67	6,53	4,52	3,35	2,28		6,49	2,98
20	Strumica	10,61	9,34	15,97	3,27	7,99	1,62	12,9	13,6	14,50	17,66	17,66	3,49	3,10	8,00	9,23	6,38	4,73	3,22	6,49		4,20
21	Gevgelija	4,87	4,28	7,33	1,50	3,66	0,74	5,9	6,2	6,65	38,94	8,10	1,60	1,421	3,67	4,23	2,93	2,17	1,48	2,98	4,20	

3.2. Algorithms for Finding the Shortest Paths

Dijkstra's algorithm solves the problem of finding the shortest path from a source (point of the graph) to the other nodes (points of the graph) when all weights (scalars) of the edges in the graph are positive (Figure 1) [13,14]. The routing table (Forwarding Database) for this graph is seen below (Table 4) and each column of the table holds data from the neighboring routers (Adjacency Database) [15].

Table 4. The data gathered from the neighboring routers.

ST	OH	BT	DE	KI	KS	PP	GV	TE	SK	KU	KP	SN	SHT	VE	KO	RA	NG	KV	SU	GE
OH/13	ST/13	KS/38	ST/40	DE/35	PP/25	KI/53	KI/32	GV/25	KU/25	SK/25	KU/52	KU/35	SN/25	SK/42	SHT/27	SHT/25	KV/9	NG/9	RA/28	KV/53
Ki/45	BT/46	PP/40	KI/35	KS/31	BT/38	KS/25	DE/43	SK/30	VE/42	KP/52		VE/22	VE/33	SN/22		NG/35	RA/35	PP/38	GE/35	SU/35
DE/40		OH/46	GV/43	GV/32	KI/31	BT/40	TE/25		TE/30	SN/35		SHT/25	KO/27	SHT/33		SU/28	VE/37	GE/53		
				ST/45		KV/38							RA/25	NG/37						
				PP/53																

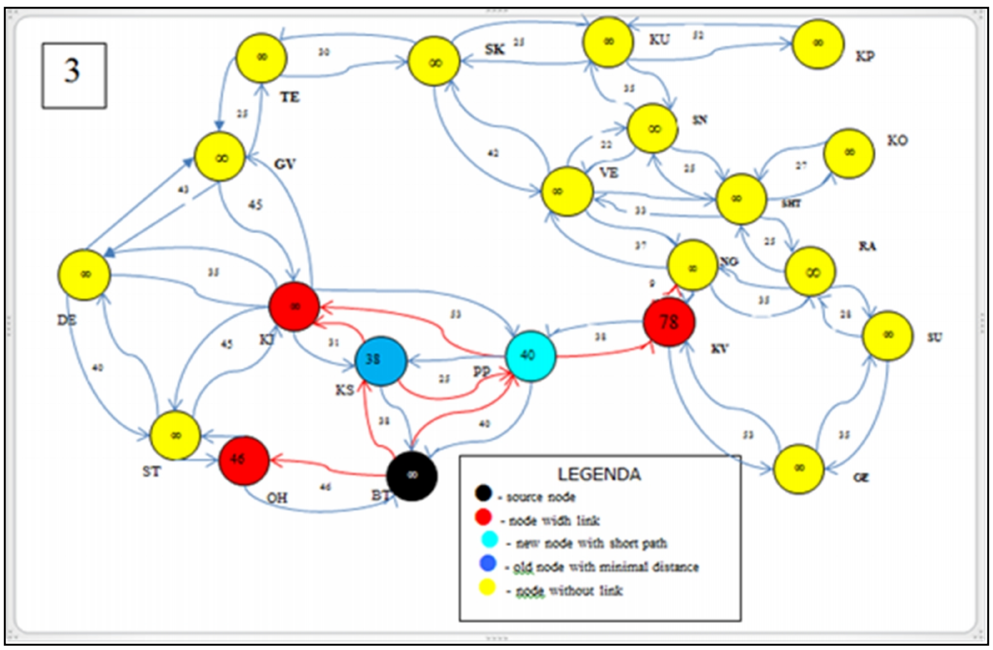

Figure1. Applying the Dijkstra's algorithm in this particular graph

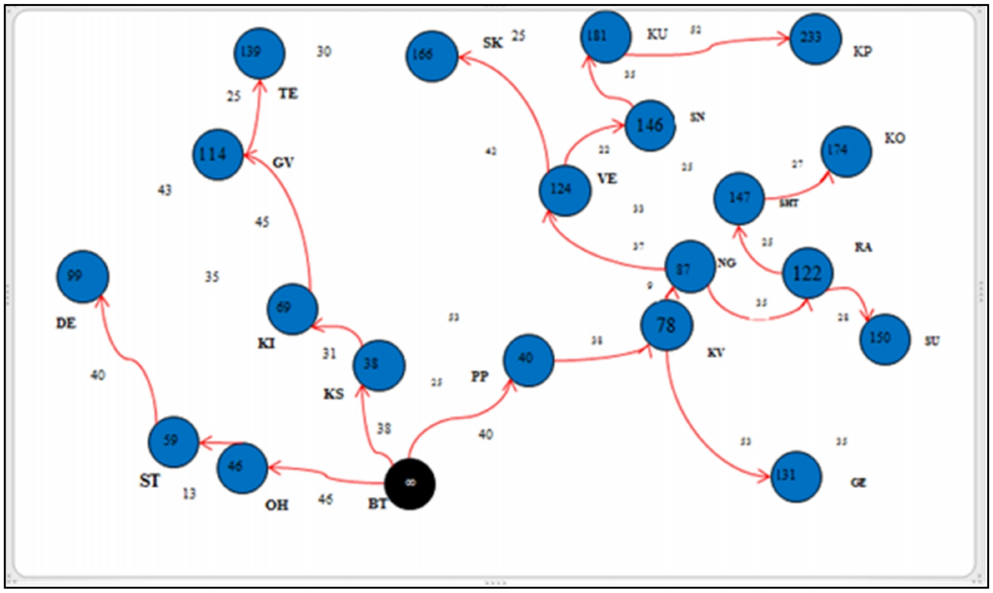

Figure 2. Shortest paths from the BT node (source) with Dijkstra's algorithm

Table 5. Determining shortest paths from the BT node with Dijkstra's algorithm.

Steps	BT	KS	PP	OH	ST	KI	KV	NG	DE	GV	RA	VE	GE	TE	SN	SHT	SU	SK	KO	KU	KP
0	0/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
1	0/NIL	38/BT	40/BT	46/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
2	0/NIL	38/BT	40/BT	46/BT	∝/NIL	69/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
3	0/NIL	38/BT	40/BT	46/BT	∝/NIL	69/BT	78/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
4	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
5	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	∝/NIL	99/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
6	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	∝/NIL	99/BT	114/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
7	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	∝/NIL	∝/NIL	131/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
8	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
9	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
10	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL	∝/NIL
11	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	∝/NIL	147/BT	150/BT	∝/NIL	∝/NIL	∝/NIL	∝/NIL
12	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	157/BT	150/BT	166/BT	∝/NIL	∝/NIL	∝/NIL
13	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	157/BT	150/BT	166/BT	∝/NIL	∝/NIL	∝/NIL
14	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	157/BT	166/BT	166/BT	∝/NIL	∝/NIL	∝/NIL
15	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	171/BT	166/BT	166/BT	∝/NIL	181/BT	∝/NIL
16	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	147/BT	166/BT	166/BT	174/BT	181/BT	∝/NIL
17	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	147/BT	150/BT	166/BT	174/BT	181/BT	∝/NIL
18	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	147/BT	150/BT	166/BT	174/BT	182/BT	∝/NIL
19	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	147/BT	150/BT	166/BT	174/BT	182/BT	∝/NIL
20	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	147/BT	150/BT	166/BT	174/BT	181/BT	233/BT
21	0/NIL	38/BT	40/BT	46/BT	59/BT	69/BT	78/BT	87/BT	99/BT	114/BT	122/BT	124/BT	131/BT	139/BT	146/BT	147/BT	150/BT	166/BT	174/BT	181/BT	233/BT

Based on Figure 2 and the final results after applying the Dijkstra's algorithm for finding the shortest path from the BT node to all other cities (Table 5), one can create a table by describing several routes (Table 6).

The Floyd-Warshall algorithm is designed to find the shortest path for all pairs of nodes (points) on a graph (Figure 3). A_k is a matrix of the type n x n, where $A_k[i, j]$ is the weight of the shortest path from i to j, which passes through nodes <= k [13,14,16]. In this case we define:

$$A_0[i,j] = \begin{cases} 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{if } i = j \\ \text{weight of branches from i to j} \ldots\ldots\ldots\ldots \text{for } i \neq j \text{ and} (i,j) \in E \\ \infty \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{if } i \neq j \text{ and } (i,j) \notin E \end{cases} \quad (6)$$

Now we examine the shortest path p from i to j, which passes through nodes 1...k – one of two possibilities apply [16]:

- path p does not pass through k and, in this case, the weight of the path is $A_{k-1}[i,j]$;
- path p passes through k and, in this case, the weight of the path is $A_{k-1}[i,k] + A_{k-1}[k,j]$.

Then we have: $A_k[i,j]$ = **min** ($A_{k-1}[i,j]$, $A_{k-1}[i,k] + A_{k-1}[k,j]$).

Based on this particular graph, we create a table in the form of a matrix (Adjacency Matrix). If $i = j$, the $A[i,j]$ element will have value 0 and will represent the diagonal of the matrix. In case there is still no link between nodes the value of the element in the matrix is described by the $\propto$ symbol (Table 7).

Table 6. Shortest paths with Dijkstra's algorithm and corresponding distances.

Source node	**Destination**	**Distance**	**Route**
Bitola	Krushevo	38	Bitola-Krushevo
Bitola	Prilep	40	Bitola-Prilep
Bitola	Ohrid	46	Bitola-Ohrid
Bitola	Struga	59	Bitola-Ohrid-Struga
Bitola	Kicevo	69	Bitola-Krushevo-Kicevo
Bitola	Kavadarci	78	Bitola-Prilep-Kavadarci
Bitola	Negotino	87	Bitola-Prilep-Kavadarci-Negotino
Bitola	Debar	99	Bitola-Ohrid-Struga-Debar
Bitola	Gostivar	102	Bitola-Krushevo-Kicevo-Gostivar
Bitola	Radovish	122	Bitola-Prilep-Kavadarci-Negotino-Radovish
Bitola	Veles	124	Bitola-Prilep-Kavadarci-Negotino-Veles
Bitola	Tetovo	127	Bitola-Krushevo-Kicevo-Gostivar-Tetovo
Bitola	Gevgelija	131	Betola-Prilep-Kavadarci-Gevgelija
Bitola	Sveti Nikole	146	Bitola-Prilep-Kavadarci-Negotino-Veles-Sveti Nikole
Bitola	Shtip	147	Bitola-Prilep-Kavadarci-Negotino-Radovish-Shtip
Bitola	Strumica	150	Bitola-Prilep-Kavadarci-Negotino-Radovish-Strumica
Bitola	Skopje	157	Bitola-Krushevo-Kicevo-Gostivar-Tetovo-Skopje
Bitola	Kocani	174	Bitola-Prilep-Kavadarci-Negotino-Radovish-Shtip-Kocani
Bitola	Kumanovo	181	Bitola-Prilep-Kavadarci-Negotino-Veles-Sveti Nikole-Kumanovo
Bitola	Kriva Palanka	233	Bitola-Prilep-Kavadarci-Negotino-Veles-Sveti Nikole-Kumanovo-Kriva Palanka

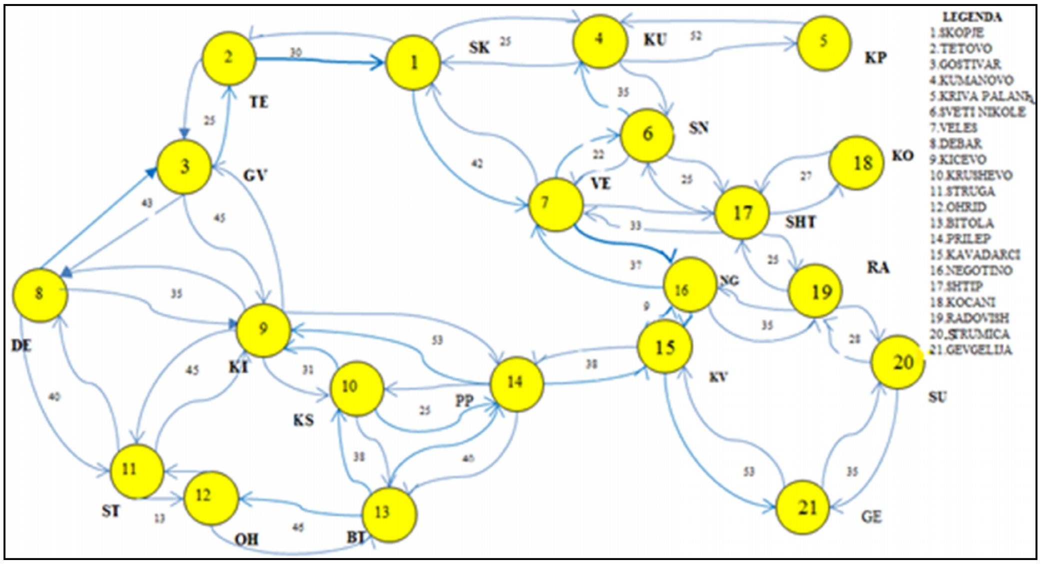

Figure 3. Applying the Floyd-Warshall algorithm in this particular graph

For example, p passes through k and these paths have been found: p_{42}=30+25=55, p_{24}=25+30=55, p_{72}=30+42=72, p_{27}=72, p_{74}=67, p_{47}= 67.

Table 7. Determining shortest paths with the Floyd-Warshall algorithm.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0	30	∝	25	∝	∝	42	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝
2	30	0	25	55	∝	∝	72	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝
3	∝	25	0	∝	∝	∝	∝	43	45	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝
4	25	55	∝	0	52	35	67	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝
5	∝	∝	∝	52	0	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝
6	∝	∝	∝	35	∝	0	22	∝	∝	∝	∝	∝	∝	∝	∝	∝	25	∝	∝	∝	∝
7	42	72	∝	67	∝	22	0	∝	∝	∝	∝	∝	∝	∝	∝	37	33	∝	∝	∝	∝
8	∝	∝	43	∝	∝	∝	∝	0	35	∝	40	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝
9	∝	∝	45	∝	∝	∝	∝	35	0	31	45	∝		53	∝	∝	∝	∝	∝	∝	∝
10	∝	∝	∝	∝	∝	∝	∝	∝	31	0		∝	38	25	∝	∝	∝	∝	∝	∝	∝
11	∝	∝	∝	∝	∝	∝	∝	40	45	∝	0	13			∝	∝	∝	∝	∝	∝	∝
12	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	13	0	46		∝	∝	∝	∝	∝	∝	∝
13	∝	∝	∝	∝	∝	∝	∝	∝	∝	38	∝	46	0	40	∝	∝	∝	∝	∝	∝	∝
14	∝	∝	∝	∝	∝	∝	∝	∝	53	25	∝	∝	40	0	38	∝	∝	∝	∝	∝	∝
15	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	38	0	9	∝	∝	∝	∝	53
16	∝	∝	∝	∝	∝	∝	37	∝	∝	∝	∝	∝	∝	∝	9	0	∝	∝	35	∝	∝
17	∝	∝	∝	∝	∝	25	33	∝	∝	∝	∝	∝	∝	∝	∝	∝	0	27	25	∝	∝
18	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	27	0		∝	∝
19	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	35	25	∝	0	28	∝
20	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	28	0	35
21	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	∝	53	∝	∝	∝	∝	35	0

Table 8. Shortest paths between all pairs in the graph with the Floyd-Warshall algorithm.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	0	30	55	25	77	60	42	98	100	131	138	151	166	126	88	79	75	102	100	128	141
2	30	0	25	55	107	90	72	68	70	101	108	121	139	123	118	109	105	132	130	158	171
3	55	25	0	80	132	115	97	43	45	76	83	96	114	98	136	134	130	167	155	183	189
4	25	55	80	0	52	35	57	123	125	156	163	176	181	141	103	94	60	87	85	113	148
5	77	107	132	52	0	87	109	175	177	208	215	228	233	193	155	146	112	139	137	165	208
6	60	90	115	35	87	0	22	158	159	131	198	192	146	106	68	59	25	52	50	78	113
7	42	72	97	57	109	22	0	140	137	109	180	170	124	84	46	37	33	60	58	86	99
8	98	68	43	123	175	158	140	0	35	66	40	53	99	88	126	135	173	200	170	198	179
9	100	70	45	125	177	159	137	35	0	31	45	58	69	53	91	100	160	187	135	163	144
10	131	101	76	156	208	131	109	66	31	0	76	89	38	25	63	72	132	159	107	135	116
11	138	108	83	163	215	198	180	40	45	76	0	13	59	98	136	145	205	232	180	208	189
12	151	121	96	176	228	192	170	53	58	84	13	0	46	86	124	133	193	220	168	196	177
13	166	139	114	181	233	146	124	99	69	38	59	46	0	40	78	87	147	174	122	150	131
14	126	123	98	141	193	106	84	88	53	25	98	86	40	0	38	47	107	134	82	110	91
15	88	118	136	103	155	68	46	126	91	63	136	124	78	38	0	9	69	96	44	72	53
16	79	109	134	94	146	59	37	135	100	72	145	133	87	47	9	0	60	87	35	63	62
17	75	105	130	60	112	25	33	173	160	132	205	193	147	107	69	60	0	27	25	53	88
18	102	132	157	87	139	52	60	200	187	159	232	220	174	134	96	87	27	0	52	80	115
19	100	130	155	85	137	50	58	170	135	107	180	168	122	82	44	35	25	52	0	28	63
20	128	158	183	113	165	78	86	198	163	135	208	196	150	110	72	63	53	80	28	0	35
21	141	171	189	148	200	113	99	179	144	116	189	177	131	91	53	62	88	115	63	35	0

Based on the results given in Table 8, obtained by applying the Floyd-Warshall algorithm, and the map of cities with numbers ranging from 1 to 21 which correspond to symbols (SK, TE, GO, KU, KP, SN, VE, DE, KI, KS, ST, OH, BT, PP, KV, NG, SHT, KO, RA, SU, GE), one can check whether the shortest path between those cities was found and can mark the route (Fig. 4).

Example: 8(DE) → 18(KO) with shortest path 200;
13(BT) → 5(KP) with shortest path 233;
2(TE) → 21(GE) with shortest path 171.

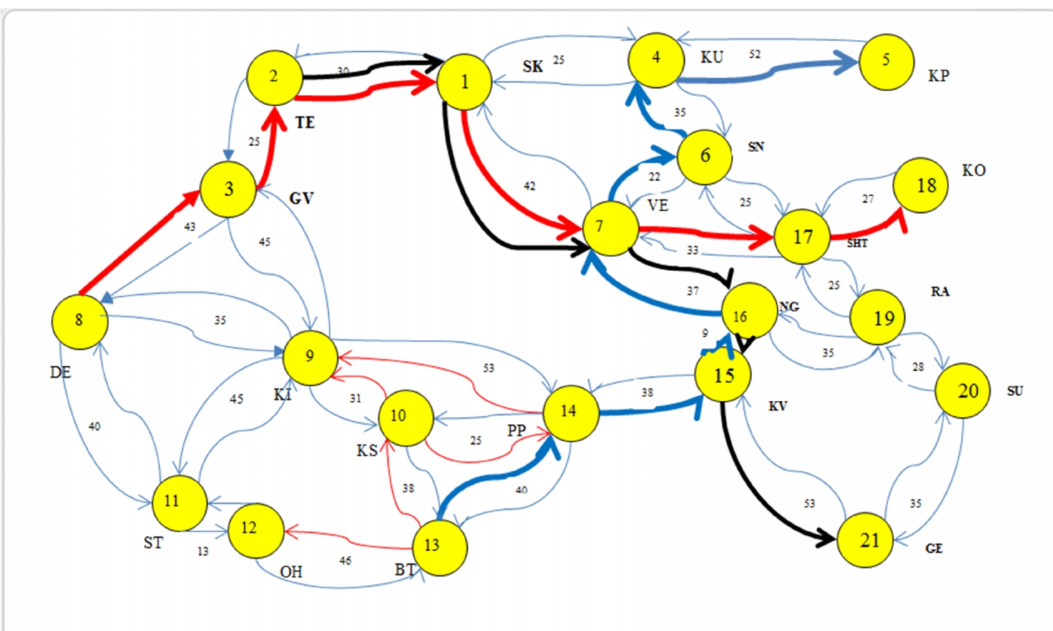

Figure 4. Marking the shortest path for three node pairs

Since the graph has 21 nodes, there are some 200 routes which describe the shortest path in one direction between all pairs of nodes on this graph. From Table 8, all the values of the shortest paths in both directions can be read (e.g. Gevgelija – Strumica = 35, Strumica – Gevgelija = 35). Below we describe several routes (Table 9).

Table 9. Shortest paths with the Floyd-Warshall Algorithm.

Node1	**Node2**	**Distance**	**Route with shortest path (Floyd- Warshal)**
Gevgelija(21)	Strumica(20)	35	Gevgelija-Strumica
Gevgelija(21)	Radovish(19)	63	Gevgelija-Strumica-Radovish
Gevgelija(21)	Shtip(17)	88	Gevgelija-Strumica-Radovish-Shtip
Gevgelija(21)	Kocani(18)	115	Gevgelija-Strumica-Radovish-Shtip-Kocani
Gevgelija(21)	Sveti Nikole(6)	113	Gevgelija-Strumica-Radovish-Shtip-Sveti Nikole
Gevgelija(21)	Kumanovo(4)	148	Gevgelija-Strumica-Radovish-Shtip-Sveti Nikole –Kumanovo
Gevgelija(21)	Kriva Palanka(5)	200	Gevgelija-Strumica-Radovish-Shtip-Sveti Nikole –Kumanovo-Kriva Palanka
Gevgelija(21)	Negotino(16)	62	Gevgelija-Kavadarci-Negotino
Gevgelija(21)	Kavadarci(15)	53	Gevgelija-Kavadarci
Gevgelija(21)	Veles(7)	99	Gevgelija-Kavadarci-Negotino-Veles
Gevgelija(21)	Skopje(1)	141	Gevgelija-Kavadarci-Negotino-Veles-Skopje

3.3. Calculating Traffic between the Nodes of the Network

To create a bandwidth of each link of the network one needs to calculate traffic (in Erlangs) for each link. This is done by passing through several stages:

- Previous calculation of the traffic of cities including SEI should be done.
- Then all the traffic between the cities is calculated and a traffic matrix between all pairs of nodes is created.
- Algorithms for finding the shortest path (e.g. Floyd-Warshall) between all pairs of nodes (cities) are applied.

Based on those routes, carried traffic in Erlangs is calculated. There are cases when a link is more loaded because there is a possibility for several routes to pass through that particular link, which determine shortest paths of a few pairs of nodes. As a result, several different traffic values for different pairs of cities are summed, and such specific links have increased traffic in Erlangs. Similarly, there are parts of routes which are not used in the determination of the traffic, because routes that do not pass across the link where traffic is calculated will simply have “zero” values. An example of the calculation of traffic between Tetovo and Skopje nodes is presented in Table 10.

By following the same methodology, the traffic for 30 pairs of nodes is calculated (Table 11): the maximum traffic (in Erlangs) is present at the Skopje-Tetovo link (908.74), while the minimum value is in the Prilep-Krushevo link (9.60).

Table 10. Traffic (in Erlangs): Tetovo-Skopje

Link	Shortest Path (km)	Run / not across Tetovo-Skopje link	Comunication (with SEI included)
Tetovo-Skopje	30	YES	148.4
Tetovo-Gostivar	25	NO	0
Tetovo-Kumanovo	55	YES	28.92
Tetovo-Kriva Palanka	107	YES	5.23
Tetovo-Sveti Nikole	90	YES	4.76
Tetovo-Veles	72	YES	14.55
Tetovo-Debar	68	NO	0
Tetovo-Kicevo	70	NO	0
Tetovo-Krushevo	101	NO	0
Tetovo-Struga	108	NO	0
Tetovo-Ohrid	121	NO	0
Tetovo-Bitola	139	NO	0
Tetovo-Prilep	123	NO	0
Tetovo-Kavadarci	118	YES	10.27
Tetovo-Negotino	109	YES	5.17
Tetovo-Shtip	105	YES	13.35
Tetovo-Kocani	132	YES	10.58
Tetovo-Radovish	130	YES	7.98
Tetovo-Strumica	158	YES	14.50
Tetovo-Gevgelija	171	YES	6.65
Skopje-Gostivar	55	YES	138.9
Skopje-Kumanovo	25	NO	0
Skopje-Kriva Palanka	77	NO	0
Skopje-Sveti Nikole	60	NO	0
Skopje-Veles	42	NO	0
Skopje- Debar	98	YES	33.50
Skopje-Kicevo	100	YES	81.78
Skopje-Krushevo	131	YES	16.6
Skopje-Struga	138	YES	108.6
Skopje-Ohrid	151	YES	95.5
Skopje-Bitola	166	YES	163.5
Skopje-Prilep	126	NO	0
Skopje-Kavadarci	88	NO	0
Skopje-Negotino	79	NO	0
Skopje-Shtip	75	NO	0
Skopje-Kocani	102	NO	0
Skopje-Radovish	100	NO	0
Skopje-Strumica	128	NO	0
Skopje-Gevgelija	141	NO	0
TETOVO-SKOPJE (Erlangs)			**908.74**

Table 11. Traffic (in Erlangs) fordifferent pairs of nodes.

	Node1-Node2	**Erlangs**
1	Skopje-Tetovo	**908.74**
2	Skopje-Kumanovo	**319**
3	Skopje-Veles	**756**
4	Tetovo-Gostivar	**383.2**
5	Gostivar-Kicevo	**235.6**
6	Gostivar-Debar	**91.1**
7	Kicevo-Debar	**15.8**
8	Kicevo-Struga	**92.6**
9	Kicevo-Krushevo	**41.6**
10	Ohrid-Struga	**190.9**
11	Struga-Debar	**193.6**
12	Bitola-Ohrid	**89.3**
13	Bitola-Krushevo	**68.7**
14	Bitola-Prilep	**320.6**
15	Prilep-Kicevo	**117.3**
16	Prilep-Krushevo	**9.6**
17	Prilep-Kavadarci	**286.4**
18	Kavadarci-Negotino	**133.9**
19	Kavadarci-Gevgelija	**88**
20	Veles-Negotino	**118.5**
21	Shtip-Veles	**130.7**
22	Kocani-Shtip	**175.2**
23	Shtip-Radovish	**161.2**
24	Shtip-Sveti Nikole	**30**
25	Veles-Sveti Nikole	**42.6**
26	SvetiNikole-Kumanovo	**206.7**
27	Kumanovo-Kriva Palanka	**87.9**
28	Radovish-Negotino	**48.3**
29	Radovish-Strumica	**172.4**
30	Strumica-Gevgelija	**23.9**

3.4. Calculating Bandwidth between the Nodes of the Network

The term "bandwidth" for communication networks means *amount of data over time that can be exchanged from point A to point B*[bits per second]. This range depends on the amount of the traffic that passes through the link – when the calculated value is multiplied by 64 kbps, one could get the bandwidth of that particular link, as seen in Table 12 below:

$$Bandwidth = Erlangs \cdot 64\ kbps \qquad (7)$$

Table12. Estimated link bandwidth.

	LINK	TRAFFIC (Erlangs)	BANDWIDTH (bits per sec)	Mbps
1	Skopje-Tetovo	**908.74**	58159360	58.1593
2	Skopje-Veles	**756**	48384000	48.384
3	Tetovo-Gostivar	**383.2**	24524800	24.5248
4	Bitola-Prilep	**320.6**	20518400	20.5184
5	Skopja-Kumanovo	**319**	20416000	20.416
6	Prilep-Kavadarci	**286.4**	18329600	18.3296
7	Gostivar-Kicevo	**235.6**	15078400	15.0784
8	Sveti Nikole-Kumanovo	**206.7**	13228800	13.2288
9	Struga-Debar	**193.6**	12390400	12.3904
10	Ohrid-Struga	**190.9**	12217600	12.2176
11	Kocani-Shtip	**175.2**	11212800	11.2128
12	Radovish-Strumica	**172.4**	11033600	11.0336
13	Shtip-Radovish	**161.2**	10316800	10.3168
14	Kavadarci-Negotino	**133.9**	8569600	8.5696
15	Shtip-Veles	**130.7**	8364800	8.3648
16	Veles-Negotino	**118.5**	7584000	7.584
17	Prilep-Kicevo	**117.3**	7507200	7.5072
18	Kicevo-Struga	**92.6**	5926400	5.9264
19	Gostivar-Debar	**91.1**	5830400	5.8304
20	Bitola-Ohrid	**89.3**	5715200	5.7152
21	Kavadarci-Gevgelija	**88**	5632000	5.632
22	Kumanovo-Kriva Palanka	**87.9**	5625600	5.6256
23	Bitola-Krushevo	**68.7**	4396800	4.3968
24	Radovish-Negotino	**48.3**	3091200	3.0912
25	Veles-Sveti Nikole	**42.6**	2726400	2.7264
26	Kicevo-Krushevo	**41.6**	2662400	2.6624
27	Shtip-Sveti Nikole	**30**	1920000	1.92
28	Strumica-Gevgelija	**23.9**	1529600	1.5296
29	Kicevo-Debar	**15.8**	1011200	1.0112
30	Prilep-Krushevo	**9.6**	614400	0.6144

Finally, based on the previous calculations, the bandwidth is determined, along with the cable or a medium that can support that amount of traffic. These proportions are seen in the image below (Figure 5).

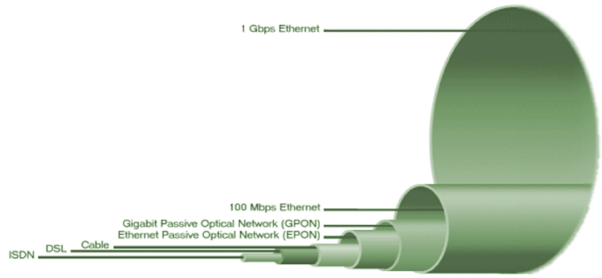

Figure 5. Cable proportions depending on bandwidth[1]

4. COST-MODELING

Prices for trunk segments of rented lines are formed on the basis of the reference price model of rented line (LLPC) with the recommendation of the European Commission EC 2005/951/1 final [17]. Rented lines are intended for use by small and large firms, where firms' work depends on the need for a permanent presence on the Internet and high speed data transfers. Advantages of rented lines are: high speed, reliability, a larger number of Internet users at the same time and the ability to be continuously present on the Internet.

Prices of rented lines are quite high because they are paid according to the length and the cost of individual services should also be added, and therefore users are looking for new cheaper rented lines. The retail market users prefer using virtual private networks or xDSL access and Ethernet access. Therefore, xDSL and cable Internet are very interesting for the users in terms of price compared with the prices of rented lines. At the moment of the analysis of the retail market, there were several service providers that use rented lines from AD Makedonski Telekom and offered services. It should be noted that AD Makedonski Telekom has been active in the retail market, providing services for the largest number of users (Table 13) [17].

Table 13. Prices for terminal and trunk segments of leased lines.

Capacity	**Prices in MKD (1 EUR = 61 MKD)**
64 kbit/s (to 2 km)	3,733.00
2 Mbit/s (to 2 km)	11,383.00
34 Mbit/s (to 2 km)	54,590.00
155 Mbit/s (to 2 km)	73,807.00
64 kbit/s (to 5 km)	4,774.00
2 Mbit/s (to 5 km)	15,178.00
34 Mbit/s (to 5 km)	58,936.00
155 Mbit/s (to 5 km)	81,518.00
64 kbit/s (to 15 km)	5,018.00
2 Mbit/s (to 15 km)	20,380.00
34 Mbit/s (to 15 km)	97,736.00
155 Mbit/s (to 15 km)	121,849.00
64 kbit/s (to 50 km)	6,059.00
2 Mbit/s (to 50 km)	32,987.00
34 Mbit/s (to 50 km)	155,387.00
155 Mbit/s (to 50 km)	253,613.00

[1]http://www.technologyuk.net/telecommunications/telecom_principles/bandwidth.shtml (Accessed March, 2014)

• In the case of ADSL, the price is calculated by a formula where we gather certain variables – the calculation depends on the type of communication network[9]:

- full-duplex;
- half-duplex;
- simplex.

Price for one year of full-duplex is calculated by the formula:

cost = 2·acc + 2·12·suba + 2·int + 2·12·subn

Parameters that are part of the overall calculation of price:

- **acc**: (access to network) price of joining the network (paid once), multiplied by two because both directions are paid
- **suba**: (subscription in access to network) price of joining the network (monthly fee), multiplied by 12 months and two directions of communication
- **int**: (initialization) price when the router initializes a link with the server in a radius, multiplied by two because communication is in both directions
- **subn**: (subscription) price of the package by month multiplied by 12 months and two directions of communication

Price for one year of half-duplex is calculated by the formula:

cost = acc + 2·12·suba + 2·int + 12·subn

In this case the communication goes in both directions but not simultaneously. **Acc** parameter is not multiplied by two because only one direction has to be paid. It happens to the price of the package **subn** as well. **Int** parameter is multiplied by two because initiation can occur in one of two extremes on the link.

Price for one year of simplex is calculated by the formula:

cost = acc + 12·suba + int + 12·subn

In this case the communication takes place only in one direction. We can see this in the formula for calculating the price for one year.

In cases where line is rented, the price for one year for the full-duplex is:

cost = 2·(int + 12·sub)

For the half-duplex and simplex the price for one year is calculated by:

cost = int + 12·sub

• For the Asynchronous Transfer Mode (ATM) technology, the calculation of the price for full-duplex from point A to point B is calculated by:

$$\mathbf{NA(A) = INS_A + SUB_A \cdot 12}$$

The $\mathbf{INS_A}$ parameter determines the price of the connection point A, and the $\mathbf{SUB_A}$ parameter is the price for a monthly fee.

The following parameters are for calculating the price from point B to the permanent network:

$$\mathbf{NA(B) = INS_B + SUB_B \cdot 12}$$

The price of the permanent network that is used is multiplied by 2 because both directions are used. It is calculated by the formula:

$$\mathbf{PVCC = 2 \cdot (INS + SUB \cdot 12)}$$

The total cost from point A to point B is the sum price from point A to the permanent network, the price of the permanent network PVCC and the price of the permanent network to point B:

$$\mathbf{TOTAL\_COST = NA(A) + NA(B) + PVCC}$$

The price for half-duplex from point A to point B is calculated using the formula:

$$\mathbf{NA(A) = INS_A + SUB_A \cdot 12}$$

Similarly,

$$\mathbf{NA(B) = INS_B + SUB_B \cdot 12}$$

The price of the permanent network that is used as a proxy of the two points is:

$$\mathbf{PVCC = INS + SUB \cdot 12}$$

Again, the total cost from point A to point B is a sum price from point A to the permanent network, the price of the permanent network PVCC and price from the permanent network to point B:

$$\mathbf{TOTAL\_COST = NA(A) + NA(B) + PVCC}$$

The calculation for the simplex from point A to point B is done using the formula:

$$\mathbf{NA(A) = INS_A + SUB_A \cdot 12}$$

$$\mathbf{PVCC = INS + SUB \cdot 12}$$

The total price calculating from point A to point B is a sum price from point A to the permanent network and the price of the permanent network PVCC – since simplex communication link is in one direction one does not have the cost and the price from the permanent network to point B:

$$\mathbf{TOTAL\_COST = NA(A) + PVCC}$$

5. CONCLUSIONS

The calculation of relevant parameter set provides indicators that help in the process of planning and modeling of WAN networks with adequate capacity and minimum price. They include: the communication matrix for each city, number of households, number of network users, total traffic for any city, the traffic matrix between all cities and shortest paths between the nodes of the graph, which are determined by using appropriate algorithms such as Dijkstra's and/or Floyd-Warshall.

As a tangible contribution, the calculation of a so-called *socioeconomic indicator* (SEI) is made up of a dozen variables which are regularly used in official statistics to illustrate patterns of behavior and outcomes, and to support and develop policies. This again is not enough to estimate the load of an edge of the graph, which connects two adjacent nodes – there might be several shortest paths that pass through an edge. This is how the carried traffic (in Erlangs) for an edge is calculated, as well as the edge bandwidth, assuming that each unit of traffic measurement (Erlang) is equivalent to 64 kbps.

The rationale behind the identification and the evaluation of these parameters is very straightforward: to develop a model which will determine the exact cost of the network that performs within the limits set by the demands of prospective users, by including some socioeconomic variables that capture different levels of technological development and different patterns of behavior.

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