

Communications Network Design Project

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1 Introduction

This project is in the form of a RFP (Request for Proposals) from the Elbonian Government. The government is seeking to build a new country-wide high-speed data network. It is seeking tenders (in the form of an RFP) from network operators to build this network.

The tenders will be considered, and the superior tender will be adopted. The choice will be made both on the basis of cost, ability to satisfy Elbonian requirements for reliability and performance, and the ability to convince the Elbonian government of your organization's ability to deliver the network "on budget".

The method you use to create your network design is entirely up to you. I suggest you do a search of the relevant literature to go beyond what you have learnt in class.

2 Formalities

- The project is to be done in teams of two. You will form teams: any individuals who cannot find a team will be assigned a team. Teams must be formed (and named) by April 8th. Once you have informed me of your group by email, I will assign you a Group ID (GID), which you will use when handing in the assignment.
- The project is due before the last CND lecture of the semester on Thursday 4th June. The competitive nature of assessment (see below) means that late assignments cannot be considered. In the real world, late tenders are not accepted! (However, I will negotiate extensions, for good reasons, if the problem is discussed in advance).
- The project will be handed up in two parts:
 1. A electronic form of your network design. See below for details of the required format. Proposals in an incorrect format will not be considered and will receive zero.
 2. A report detailing your design strategy and the results, in enough detail to convince the Elbonian government of your competence to complete the network on budget.
- Marks will be assigned on the following basis
 - 50% will be based on the quality of your solution, i.e., its cost and how well it satisfies the required constraints.

Approximate marking scheme

Mark	Description
0	network is not submitted in the required format
10	network fails to satisfy several required conditions
20	network fails to satisfy one required conditions
25-50	network satisfies all required conditions, score depends on cost.

This project is a competition. The marks for network quality (for networks that satisfy required conditions) will be based on how good your network is in comparison to all of the other networks. Assuming N network designs all pass the constraints, I will place the network designs in order of their cost c_i , so that $c_i \geq c_{i+1}$, where $i = 0, \dots, N - 1$. I will assign the mark m_i for the i th best network design to be

$$m_i = 25 + 25 \frac{i}{N - 1}.$$

The best network design will get 50 marks, and the worst network design, including my own example design will receive 25 marks. If there are ties, I will assign equal marks to both groups.

– 50% of your mark will be based on the quality of your report. Your report (your “tender”) must be well written. In order that you present your material well I have provided some hints.

* There are numerous articles on report writing on the Internet, for instance, see:

<http://www.wikihow.com/Write-a-Report>

<http://www.monash.edu.au/lls/llonline/quickrefs/15-report-writing.xml>

* Two books I find useful are

· “The Elements of Style”, Strunk and White, Allyn and Bacon, 2000.

· “Handbook of Writing for the Mathematical Sciences”, N.J.Higham, SIAM, 1995.

* If you use third party code in your solution, make sure you acknowledge this, and also ensure that you display your understanding of this code, rather than just treating it as a black box.

The report need not be long, but please remember that your report must contain enough information for the “Elbonian” government to properly assess your results. It must: show you understood the RFP; describe the method you use to design your network in enough detail for it to be believed to be a good design, including references to the design method; and show the details of the final design and how it will carry the network load.

The following table is intended to help guide you as to how marks will be allocated.

Criteria	Fail (0-25)	Pass (25-32)	C (33-37)	D (38-42)	HD (43-50)
Structure	failure to include standard structural components: title, authors, introduction, conclusion, etc.	standard report structure	clear structure, terms defined before use	natural and easy to follow	
Diagrams	illegible graphs	diagrams legible	diagrams clear and useful, axes labelled, captions provide clear explanation of diagrams	diagrams enhance reading of report	
Presentation	common spelling and grammatical mistakes		logical arguments, few mistakes		a pleasure to read
References	plagiarism, ambiguous references, inaccurate references	references aren't significant, but are accurate	references provide correct attribution of ideas and motivations.	references used to support most arguments	
Evidence of Understanding	common inaccuracies	ideas are explained, but only by paraphrasing existing works	logical explanations, demonstrated understanding of assumptions and limitations	use of examples to illustrate advantages and disadvantages	new ideas, new insights, new examples

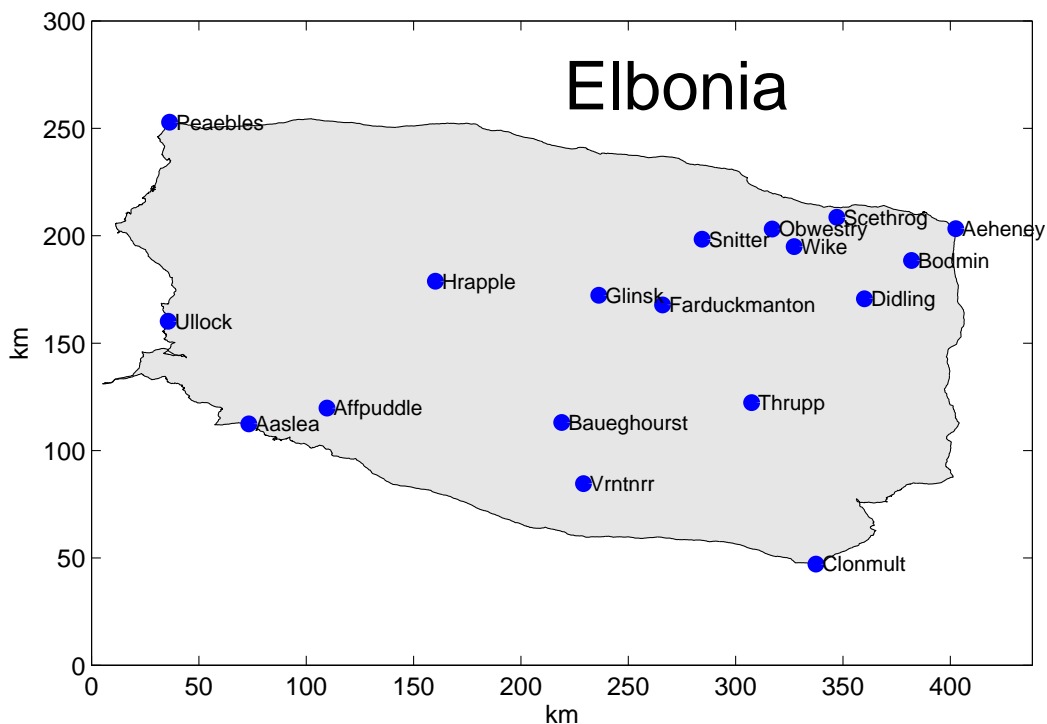
3 Request for Proposals

1. The Elbonian Government requests that network operators present designs for the new Elbonian High-Speed Backbone Network (EHSBN).

For more details of the history and culture of Elbonia please see
<http://uncyclopedia.wikia.com/wiki/Elbonia>
<http://en.wikipedia.org/wiki/Elbonia>

2. Specified coverage of the EHSBN

The EHSBN must connect all 18 major Elbonian cities: Aaslea, Affpuddle, Aeheney, Baueghourst, Bodmin, Clonmult, Didling, Farduckmanton, Glinsk, Hrapple, Obwestry, Peabables, Scethrog, Snitter, Thrupp, Ullock, Vrntrrr, and Wike, shown in the map below.



3. Network requirements:

- (a) The EHSBN must provide enough capacity for the expected monthly peak traffic demands (see Table 2), plus a 10% overhead to account for possible variations in the traffic.
- (b) Elbonia has historical and geographic problems that mean that network links are likely to be unreliable. As a consequence, the network design is required to be resilient to any single link failures, i.e., the network must remain connected if any single link fails. The network must also remain connected if a single router fails. In this case it is acceptable that customers of that PoP loose connectivity, but the rest of the network must remain functional.
- (c) In order to maintain a simple design, the network will be built using a limited number of types of links, namely, OC48 and OC192 links. For the purpose of design we shall approximate the capacities of these links as 2.5 and 10 Gbps.
- (d) Links must be bi-directional and symmetric, that is, there must be equal capacity in both directions.
- (e) The Elbonian government wish that the network provide good performance to all customers, and so require that the network routing follow “Shortest-Paths” where path length is determined by geography. In addition they require that the longest (uncongested) round-trip time in the network be ≤ 10 ms.

4. Additional conditions

The Elbonian Government requires that all contractors operating in Elbonia use Elbonian vendors for equipment (where available). There is one Elbonian network equipment vendor, “The Elbonian Rebadging Company”. The costs of equipment from this vendor are given in Table 1.

Equipment	Cost	Description
Router	\$100	1 Tbps router, 30 line card slots
Line card 1	\$110	One port OC48, 2.5 Gbps
Line card 2	\$230	One port OC192, 10 Gbps

Table 1: Elbonian Rebadging Company Pricelist

The unusual terrain in Elbonian (consisting mainly of mud) requires that all works must be conducted by the Elbonian State Digging corporation who charge a set rate for laying optical fiber at \$4 per km. Distances between locations can be calculated from their locations assuming that fiber is run in a straight line.

The difficult terrain requires that routers can only be placed in population centers.

Source	Destination																	
	Aaslea	Affpuddle	Aeheney	Baueghourst	Bodmin	Clonmult	Didling	Farduckmanton	Glinsk	Hrapple	Obwestry	Peables	Scethrog	Snitter	Thrupp	Ullock	Vrntnrr	Wike
Aaslea	0.01	0.01	0.01	0.04	0.04	0.04	0.08	0.08	0.01	0.04	0.01	0.04	0.02	0.05	0.01	0.03	0.07	0.04
Affpuddle	0.03	0.02	0.01	0.09	0.10	0.09	0.20	0.21	0.01	0.11	0.01	0.09	0.05	0.13	0.01	0.08	0.17	0.09
Aeheney	0.02	0.01	0.01	0.07	0.07	0.06	0.14	0.15	0.01	0.08	0.01	0.06	0.04	0.09	0.01	0.06	0.12	0.06
Baueghourst	0.11	0.07	0.02	0.41	0.46	0.40	0.92	1.00	0.01	0.50	0.02	0.40	0.23	0.59	0.02	0.38	0.80	0.40
Bodmin	0.03	0.02	0.01	0.11	0.12	0.10	0.23	0.25	0.01	0.13	0.01	0.10	0.06	0.15	0.01	0.10	0.20	0.10
Clonmult	0.02	0.01	0.01	0.04	0.05	0.04	0.09	0.10	0.01	0.05	0.01	0.04	0.03	0.06	0.01	0.04	0.08	0.04
Didling	0.07	0.04	0.02	0.25	0.28	0.24	0.55	0.60	0.01	0.30	0.02	0.24	0.14	0.35	0.01	0.23	0.48	0.24
Farduckmanton	0.06	0.04	0.02	0.23	0.25	0.22	0.50	0.55	0.01	0.27	0.01	0.22	0.13	0.32	0.01	0.21	0.44	0.22
Glinsk	0.05	0.03	0.01	0.19	0.21	0.18	0.42	0.45	0.01	0.23	0.01	0.18	0.11	0.27	0.01	0.17	0.36	0.18
Hrapple	0.02	0.01	0.01	0.07	0.08	0.07	0.15	0.16	0.01	0.08	0.01	0.07	0.04	0.10	0.01	0.06	0.13	0.07
Obwestry	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Peables	0.03	0.02	0.01	0.11	0.12	0.11	0.24	0.26	0.01	0.13	0.01	0.11	0.06	0.16	0.01	0.10	0.21	0.11
Scethrog	0.05	0.03	0.01	0.19	0.21	0.18	0.41	0.45	0.01	0.22	0.01	0.18	0.10	0.26	0.01	0.17	0.36	0.18
Snitter	0.05	0.03	0.01	0.19	0.21	0.18	0.42	0.46	0.01	0.23	0.01	0.19	0.11	0.27	0.01	0.18	0.37	0.19
Thrupp	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
Ullock	0.07	0.04	0.02	0.25	0.28	0.24	0.56	0.61	0.01	0.30	0.02	0.25	0.14	0.36	0.01	0.23	0.49	0.25
Vrntnrr	0.04	0.03	0.01	0.16	0.17	0.15	0.35	0.38	0.01	0.19	0.01	0.15	0.09	0.22	0.01	0.14	0.30	0.15
Wike	0.04	0.03	0.01	0.14	0.16	0.14	0.31	0.34	0.01	0.17	0.01	0.14	0.08	0.20	0.01	0.13	0.27	0.14

Table 2: Elbonian peak traffic demands (Gbps). Note that this data is available directly in `elbonian_traffic.dat`.

4 Data and formats

All materials for this project may be found at http://www.maths.adelaide.edu.au/matthew.roughan/Lecture_notes/Comm_Net_Design/06project.html

4.1 Input formats

This section details the available data files, and their precise input format.

Elbonia does not acknowledge imperialist western longitudes and latitudes, or the ludicrous theory that the Earth is round. The Earth is self-evidently flat, and Elbonia measures in km relative the the location of the “Elbowspond”, which used to be part of Elbonia but was annexed by Kneebonia in the 14th century. The file

```
elbonian_city_locations.dat
```

gives the locations of the major Elbonian population centers, at which the network must have a PoP. The file starts with a few lines of comments, each of which starts with the '#' symbol. This is followed by one line for each city, e.g.,

```
1|Aaslea|73.24|112.40
2|Affpuddle|109.68|119.77
```

Each line has four field, separated by the '|' symbol. The fields are

1. the city number
2. the city name
3. the x location of the city (in km)
4. the y location of the city (in km)

The map of Elbonia (that also appears in this document) is available at the server as `elbonian_map.eps`.

The second important file, `elbonian_traffic.dat`, contains Elbonia's expected peak traffic demands. Again the file starts with comments, but then presents a matrix of values. The rows correspond to source (cities) and the columns to destinations. The ordering is the same as the order in `elbonian_city_locations.dat`.

There is one additional file, `elbonian_border.dat`, which gives points along the border or Elbonia suitable for drawing a map of the country.

Note that on the web page associated with this project I have provided Matlab scripts that will read the input files (see below for details).

4.2 Outputs

This section explains the *required* format for files that are to be handed up for assessment. Note that all files will assessed by computer without any manual intervention. Files which are not in this format, and hence cannot be read, will result in a mark of zero.

Your network design will appear in one file named

```
network_GID.dat
```

where `GID` is your Group ID number which I will assign once you have given me your group members. The file will begin with comments of the following form:

```
# group ID = GID
# group members = NAMES
# date = DATE
# network cost = COST
# cost breakdown
#     router cost = ROUTER COST
#     fiber cost = FIBER COST
#     line card cost = LINE CARD COST
```

where the fields on the RHS of the equalities should be replaced by the correct information. You may round off your calculated costs to the nearest dollar.

Once you have entered your comments, you will enter the network design by inputting a list of links, one per row, in the following format

PoP1 | PoP2 | type | n | capacity

As you can see, there are 5 fields, again separated by the '|' symbol. In more detail the fields are

1. **PoP1:** The PoP at one end of the link. Give the number from `elbonian_city_locations.dat`. Do not give the name.
2. **PoP2:** The PoP at the other end.
3. **type:** this indicates whether the link uses OC48 (type=1) or OC192 (type=2) links.
4. **n:** the number of links.
5. **capacity:** the capacity of the group of links.

Note that because links are symmetric, you only need to list each link once (not twice giving each direction separately). We will also assume that only one router is used per PoP, so we only need to give the links, not the routers, and the cost of the routers is fixed, but should still be included in your total network costs. An example file, `elbonian_example_net.dat` is provided. It is reprinted here in full:

```
# group ID = 2009_00
# group members = Matthew Roughan
# date = 10 March, 2009
# network cost = 16333
# cost breakdown
#   router cost = 1800
#   fibre cost = 5853
#   line card cost = 8680
1|2|1|1|2.5
1|16|1|1|2.5
2|16|1|2|5.0
2|4|1|2|5.0
2|10|1|2|5.0
3|5|1|1|2.5
3|13|1|1|2.5
4|17|2|1|10.0
4|15|2|1|10.0
5|13|1|1|2.5
5|7|1|2|5.0
6|15|1|1|2.5
6|17|1|1|2.5
7|18|1|2|5.0
7|15|1|2|5.0
8|9|2|1|10.0
8|14|2|1|10.0
8|15|1|2|5.0
9|10|1|2|5.0
10|12|1|1|2.5
11|18|1|2|5.0
11|13|1|2|5.0
11|14|2|1|10.0
12|16|1|1|2.5
```

5 Hints and help

A few things to note in the above problem:

- Routers have been specifically designed so that they shouldn't be a limitation, and given the reliability requirements your solution should only need one router in each PoP.
- Link capacities are limited to a finite range, but there is nothing to stop you from having two or more links between two nodes if you need additional capacity. However, due to the way SPF load balancing works (with equal loads on all alternative paths), all of the links between one pair of nodes should have the same capacity (either they should all be OC48s or all OC192s).
- We assume that WDM is used so that a single optical fiber can carry many wavelengths, and hence many links (at least at the OC48 and OC192 speeds). Hence, only one fiber is needed between any two locations, and so the distance component of costs is independent of the required capacity.

There are many approaches you might adopt to solving this problem.

- You could adapt one of the simple heuristics discussed in lectures: a greedy algorithm, a star, or tree-like network, a genetic algorithm, relaxation to a LP, or branch and bound. In each of these cases you will have to work out how to map the specifics of this problem onto the appropriate algorithm.
- You are free to search the research literature. You might like to check out journals such as *IEEE/ACM Transactions on Networking*, *Networks*, *SIAM J. of Computing*, *Transportation Research*, *Mathematical Programming*, *J. of Algorithms* for inspiration.

There are approximately 10^{30} 18-node biconnected graphs, so a complete search will take some time. The problem is NP-hard, so there are no obvious short-cuts. It may be in your best interest to try several different methods and compare the solutions.

I have provided on my web page a number of Matlab scripts that may help you:

- `read_links.m` will read a network description file in the same format as you need to hand up. You should use this to test that the format of your file is correct.
- `read_cities.m` will read the list of Elbonian cities in the given file format. This is included as an example of how to easily read in formatted text files into Matlab.
- `elbonian_network_map.m` draws a picture of Elbonia, and a prospective network. It takes as input a network description file in the same format as you need to handout, and it also uses the following two data files:

```
elbonian_city_locations.dat
elbonian_border.dat
```

which must be in the same directory.

- `compute_link_cost.m` computes the cost of links so that we are all in agreement about this cost. You need to understand this function though, don't just use it blindly.
- `distance2delay.m` convert distances (in km) into approximate propagation delays (in seconds).
- `elbonian_example_net.dat` is an example network, showing the data format required for the assignment. The network is illustrated in `elbonian_example_net.eps`.

You may also wish to use your Dijkstra code from earlier in the course, but there are also many useful resources on the Internet, for instance, you may use code from the MatlabBGP library <http://www.mathworks.com/matlabcentral/fileexchange/10922>.

However, your report **MUST** reference any third party code you have used, describe how it was used, and exhibit your understanding of what the code does. That's easy for Dijkstra (assuming you got full marks for your assignment), but don't

take random chunks of code from the Internet and use them like a black box. Show me that at the very least, you understand their assumptions, limitations, and advantages.

Your expected workload for this project is 70 hours per person. Obviously this will vary between groups, the figure is included only as a guideline, and to ensure that you spread the workload out across the semester (do not attempt to do this project in the last week).

6 Acknowledgements

Elbonia is the creation of Scott Adams, author of the Dilbert comics, though I take the blame for the map and city names.