Air Force Institute of Technology
Department of Electrical and Computer Engineering

CSCE 654 - Computer Communication Networks
Project #4 - Network Routing

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May 15, 2019

1 Optimization Process/Methodology:

We optimized our network using the following methodology. Due to full-duplex communications, both directions of each link see the full link capacity. Thus, for any pair of bases A and B, we only need to optimize for the highest load of $\lambda_{A \to B}$ or $\lambda_{B \to A}$.
We thus minimized the score function by changing the configuration of links between each pair of bases, giving an optimal 4-connected topology.
After we had our optimal configuration, we removed the two lowest-loaded links to achieve 3-connectedness. This prevented as much additional strain on the existing infrastructure as possible. We then optimized the remaining 8 links by routing the deleted channel's traffic through remaining channels. The 3-connected topology had a better score by ≈ 0.3. This difference is small enough that the only way to know which network performs better is through simulation; thus, we are utilizing the 4-connected topology.

2 Network Topology:

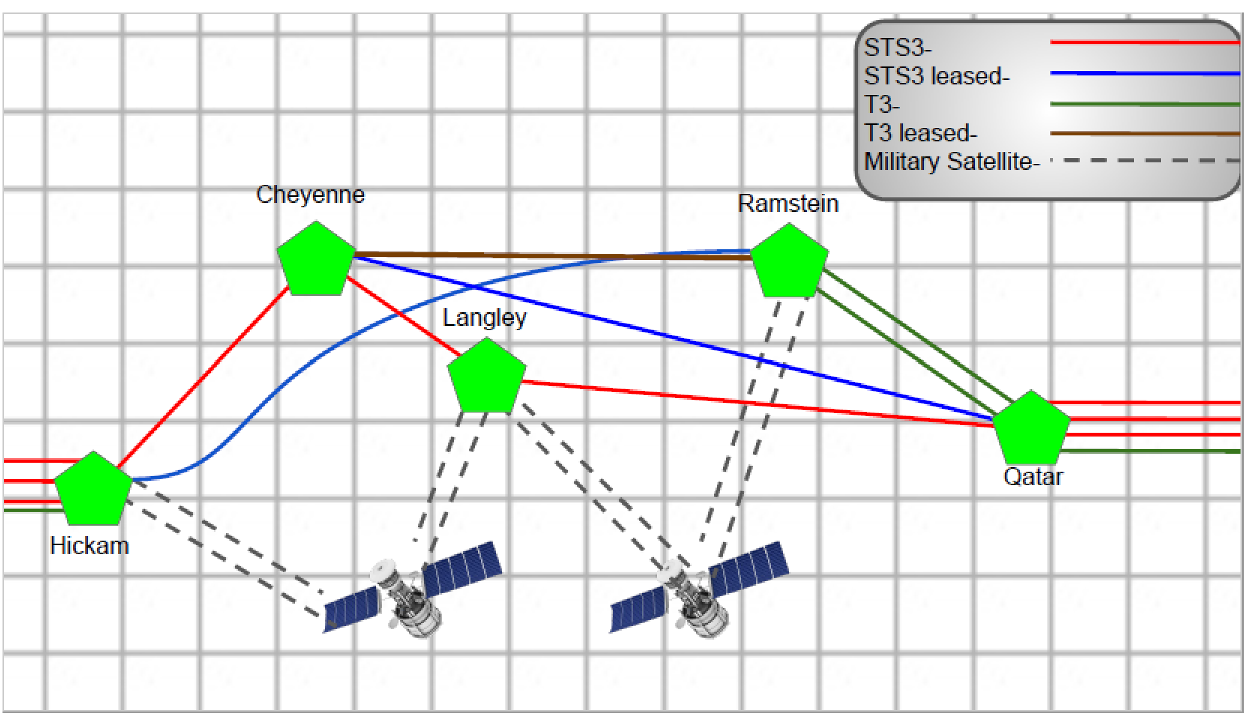

Figure 1: Network Topology of Routing Network

3 Cost Calculation:

Given the costs in the Project Requirements, we went through the following steps to build our total network cost.
Installation Costs:
For any leased system, satellite or otherwise, there was no installation cost. If there was an owned land line (STS-3 or T3), we incurred a trenching cost. This cost is calculated as follows, where d is the distance between the two nodes:

$$\text{Trenching Cost } = IC_{trench} = d_{A\to B} \cdot \$10,000 \tag{1}$$

For owned land lines, we incurred a per-link installation cost.

$$\text{Link Installation Cost } = IC_{link} = d_{A\to B} \cdot \frac{cost}{km} \tag{2}$$

For any owned satellites (we have none), we would incur the following satellite installation cost, where k is the cost of installing a given type of satellite:

$$\text{Satellite Installation Cost } = IC_{sat} = k \tag{3}$$

The overall installation cost is shown below:

$$\text{Installation Cost } = IC_{total} = IC_{trench} + IC_{sat} + \sum_{links} IC_{link} \tag{4}$$

Monthly Costs:
Each type of link had a given monthly cost, based on the type of link. Additionally, each node communicating with a satellite has a ground station. Our monthly cost (MC) was the sum of each link's monthly cost, plus the monthly cost of the 3 ground stations needed for satellite communication.[1]

Server Costs: Each outbound link requires a server, so our total server cost is shown below, where n is the total number of links

$$\text{Server Costs } = SC = 2 \cdot n \cdot \$20,000 \tag{5}$$

Total/10 year cost:
The total cost for 10 years is shown below:

$$\text{Total Cost } = IC_{total} + SC + 120 \cdot MC \tag{6}$$

4 Network Analysis:

Let λ be the required traffic on a given node. Given a mean packet length of 20,000 bits, we calculated μ for each link as follows:

$$\mu = \frac{50\,packets}{Mb} \times \sum_{A\to B\,links} Bandwidth_{link}(Mbps) \tag{7}$$

Once we had an expression for λ and μ, we calculated the following parameters, where the "system" is the destination node:

$$Utilization = \frac{\lambda}{\mu}$$
$$E[n] = \frac{\lambda}{\mu - \lambda}$$
$$E[r] = \frac{1}{\mu - \lambda}$$

[1] We need 3 ground stations because 3 bases require satellite communication, 1 base communicates with 2 satellites

To find the end-to-end delay, we needed to account for propagation delay. We assumed that each type of link between $A \to B$ has the same utilization. Thus, the propagation delay is a weighted average

$$t_{prop} = percent_{ground} \cdot t_{ground} + percent_{satellite} \cdot t_{satellite} \tag{8}$$

For nodes involving an intelligent satellite, there is an additional $E[r]$ at the satellite. The end to end delay for a link $A \to B$ is shown below:

$$Delay_{A\to B} = t_{prop\,A\to B} + E[r]_{A\to B} \tag{9}$$

To calculate the total system response, we used a weighted average of the total network load and the load on link $A \to B$.

$$\text{Network Delay} = \sum_{allnodes} \frac{\lambda_{A\to B}}{\lambda_{network}} \cdot Delay_{A\to B} \tag{10}$$

5 Cost Function:

We calculated the total cost of the network using the following function:

$$Score = \frac{\text{Total Cost}}{\$6M} + \text{Network Delay (ms)} \cdot 0.10 + \text{K-Connectedness} \tag{11}$$

6 Expected Performance:

Due to the low utilization of most connections, except links A-C and E-B, we expect our model performance to be in line with analytical results. Due to the high utilization of links A-C and E-B we are anticipating a need for longer queues to accommodate bursts of packets. Since these two links also account for approximately 27% of network traffic we are expecting the overall weighted delay to swing in conjunction with queue lengths. If these cause the average weighted delay to swing too wildly a intelligence satellite link will be added to link A-C and a leased T-3 line will added to link E-B.