Evaluating Technical Goals
Project Costing

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Slides 3
http://www.sis.pitt.edu/~dtipper/2110.html

Top Down Network Design

- Top Down Network Design
  - Conceptual Model
    - Objectives
      - Business Goals, Technical Goals
    - Requirements
      - Business (e.g., support XYZ application), Technical (availability, delay, bandwidth, security, etc.,)
    - Constraints
      - Business (organizational, budget, etc.,) and Technical (vendor, technology, sites to connect, etc.)
  - Logical Model
    - Technology, network graph, node location, link size, etc. (where algorithms are used to minimize cost)
  - Physical Model
    - Specific hardware/software implementations
    - (e.g., wiring diagram, repeater locations, etc.)
Technical Requirements & Constraints

- From surveys/questionnaires, meetings etc. application data determine technical requirements and constraints
- Technical goal is to build a network that meets user’s requirements + some they may not know they need.
- Technical Goals
  - Scalability
  - Availability/reliability
  - Network Performance
    - Utilization, Throughput, Delay, Delay Jitter, packet loss rate, call/connection blocking rate
    - Traffic Estimation may be needed
  - Security
  - Manageability/Interoperability
  - Affordability $$
- Need to determine reasonable goal for each category and the importance of each.

Technical Requirements

- Traffic estimation is need to determine many network performance goals and requirements
- Start by meeting with customer and develop a list of current/potential applications and evolve an application map
- Goal is to quantify application behavior/network traffic and construct a traffic demand matrix

<table>
<thead>
<tr>
<th>Application</th>
<th>Type</th>
<th>New?</th>
<th>Criticality</th>
<th>Availability Goal</th>
<th>MTTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Email</td>
<td>Terminal - host</td>
<td>No</td>
<td>High</td>
<td>99.9%</td>
<td>1 hour</td>
</tr>
</tbody>
</table>
Application Modeling

- Can roughly classify applications into categories
  - Terminal/Host
  - Distributed Client Server
  - Peer-to-Peer Model
  - Server/server
  - Distributed Computing

- Classifications used to define
  - application flows directions and characteristics
    - Unidirectional or bidirectional
    - Symmetric or asymmetric
    - low, medium, or high bit rate
  - flow boundaries
    - e.g., LAN-WAN traffic, intra-campus flow etc.

Application Types

- Terminal/Host
  - Tend to be produce asymmetric traffic – larger in downstream direction
  - Hierarchical organization
  - Examples:
    - Telnet, email, etc.
Application Types

• Distributed Client Server
  - Tend to be produce asymmetric traffic – larger in downstream direction
  - Hierarchical organization
  - Examples:
    • Web applications
    • Sales Tracking etc.

• Server to Server
  - Tend to be produce bi-directional traffic at the server layer/larger in downstream direction to client
  - Managed correlated distributed servers
  - Variation of client server
  - Examples:
    • Collaborative Document Processing
    • Inventory Control/management
    • Mirrored databases/web sites
Application Types

• Peer-to-Peer Model
  – No obvious hierarchy or asymmetry to traffic
  – Examples:
    • IP based Video/audio conferencing

• Distributed Computing
  – Tend to be produce symmetric traffic
  – Managed correlated computers
  – Examples:
    • Computer Aid Manufacturing
    • Computer Aided Design
Applications Map

- List Applications supported at various sites and between sites
- Example - company with offices in Dallas and Vienna, VA,
- Factory in Denver - consider WAN applications only
- Appl A: Sales/inventory control
- Appl B: CAM
- Appl C: CAD
- Appl D: video conference
- Appl E: Intranet Voice over IP

Applications Map

- From Applications Map – get rough idea of traffic flows between network nodes
- Get the beginnings of a traffic demand matrix across the network
  - For example – applications across the WAN table below

<table>
<thead>
<tr>
<th>Sources</th>
<th>Dallas</th>
<th>Denver</th>
<th>Vienna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas</td>
<td>—</td>
<td>1A</td>
<td>1D+1A</td>
</tr>
<tr>
<td>Denver</td>
<td>3A</td>
<td>—</td>
<td>3A+1C</td>
</tr>
<tr>
<td>Vienna</td>
<td>5A+1D</td>
<td>5A+2C</td>
<td>—</td>
</tr>
</tbody>
</table>
Characterizing Application/ Network Traffic

• Traffic Characterization
  – What kind of traffic is generated?
    • Client-server, peer-to-peer, etc.
  – When is Busy Period?
    • For applications, network components, etc.
  – What is the relative impact on the network?
    • Peak rate, mean sustained rate, min rate
    • Burst size, burst duration
    • Degree of multi-casting
  – How much overhead in operation of network?
    • For example IP RIP, BGP, ICMP traffic
  – If greenfield design need to guess estimate the traffic load from collect data and number of users

Application Assumptions

• If greenfield design or unable to benchmark traffic
• Use data gathered from user surveys or assume characteristics from similar applications or other benchmark studies - make overly conservative assumptions:
  – number of application users = # simultaneous users
  – all applications are used all the time
  – each user opens session and the session lasts all day
  – Typical values of applications data given in textbook
    • Web page with graphics - 50 Kbytes
    • Spreadsheet - 100 Kbytes
    • Word processing document - 200 Kbytes

<table>
<thead>
<tr>
<th>Application or Network</th>
<th>Type of Application</th>
<th>New App? Freq of use</th>
<th>Criticality</th>
<th>Data Rate/Goal</th>
<th>Delay Goal/Variation Goal</th>
<th>Acceptable MTBF/MTTR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales Tracking</td>
<td>Distributed client/server</td>
<td>No/hourly</td>
<td>Very</td>
<td>Bursty/Max .5Mbps ~ mean ~100Kbps</td>
<td>&lt; 1 sec/NA</td>
<td>6 months/2 hours</td>
</tr>
</tbody>
</table>
• If incremental network design can possibly characterize data network traffic on existing network – two options
  – Application Monitoring
    • What are applications and how much bandwidth needed
  – Network Monitoring
    • What is network traffic pattern and bandwidth usage (often by protocol)
  – List of Tools for Application and Network Monitoring on class web page (link to useful info)

Characterizing Application Traffic

• Application Monitoring
  – If current applications – benchmark the traffic
  – Software tools can be used to determine application performance statistics
  – Uses “agents” to collect data and send information to a “management” station
  – Agents run on the different OS where the applications are installed
  – Standalone software or integrated into network management package software (e.g., Openview)
  – Normally, the profiling software transforms raw application data captured from the network into an application profile (passive monitoring)
  – Active stress test tools for performance tuning also possible
Application Usage Patterns

- Application Monitoring allow one to develop *Profiles* of each *Application*
  - Number of users,
  - Number of sessions per user-day
  - Average duration of session
  - Average number of simultaneous sessions
  - Peak data rate, Burst Duration, Busy period
  - Mean data rate, min data rate, multi-cast, etc.

- Translate Application monitor and profile data into traffic demand matrix

Network Monitoring

- Identify Traffic Flows
  - Establish traffic flow boundaries
    - Host to server
    - Floor – to – floor
    - LAN to WAN
    - Management traffic
    - Multi-cast
    - Etc.
  - Capture the appropriate traffic for each flow
  - Use a network capturing and analysis tool
    - Sniffer, Network Management software, etc.
  - Identify each flow in the capture
  - Can separate flow by protocol type, destination, etc.
Network Monitoring

• Method for Characterizing a Traffic Flow
  – Determine statistics for traffic flows
    • Individual flow, composite flow, backbone flow
  – Busy period, peak data rate, burst duration, mean data rate, mean response time, etc.
  – Create source–destination traffic matrix – typically are PEAK data rate requirements
  – May include path info in matrix

<table>
<thead>
<tr>
<th>Source</th>
<th>Destination 1</th>
<th>Destination 2</th>
<th>Destination 3</th>
<th>Destination 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAN Segment 1</td>
<td>3 Mbps</td>
<td>500 Kbps/Path A-B-C</td>
<td>100 Kbps</td>
<td>50 Kbps</td>
</tr>
</tbody>
</table>

Example

• Example- company with offices in Dallas and Vienna, VA,
• Factory in Denver
• Appl A: Sales/inventory control
• Appl B: CAM
• Appl C: CAD
• Appl D: video conference
• Appl E: Intranet Voice over IP
Applications Map

• From Applications Map – get rough idea of traffic flows between network nodes
• Get the beginnings of a traffic demand matrix across the Wide Area Network
• If use Applications Monitoring Approach – gather data on each application
  • A: Mean rate = .1 Mbps, Peak = .15 Mbps
  • C: Mean rate = .5 Mbps, Peak = .75 Mbps
  • D: Mean rate = 2 Mbps, Peak = 2.5 Mbps

Traffic Demand Matrices

• From the application map and associated matrix and the application monitoring data we have the mean traffic demand matrix and peak traffic demand matrix as below
• Note, if the network monitoring approach is used get traffic demand directly.
Traffic Forecasting

• For service providers will integrate data from multiple sources to determine traffic flows & characteristics:
  – Business Service Demand forecasts
  – Coarse-grained traffic demand from SLAs
  – Fine-grained Traffic Profiling (direct measurements)
• In greenfield case must rely on business, consumer demand forecasts

<table>
<thead>
<tr>
<th>Auck</th>
<th>Gisb</th>
<th>Palm</th>
<th>Well</th>
<th>Ricc</th>
<th>Chch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auck</td>
<td>0</td>
<td>x1</td>
<td>x2</td>
<td>x3</td>
<td>x4</td>
</tr>
<tr>
<td>Gisb</td>
<td>x5</td>
<td>0</td>
<td>x6</td>
<td>x7</td>
<td>x8</td>
</tr>
<tr>
<td>Palm</td>
<td>x9</td>
<td>x10</td>
<td>0</td>
<td>x12</td>
<td>x14</td>
</tr>
<tr>
<td>Well</td>
<td>x15</td>
<td>x16</td>
<td>x18</td>
<td>0</td>
<td>x20</td>
</tr>
<tr>
<td>Ricc</td>
<td>x21</td>
<td>x22</td>
<td>x24</td>
<td>0</td>
<td>x26</td>
</tr>
<tr>
<td>Chch</td>
<td>x27</td>
<td>x28</td>
<td>x30</td>
<td>x32</td>
<td>0</td>
</tr>
</tbody>
</table>

Technical Requirements & Constraints

• From surveys/questionnaires, meetings etc. application data determine technical requirements and constraints
• Technical goal is to build a network that meets user’s requirements + some they may not know they need.
• Technical Goals
  – Scalability
  – Availability/reliability
  – Network Performance
    • Utilization, Throughput, Delay, Delay Jitter, packet loss rate, call/connection blocking rate
    • Traffic Estimation crucial
  – Security
  – Manageability/Interoperability
  – Affordability $$
• Need to be able to determine cost of a project
Project Costing

- Review of Economics
- Value of money changes with time
  - Inflation causes future dollars to be worth less than today’s dollars
  - Investment risk devalues future dollars proportionately to the risk

- Elements
  - Future value \( (F) \)
  - Present value \( (P) \)
  - Rate \( (i) \)
  - Annuity \( (A) \) - A sequence of uniform payments
  - Net Present Value NPV sum of all cash flows moved to the present

Formulation

- If an amount of money \( (P) \) were invested such that it grew at precisely the rate of inflation \( (i) \) for one time period, then
  \[ F = P + Pi = P(1 + i) \]
  - That is, \( F \) has the equivalent future value of \( P \)

- For 2 time periods,
  \[ F = P(1+i) + P(1+i)i = P(1+i)(1+i) \]

- Generalizing, for \( n \) time periods
  \[ F = P(1+i)^n \]
  - This is referred to as the future worth of a present amount
Cash Flow Diagrams

\[
F = P (1 + i)^N
\]

\[
P = F (i\%, N)
\]

Example: $1000 today if invested in CD with 3% annual compound interest is worth in 5 years

\[
F = 1000(1+.03)^5 = $1159
\]

Can also find Present value of a Future Payment

\[
P = F \left( \frac{1}{1 + i} \right)^N
\]

\[
P = F \left( i\%, N \right)
\]

Cash Flow Series

- Annuity - payments of A made at regular intervals
- Compute future value

\[
F = A \left[ 1 + (1 + i) + (1 + i)^2 + \ldots + (1 + i)^N \right]
\]

\[
= A \left[ \frac{(1 + i)^N - 1}{i} \right]
\]

Example: A company leases a PBX for $1000 a quarter for 3 years. What is the value of the contract at the end if inflation is 2% quarterly

\[
F = 1000(1+.02)^{12}-1)/0.02) = $13,412
\]
Cash Flow of Series

- Computing present value $P$ of annuity $A$

\[ F = A \left( \frac{(1 + i)^N - 1}{i} \right) \]

and

\[ F = P \left( 1 + i \right)^N \]

\[ \therefore P = A \left( \frac{(1 + i)^N - 1}{i} \right) \left( \frac{1}{1 + i} \right)^N = A \left( \frac{(1 + i)^N - 1}{i(1 + i)^N} \right) \]

\[ i = \% \]

P dollars deposited  | F dollars in future
--- | ---
Example Present value of PBX lease | P = 1000 \([((1+.02)^{12} -1)/(0.02(1+.02)^{12})]\]
| P = $10,575

Cost Example

- Move project cost either to net present value NPV or to Future Present Value to compare alternatives
- Example buying PBX vs. leasing PBX for 10 year project ($i = 5\%$)

<table>
<thead>
<tr>
<th>Buy PBX</th>
<th>Lease PBX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purchase value = $27,000</td>
<td>$4000 yearly fee</td>
</tr>
<tr>
<td>Maintenance = $1000 year</td>
<td>NPV = [4000 \left[ \left(1+0.05\right)^{10} - 1 \right]/\left(0.05(1+0.05)^{10}\right)]</td>
</tr>
<tr>
<td>Salvage value = $2000</td>
<td>$30,887</td>
</tr>
<tr>
<td>NPV = $27000 + [1000\left(\left(1+0.05\right)^{10} -1\right)/\left(0.05(1+0.05)^{10}\right)] - $2000 (1/(1+.05)^{10})</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>NPV = $27000 + $7,722 - $1,228</td>
<td></td>
</tr>
<tr>
<td>= $33,494</td>
<td></td>
</tr>
</tbody>
</table>

Outcome may be different if include taxes and if depreciation applicable to taxes!
Depreciation

- Definitions of Depreciation
  - A System of Accounting which Aims to Distribute Cost or Other Basic Value of Tangible Capital Assets, Less Salvage Value, Over the Estimated Useful Life of a Unit in a Systematic and Rational Manner for the Purpose of Allocation (Paraphrased from ACPA)
  - Loss in Service Value Not Restored by Maintenance
  - Due to Normal Wear and Tear, Exposure and Decay, Technological Obsolescence, etc.
- Depreciation Does Not Involve Actual Cash Outlays

Computing Depreciation Expense

- Original Cost of Equipment
- Estimated Service Life of Equipment
  - Data equipment 3-7 years lifetime
  - Telecom equipment 5-20 years lifetime
- Estimated Net Salvage Value of the Equipment
  - Remaining Value at the End of the Service Life
  - Can Include the Cost of Removal
- Depreciation Method
  - Retirement/Replacement
    - Not widely used because carry cost until retirement
  - Age-Life
Age-Life Methods

• Designed to Provide More Consistent Expense Accounts from Year to Year
• Straight-Line Depreciation
  – Depreciation Charge is Computed for Each Retirement Period
  – Draw a Straight Line Between Original Cost and estimated Salvage Value, and Allocate the Difference over Service Life

\[
\text{Depreciation Charge} = \frac{\text{Original Cost} - \text{Salvage Value}}{\text{Service Life}}
\]

Deprecation Concepts
Age-Life Methods

- Accelerated depreciation allows higher depreciation early in the equipment life than straight line method
- Sum-of-the-Year’s-digits

\[
\text{Depreciation Expense} = \frac{\# \text{Years Remaining at Beginning of Year}}{\text{Total of the Digits of the Year’s Life}} \times (\text{Original Cost} - \text{Salvage Value})
\]

- Subtract from current value (un-depreciated value)
- Repeat next year

- Double declining balance
  - Double the depreciation rate of straight line
  - Subtract from current value
  - Depreciate remaining balance by straight line

Comparison of Depreciation Approaches

- Straight-Line
- Sum of the Year’s Digits
- Double Declining Balance

<table>
<thead>
<tr>
<th>Cost ($)</th>
<th>Original Cost = $2M</th>
<th>$2M - $100K = $1.9M</th>
<th>$1.8M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salvage Value = $500,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service Life</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (Years)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Comments

- Size of depreciation charge depends on
  - Service Life
  - Salvage value
- Estimating both parameters in advance is difficult
  - Service life must take technological and usage factors into account
  - Actual salvage value depends on costs and prices at the time of decommissioning
- Summarizing
  - Using GAAP the value of an asset is
    - Current Value = Purchase Value – Depreciation
- Can be factored into network design cost depends on organization whether it is or not

Network Design Cost

- Design cost can be determined in various ways depending on situation/application
- Consider cash flows – receipts and disbursements over a given period
Network Design Cost

- **CAPEX vs. OPEX**
  - **CAPEX** – Capital Expenses
    - Land, Building Space, Equipment, Network Deployment cost, Software, spectrum license, etc. (one time cost)
    - Can be depreciated if value at the end of project
    - Networks typically have a high CAPEX Cost
  - **OPEX** – Operating Expenses
    - Power Consumption, operations, maintenance and administration (OA&M) cost, software upgrade, bandwidth, etc. (recurring cost)

- **Service Provider vs. Enterprise**
  - Service Provider - Net Income from project, ARPU (Average Revenue Per User) – Average Cost Per User (ARCU)
  - Enterprise – Direct Cost (CAPEX + OPEX) + Indirect Cost (benefit to business units, improved efficiency, etc)

Project Cash flows

- Cash Flows for a specific project
Network Design Cost

- EBITDA: Earnings before income taxes, depreciation and amortization
- EBIT: Earnings before interests and income taxes

Different Metrics can be used to evaluate Cost
- Payback Time
  - Time need to recoup initial investment
  - Indicates risk: shorter payback time ➔ smaller risk
- ROI - Return on Investment
  - Average future annual cash flow/(initial investment)
- IRR – Internal Rate of Return
  - Rate for which 
    present value of expenses = present value of returns (NPV = 0)
- NPV – Net Present Value
  - Present value of all cash flows in the project (CAPEX, OPEX, Revenue, Taxes, etc) - usually EBITDA or EBIT

Most enterprise/service providers use NPV
NPV

- Comparison of NPV for two projects

Network Design Cost

- Network Cost
  - Project cost usually determined as Net Present Value (NPV) of all cash flows in the project
  - In WANs and metro access networks in addition to equipment cost, link BANDWIDTH is a significant cost
  - Leased Bandwidth is a reoccurring cost (treat like an annuity) – maybe defined in a service level agreement (SLA) – may include tariffs

<table>
<thead>
<tr>
<th>Item</th>
<th>Example Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal router</td>
<td>$2000 purchase price</td>
</tr>
<tr>
<td>Transit router</td>
<td>$3700 purchase price</td>
</tr>
<tr>
<td>WAN adapter</td>
<td>$500 purchase price</td>
</tr>
<tr>
<td>T1 1.544Mbps link</td>
<td>$1000 to hook up + $400/month</td>
</tr>
</tbody>
</table>
Bandwidth Cost/Tariffs

- A Tariff is a published rate used to pay for telecommunications services and facilities cost.
- USA carriers file tariffs with FCC and state regulators (PA PUC)
- See link on class web page for PA

- Types of Links
  - Usage-sensitive
    (fixed cost + variable cost charged per minute or per X bytes)
  - Usage insensitive (leased line)
    (fixed cost + monthly fee)

Usage Sensitive Tariffs

- Typical Usage Sensitive Tariff factors
  1. Access fees (the cost of maintaining a physical network connection) – standing/fixed cost
  2. Setup fees.
  3. Teardown fees.
  4. Usage fees, which depend on
     - channel capacity
     - usage (# phone calls, mean bit rate, peak bit rate, etc.)
     - distance (local, long distance, international)
     - time of day
     - national and administrative borders
     - usually in minutes or bytes
Some data services are based on usage sensitive pricing
   - For example Frame Relay Service
   - Get peak rate and committed information rate (CIR), charged usage fee per mean kbps above CIR
   - London – Manchester, UK,
     - Cable and Wireless 256K link, CIR = 64Kbps
       • Connection $16,393,
       • Rental (yearly) $17,591,
       • Bandwidth charge $ 974 x 1kbps/month
   - Some wireless data services have similar pricing

Leased Line Cost of Link Bandwidth depends on variety of factors
   - Tariffs
   - Service Provider
   - Capacity of link
     • fractional T1, T1, multiple T1, OC1, OC3, etc..
   - Length
   - Technology (Fiber, 3G wireless, etc.)
   - Location
     • NYC-DC cheaper than Asheville, NC – Memphis, TN
   - QoS/Availability/survivability requirements
Leased Line Data Rates

- **U.S. leased line rates**
  - ISDN 56 Kbps; fractional T1, e.g. 128 Kbps, 256 Kbps, 512 Kbps, full T1. and rest of synchronous digital hierarchy (SDH) in Table

- **Europe leased line rates**
  - multiples of 64 Kbps, including half E1 = 1024 Kbps, multiple E1, E3 etc.

- Note with leased line – get *symmetrical* bandwidth allocations
- If go with data service (ATM, Frame Relay, IP/MPLS) can get asymmetrical bandwidth allocations as part of a Service Level Agreement (SLA)

<table>
<thead>
<tr>
<th>Signal name</th>
<th>Bit Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DS0 (voice circuit)</td>
<td>0.64</td>
</tr>
<tr>
<td>T1 (DS-1)</td>
<td>1.54</td>
</tr>
<tr>
<td>E1</td>
<td>2.04</td>
</tr>
<tr>
<td>T3 (DS-3)</td>
<td>45.00</td>
</tr>
<tr>
<td>E3</td>
<td>34.36</td>
</tr>
<tr>
<td>STS-1</td>
<td>51.84</td>
</tr>
<tr>
<td>OC-3/STS-3</td>
<td>155.52</td>
</tr>
<tr>
<td>OC-12/STS-12</td>
<td>622.08</td>
</tr>
<tr>
<td>OC-24/STS-24</td>
<td>2,488.32</td>
</tr>
<tr>
<td>OC-48/STS-48</td>
<td>9,953.28</td>
</tr>
</tbody>
</table>

Leased Line Tariffs

- **U.S. leased line rates**
- Tariff rate very in U.S. with amount of competition – rough approximation fixed cost + linear distance cost, in reality more complicated
- In Europe tariffs are largely regulated and consistent within a country
  - Usage-insensitive data tariff for British Telcom in U.K. in table below
- Software tools exist that incorporate detailed tariff data (e.g., Pricer at http://www.tarifica.com) for analysis

<table>
<thead>
<tr>
<th>Service</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK D64 fixed cost</td>
<td>$274.00/month</td>
</tr>
<tr>
<td>UK D64 cost/km</td>
<td>$0.90/month</td>
</tr>
<tr>
<td>UK E128 fixed cost</td>
<td>$757.00/month</td>
</tr>
<tr>
<td>UK E128 cost/km</td>
<td>$2.40/month</td>
</tr>
<tr>
<td>UK F256 fixed cost</td>
<td>$821.00/month</td>
</tr>
<tr>
<td>UK F256 cost/km</td>
<td>$4.80/month</td>
</tr>
</tbody>
</table>
Linear Distance Based Tariffs

- As noted bandwidth costs are function of a variety of factors.
- In practice use simple linear distance based model to represent cost of service
  - Cost = Fixed cost + distance cost x distance
    - For example, for a 128 Kbps link in the U.K. we can use the approximation of $757.09 + $2.40/km
- If detailed tariff data available can develop linear model by using regression analysis on the tariff table data
- Such an approach often results in a piecewise linear model

Distance Coordinate Systems

- Need to determine distance between sites to estimate cost – two coordinate system approaches
  - Vertical and Horizontal (V&H)
    - a grid of lines defined by AT&T in 1950’s for North America
    - allows for a simplified computation of distances
      - Widely used in Telco industry
  - Latitude and Longitude (L&L)
    - defined for all locations on the surface of the earth.
    - The distance calculation is essentially an exercise in spherical geometry.

C code and formula in book
V&H Coordinate System

Given two cities coordinates \((v_1, h_1), (v_2, h_2)\) find distance \(d\) apart

\[
d = \text{ceil} \left( \sqrt{\left( (v_1 - v_2)^2 + 9 \right) / 10 + \left( (h_1 - h_2)^2 + 9 \right) / 10} \right)
\]

Can approximate by

\[
d = \text{ceil} \left( \sqrt{(v_1 - v_2)^2 / 10 + (h_1 - h_2)^2 / 10} \right)
\]

For example for simple network discussed earlier,

- DC (5622, 1583) – Denver (7501,5899)
  \(=> d = \text{ceil}(\sqrt{353064.1 + 1862785})\)
  \(d = 1489\) miles

- Denver – Dallas \(=> d = 660\) miles
- Dallas – DC \(=> d = 1180\) miles

<table>
<thead>
<tr>
<th>City name</th>
<th>V coordinate</th>
<th>H coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>4997</td>
<td>1406</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>9213</td>
<td>7878</td>
</tr>
<tr>
<td>Chicago</td>
<td>5986</td>
<td>3427</td>
</tr>
<tr>
<td>Dallas</td>
<td>8436</td>
<td>4034</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>5621</td>
<td>2185</td>
</tr>
<tr>
<td>DC</td>
<td>5622</td>
<td>1583</td>
</tr>
<tr>
<td>Seattle</td>
<td>6336</td>
<td>8896</td>
</tr>
<tr>
<td>Miami</td>
<td>8351</td>
<td>0527</td>
</tr>
<tr>
<td>Atlanta</td>
<td>7260</td>
<td>2083</td>
</tr>
<tr>
<td>Boston</td>
<td>4422</td>
<td>1249</td>
</tr>
<tr>
<td>Denver</td>
<td>7501</td>
<td>5899</td>
</tr>
</tbody>
</table>

Latitude and Longitude Coordinate

- Distance \(D\) in degrees between two points X and Y on a sphere with latitude and longitude values \((\text{Lat}_X, \text{Long}_X), (\text{Lat}_Y, \text{Long}_Y)\) found from

\[
\cos(D) = \sin(\text{Lat}_X) \sin(\text{Lat}_Y) + \cos(\text{Long}_X) \cos(\text{Long}_Y) \cos(|\text{Long}_Y - \text{Long}_X|)
\]

- Find \(D\) in degrees by \(D = \cos^{-1}(\cos(D))\)

- Convert to kilometers multiply by 111.23 km/degree

- Example: Paris, France \((48.87^\circ\text{N}, 2.33^\circ\text{E})\),
  Austin, Tx \((30.27^\circ\text{N}, 97.74^\circ\text{W})\)

  \[
  \cos D = [\sin(48.87) \times \sin(30.27)] + [\cos(48.87) \times \cos(30.27) \times \cos(|-97.74 - 2.33|)] = 0.281
  \]

  Distance = \(111.23 \times \cos^{-1}(0.281) = 8,195.44\) km
Simple Network Design Example

- Example - company with offices in Dallas and Vienna, VA,
- Factory in Denver
- Appl A: Sales/inventory control
- Appl B: CAM
- Appl C: CAD
- Appl D: video conference
- Appl E: Intranet Voice

Applications Map

- From Applications Map – get rough idea of traffic flows between network nodes
- Get the beginnings of a traffic demand matrix across the Wide Area Network
- If use Applications Monitoring Approach – gather data on each application
  - A: Mean rate = .1 Mbps, Peak = .15 Mbps
  - C: Mean rate = .5 Mbps, Peak = .75 Mbps
  - D: Mean rate = 2 Mbps, Peak = 2.5 Mbps
Traffic Demand Matrices

- From the application map and associated matrix and the application monitoring data we have the mean traffic demand matrix and peak traffic demand matrix as below.
- Note, if the network monitoring approach is used get traffic demand directly.

<table>
<thead>
<tr>
<th>Mean data rate demands</th>
<th>Dallas</th>
<th>Denver</th>
<th>Vienna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas</td>
<td>.1 Mb</td>
<td>.45 Mb</td>
<td>3.25 Mb</td>
</tr>
<tr>
<td>Denver</td>
<td>.3 Mb</td>
<td>.8 Mb</td>
<td>2.25 Mb</td>
</tr>
<tr>
<td>Vienna</td>
<td>2.5 Mb</td>
<td>1.5 Mb</td>
<td>.3 Mb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak data rate demands</th>
<th>Dallas</th>
<th>Denver</th>
<th>Vienna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas</td>
<td>.15 Mb</td>
<td>.45 Mb</td>
<td>3.25 Mb</td>
</tr>
<tr>
<td>Denver</td>
<td>.8 Mb</td>
<td>1.2 Mb</td>
<td>.3 Mb</td>
</tr>
<tr>
<td>Vienna</td>
<td>2.25 Mb</td>
<td>1.5 Mb</td>
<td>2.5 Mb</td>
</tr>
</tbody>
</table>

Example Network Design

- Consider simple network design based on mean data rates.
- Objective: average link utilization 50% or less at each link.
- Link capacity is purchased in T1 or multiple T1 sizes.
- A logical layer network design solution is a minimum spanning tree (discussed later).
- The demands for each direction per link are given next to the directional arrow.
- In order to size link:
  - pick max demand in either direction
  - double max demand to meet 50% utilization objective
  - Modularize into T1 multiples
- For example Dallas –Vienna Link:
  - Max = 2.8 Mb, double to 5.6 Mb => 4 T1 lines each 1.54 Mbps
  - Similarly Denver –Vienna link is 3 T1 lines
  - Need 7 Total T1 lines
  - Check shows peak demands can be carried.
Example Network Design

- Note many alternate network designs possible
  - A solution is a minimum spanning tree
  - If we root tree and Denver
  - Again to size link
    - pick max demand in either direction
    - double max demand to meet 50% utilization objective
    - Modularize into T1 multiples
  - For example Denver – Vienna Link
    - Max = 4 Mb, double to 8 Mb => \textbf{6 T1} lines each 1.54 Mbps
    - Similarly Denver – Dallas link is \textbf{4 T1 lines}
    - \textbf{Need 10 total T1 lines}
    - Checking shows peak demands can be carried

Example Network Design

- If spanning tree is rooted at Dallas
- The demands for each direction per link are given next to the directional arrow
- Again to size link
  - pick max demand in either direction
  - double max demand to meet 50% utilization objective
  - Modularize into T1 multiples
- For example Dallas – Vienna Link
  - Max = 4 Mb, double to 8 Mb => \textbf{6 T1} lines each 1.54 Mbps
  - Similarly Dallas – Denver link is \textbf{3 T1 lines}
  - \textbf{Need 9 T1 lines Total}
  - Note peak demands can be carried
Example Network Design

- Consider simple network design again – three options
- Assume cost of T1 = $2406.00 + $0.49/mile per month
- Dallas – Vienna Link
  - 4 T1 lines = 4 x(2406 + .49 x 1180) = $11,937
- Similarly Denver – Vienna link is 3 T1 lines
  - Cost = 3*(2406 + .49 x 1489) = $9407
- Total Bandwidth Cost = $21,344 per month
- Similarly Cost of Other Designs
- Denver Root Cost = $29,731
- Dallas Root Cost = $26,093

Summary

- Traffic estimation
  - Important to determine network performance and capacity assignment in design
  - Use of applications maps and surveys to estimate traffic

- Project Costing
  - Need to evaluate design and tradeoffs
    - Net Present Value typically used
    - Tariffs and bandwidth cost an important component
    - Simple Example Design