A Planning Methodology and Cost Models for Designing A Wide Area Network

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Abstract - **The planning and cost-modeling of large-scale computer Wide Area Networks (WANs) are important issues for carrier service providers, Internet Service Providers (ISP), and for large enterprises that use WANs. In this research, we develop several quantitative and business-oriented cost models that define the mathematical relationships needed to derive the cost estimate of a set of current WAN transmission technologies including: digital private lines, Frame Relay, ATM, ADSL, VSAT, and VPN. In addition, the research presents a cost-effective methodology for planning a large scales WAN. Based on the research methodology and cost models, a planning program for constructing a minimum-cost WAN design is developed and a case study is carried out for the design of a Kingdom-wide Saudi WAN.**

The research achievements are expected to be very useful for enterprise WAN designers due to the essential roles of computer networks in maintaining the competitiveness of today's organizations.

Keywords- **WAN cost modeling, WAN design methodology.**

I. INTRODUCTION

A Wide Area Network (WAN) is a data communications network that covers a relatively wide geographical area. WAN often mixes various transmission technologies, and uses transmission facilities provided by common carriers [1]. Building such a network is a overwhelming task due to the large financial investment needed, and the large array of technological and design options to be investigated. In addition, much expertise, up-to-date knowledge and great practical skills are required to construct a design that is fit for purpose, some of which may not be available to the design team. Anther difficulty arises from the fact that there is no standard process for WAN design or for the implementation of WAN internetworks [1, 2]. For all of these, having a cost effective design and good planning for WAN development and implementation are essential.

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This paper is organized as follows: the next section presents our planning and design process for an enterprise WAN. Requirements, definitions, and a case study of Saudi WAN are all presented in Section 3. Section 4 discusses the topological design of the WAN. In Section 5, the WAN transmission technologies and cost models are presented. Planning software and the results are shown in Section 6. Finally, conclusions are presented.

II. THE WAN DESIGN PROCESS

There is no single right way to tackle the Wide Area Network (WAN) design process. The approach in this research is to describe a workable and adequate process that can be applied to a wide range of situations [2,3]. We have defined four major design phases for the project design process, as follows:

- *Phase 1- Definition of requirements:*

  This phase identifies the traffic generated at each network node as well as from remote users, plus traffic across the inter-node links.

- *Phase 2- Topological design:*

  In this phase, once the traffic requirements and services statistics are compiled, and relevant operational and business-related data are identified, the new network topological design is evaluated.

- *Phase 3- Cost analysis:*

  In this phase, an analysis of the network cost is performed, based on an understanding of the network requirements and topology,

- *Phase 4- Final design:*

  Based on cost analysis, the design is completed and the minimum cost network design is selected.

III. WAN APPLICATION REQUIREMENTS

In this section, we discuss how to translate an organization's overall communication traffic needs and desires into quantifiable design criteria. To evaluate the WAN requirements, it is important to realize that in the future WAN will not be just a transport network but also a multifunctional shared resource for various network-based applications [4]. As a result, WAN network requirements are ultimately driven based on the required applications. These applications can be classified in general as follows:

1. Internet services.
2. Transaction processing.
3. Multimedia and real-time voice or video.

For this research, we assumed broad averages of application traffic, as they are analytically convenient. This is followed by identifying the traffic matrix that describes the traffic requirements in terms of Erlang, units which we wish to transmit from a given service location in the network to all other service locations. The steps taken for the traffic analysis are as follows:
Total traffic for any city

$$= C \times \frac{P}{N} \times \frac{CC \times CL}{24} + R \times \frac{P}{N} \times \frac{CR \times RL}{24} \quad (1)$$

Where:
C: Percent of commercial households.
P: No. of inhabitants per city.
N: No. of inhabitants per household.
CC: No. of calls per commercial household per day (24 hours).
CL: Commercial call duration (in hours) per day.
R: Percent of residential households.
CR: No. of calls per residential household per day (24 hours).
RL: Residential call duration (in hours) per day.

The interchange of city traffic between City A and City B is given by:

$$T_{AB} = T_A \times \frac{P_B}{P_T} \quad (2)$$

Where:
T_A: The traffic from City A to all cities.
P_B: The population of City B.
P_T: The total population for all twelve of the case study cities in KSA [5].

IV. Topological Design of the Network

In the topological design phase, we aim toward the optimum topological design for our case study. This objective is achieved by using a 'shortest path' algorithm to build a graph for the subnet [6-7]. Each node of the graph represents a router and each arc of the graph represents a communication line (link). The weight or length of a path is calculated as the sum of the weights of the edges in the path. A path from x to y is the shortest if is there is no path from x to y with a lower weight.

Based on the traffic matrix, and the shortest path, we applied Dijkstra's algorithm to our case study network; the traffic that is carried by the various links of the shortest path network is then estimated. To estimate the required bandwidth, we assumed that each Erlang unit of traffic (LE) is equivalent to w kbps. The required link bandwidth (B) is then calculated by: $B = LE * w$

V. WAN Transmission Technologies and Cost Models

To complete the Wide Area Network (WAN) topological design, we need to select the appropriate transmission technology for each WAN link. Various technologies suitable for of our case study are available from the Saudi Telecom Company (STC), including:

i. Asymmetrical Digital Subscriber Line (ADSL) technology [8].
ii. Digital Data Leased Line technology (DDL).
iii. Asynchronous Transfer Mode (ATM) technology [9, 10].
iv. Frame Relay technology [11].
v. Very Small Aperture Terminals (VSAT) technology [12, 13].
vi. Virtual Private Network (VPN) technology [14].

In what follows, we present various cost models of STC transmission technologies based on STC prices. The general technology model used in our cost study is shown in Figure 1.0. The cost for each technology consists of two components: the access link cost and the permanent virtual circuit (PVC) cost. For each cost component, there is a fixed installation cost and a subscription cost that is paid monthly or quarterly.

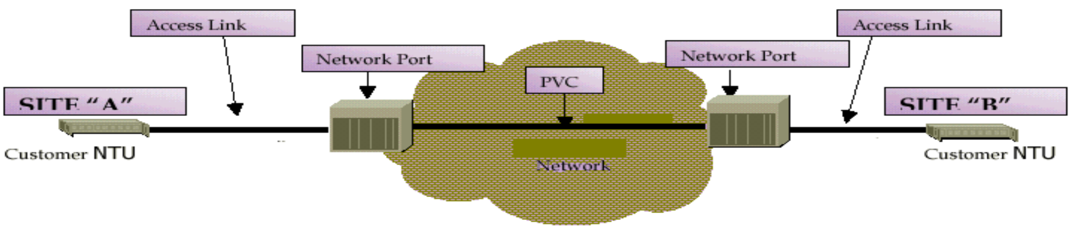

Fig. 1.0 The general technology model used

Based on the STC price list , we developed the following models for the cost of each transmission technology. These models are considered as input for the next design phase where the minimum cost network design is selected.

Digital Data Leased Line (DDL)

The cost of the digital data leased line (DDL) cost is:

$COST_{DDL} = a\ (I_{DDL}\ (rate) + S_{DDL}\ (rate, location, distance) * n$ *(3)*

I_{DDL} is the installation cost
where
I_{DDL} depends on the link bit rate.
S_{DDL} is the subscription cost per month. S_{DDL} depends on the link bit rate and whether the link is local i.e. within a city boundary, or national or international. It also depends on the link distance in kilometers.
a depends on the transmission mode being full duplex, half duplex or simplex.
$a = 1$ half duplex and simplex mode
$= 2$ full duplex mode
n = number of months

Asynchronous Transfer Mode (ATM)

The cost of an ATM link $COST_{ATM}$ is:

$$COST_{ATM} = a\ (IA_{ATM}\ (rate) + SA_{ATM}\ (rate)\ X\ n) + b\ (IC_{ATM} + SC_{ATM}\ (rate, service\ type, location) * n) \quad (4)$$

Where:
IA_{ATM} is the access link installation cost.
IA_{ATM} is a once-only paid cost and depends on the link bit rate.
SA_{ATM} *is* the access link subscription cost per month. SA_{ATM} depends on the link bit rate.
IC_{ATM} is the permanent virtual circuit installation cost. IC_{ATM} is a once-only paid cost.
SC_{ATM} *is* the permanent virtual circuit subscription cost per month. SC_{ATM} depends on the circuit bit rate and service type being CBR, VBR-NRT or UBR service. It also depends on the circuit location being local within a city boundary or national.
a, b depends on the transmission mode being full duplex, half duplex or simplex.
a *= 1 simplex mode, = 2 half duplex and full duplex mode*
b *= 1 simplex mode and Half duplex, = 2 full duplex mode*
n = *number of months*

Asymmetric Digital Subscriber Line (ADSL)

The cost of the asynchronous digital subscriber line $COST_{ADSL}$ is:

$$COST_{ADSL} = a\ (IA_{ADSL} + SA_{ADSL}\ (rate)\ X\ n) + b\ (IC_{ADSL} + SC_{ADSL}\ (rate, service\ type, location) * n) \quad (5)$$

Where:
IA_{ADSL} is the access link installation cost. IA_{ADSL} is a once-only paid cost.
SA_{ADSL} is the access link subscription cost per month. SA_{ADSL} depends on the link bit rate and whether the link is local within a city boundary or national or international. It also depends on the link distance in kilometers.
IC_{ADSL} is the permanent virtual circuit installation cost. IC_{ADSL} is a once-only paid cost.
SC_{ADSL} is the permanent virtual circuit subscription cost per month. SC_{ADSL} depends on the circuit bit rate and service type being VBR-NRT or UBR service.
It also depends on the circuit location being local within a city boundary or national.

a, b depends on the transmission mode being full duplex, half duplex or simplex.
a *= 1 simplex mode, = 2 Half duplex and full duplex mode*
b *= 1 simplex mode and half duplex, = 2 full duplex mode*
n = *number of months*

Frame Relay

The cost of a Frame Relay link $COST_{FR}$ is:

$$COST_{FR} = a\ (IA_{FR}\ (rate) + SA_{FR}\ (rate)\ X\ n) + b\ (IC_{FR} + SC_{FR}\ (rate, service\ type, location) * n) \quad (6)$$

Where:
IA_{FR} is the access link installation cost. IA_{FR} is a once-only paid cost and depends on the link bit rate.
SA_{FR} is the access link subscription cost per month. SA_{FR} depends on the link bit rate .
IC_{FR} is the permanent virtual circuit installation cost. IC_{FR} is a once-only paid cost.
SC_{FR} is the permanent virtual circuit subscription cost per month. SC_{FR} depends on the circuit bit rate and service type being CIR or EIR service.
It also depends on the circuit location being local within a city boundary or national.

a, b depends on the transmission mode being full duplex, half duplex or simplex.
a *= 1 simplex mode, = 2 half duplex and full duplex mode*

***b** = 1 simplex mode and half duplex, = 2 full duplex mode*
***n** = number of months*
The Saudi Telecom Company uses only full duplex for Frame Relay & ATM services.

Virtual Private Network (VPN)

The cost of virtual private network (VPN) link $COST_{VPN}$ is:

$$COST_{VPN} = a\,(I_{VPN}(rate) + S_{VPN}(rate) * n) \quad (7)$$

I_{VPN} is the VPN link installation cost. S_{VPN} is the VPN link subscription cost per month.
***n** = number of months*

VSAT

The two access alternatives solutions for VSATs at STC are: Permanent assigned multiple access (PAMA) and demand assigned multiple access (DAMA).

DAMA LINK COST

The cost of DAMA link $COST_{DAMA}$ is:

$$COST_{DAMA} = (IA_{DAMA} * m + SC_{DAMA} * n * m) + (DS_{DAMA}(rate) * m * t + PS_{DAMA}(rate) * t) \quad (8)$$

Where:
IA_{DAMA} is the access link installation cost per site. IA_{DAMA} is a once-only paid cost.
SC_{DAMA} is the access link service charge cost per site per month.
DS_{DAMA} is the DAMA circuit service usage charge per minute. DS_{DAMA} depends on the link bit rate.
PS_{DAMA} is the public switched terrestrial circuit cost per minute. PS_{DAMA} depends on the link bit rate.
***n** = number of months*
***m** = number of sites*
***t** = number of minutes of usage*

PAMA LINK COST

The cost of PAMA link $COST_{PAMA}$ is:

$$COST_{PAMA} = (IA_{PAMA} * m + SC_{PAMA}(rate, mode) * n * m) \quad (9)$$

Where:
IA_{PAMA} is the access link installation cost per site. IA_{DAMA} is a once-only paid cost.
SC_{PAMA} is the access link service charge cost per site per month. SC_{PAMA} depends on the link bit rate and the transmission mode being simplex or full duplex.
***n** = number of months*
***m** = number of sites*

VI. WAN PLANNING SOFTWARE

In this research, we developed a computer program to implement the WAN cost models in order to determine the optimum (minimum cost) WAN topology of the enterprise network, based on the proposed WAN traffic, enterprise access locations, and various communication technologies.

We have run the program for various values, shown below, and we have made comparisons of the various results as a function of these variables. Some samples of the program outputs are as follows:

For the following input values: N = 7, C = .15, CC = 4, CL = .5, R = .85, CR = 1 and RL = .5, we achieved the results as in Figure 2.

Table 1.0 shows the various costs that are obtained from the planning program.

Fig. 2: Cost vs. technologies for Sample 1

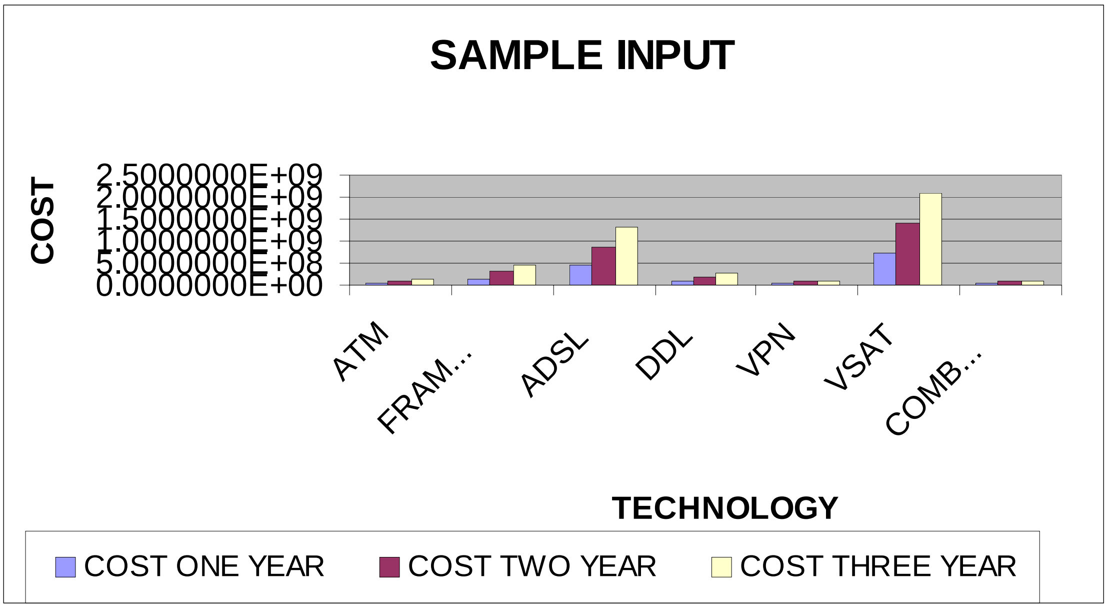

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Table 1: Various cost results from the planning program for the sample inputs

THE MINIMUM COSTS BETWEEN CITIES (LINKS MAY TAKE DIFFERENT TECHNOLOGIES):

FROM	***TO***	***TECHNOLOGY***	***INSTALLATION COST***	***COST- ONE YEAR***	***COST- THREE YEARS***
RIYADH	*DAMMAM*	*ATM*	*8.000E+02*	*1.50560E+06*	*4.51520E+06*
RIYADH	*TAIF*	*VPN*	*9.000E+04*	*5.13000E+06*	*1.52100E+07*
RIYADH	*GASSIM*	*VPN*	*3.740E+04*	*1.84460E+06*	*5.45900E+06*
RIYADH	*ABHA*	*VPN*	*3.000E+04*	*7.86000E+05*	*2.29800E+06*
RIYADH	*NAJRAN*	*ATM*	*1.000E+03*	*3.88600E+05*	*1.16380E+06*
MAKKAH	*JEDDAH*	*VPN*	*6.000E+04*	*3.42000E+06*	*1.01400E+07*
MADINAH	*TABUK*	*VPN*	*3.250E+04*	*8.10100E+05*	*2.36530E+06*
TAIF	*MAKKAH*	*VPN*	*1.200E+05*	*4.99200E+06*	*1.47360E+07*
GASSIM	*MADINAH*	*VPN*	*3.000E+04*	*1.71000E+06*	*5.07000E+06*
GASSIM	*HAIL*	*VPN*	*3.000E+04*	*7.86000E+05*	*2.29800E+06*
ABHA	*JAZAN*	*ATM*	*6.000E+02*	*2.58600E+05*	*7.74600E*
TOTAL MINIMUM COST			*4.32300E+05*	*2.16315E+07*	*6.40299E+07*

THE COST IS SORTED BY MINIMUM COST (LINKS TAKE THE SAME TECHNOLOGY)

SERVICE	***INSTALLATION COST***	***MONTHLY SUBSCRIPTION COST***	***COST - ONE YEAR***	***COST -THREE YEARS***
COMBINED	*4.32300E+05*	*1.76660E+06*	*2.16315E+07*	*6.40299E+07*
VPN	*5.19500E+05*	*1.76940E+06*	*2.17523E+07*	*6.42179E+07*
ATM	*5.80000E+03*	*2.61200E+06*	*3.13498E+07*	*9.40378E+07*
LEASED LINE	*1.04000E+06*	*4.45880E+06*	*5.45456E+07*	*1.61557E+08*
FRAME RELAY	*1.47200E+05*	*6.88920E+06*	*8.28176E+07*	*2.48158E+08*
ADSL	*1.14180E+06*	*1.99902E+07*	*2.41025E+08*	*7.20791E+08*
VSAT	*1.44400E+07*	*3.11532E+07*	*3.88278E+08*	*1.13596E+09*

VII. CONCLUSION

From a financial perspective, this work built quantitative and business-oriented cost models for a WAN design. A planning software for a practical WAN design was developed. Our focus was on the economics of various carrier service options, and on the cost-performance characteristics of various network technologies such as Frame Relay, ATM, ADSL, VSAT, VPN and Digital Leased Line. Our goal was achieved by building a top-down and step-by-step process. This work has also discussed in depth: distance-insensitive tariffs, creating the backbone for a WAN topological design, and the selection of appropriate WAN transmission technologies.

Based on this Saudi case study, the planning and cost-modeling of this research should ease the daunting task of designing a large-scale Saudi WAN, and minimize the required financial investment.

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