A Modular Software System for Planning and Cost Modeling of a Wide Area Network

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***Abstract*— This research presents a modular software system that computes the mathematical relationships needed to evaluate planning and business-oriented models for estimation of the cost of a set of current Wide Area Networks (WAN) transmission technologies. Based on the software modular design, a program for constructing a minimum-cost WAN design is built. In addition, a case study is carried out for the design of a nation -wide 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. Besides, the development of large-scale WANs planning and cost-modeling software are important issues for large enterprises that use WANs, for carrier service providers, and for Internet Service Providers (ISP).

***Index Terms*— WAN modeling software, WAN Planning program, WAN design methodology.**

I. Introduction

A Wide Area Network (WAN) is a network that spans many cities and provides data communication services over a relatively wide geographical area. [1] Building such a network with a mixes of various transmission technologies is a overwhelming task. This is due to the large financial investment needed, and the large array of technological and design options to be evaluated. 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 are many different process for WAN design and for the implementation of WAN internetworks [2, 3]. Thus, having a cost effective design tool and good planning for WAN development and implementation are essential.

This paper is organized as follows: the next section presents an over view of the modular software system for WAN planning and design and its various modules. The requirements definitions module is presented in Section 3. Section 4 discusses the WAN topological design Module. In Section 5, the WAN transmission technologies cost evaluation module is presented. A case study of a national WAN Planning and the implantation results are shown in Section 6. Finally, conclusions are presented.

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II. The WAN Planning Software System

There are several ways to tackle the wide area network design process. The approach in this research is to base the WAN design and planning software on a systemic methodology that provides a workable and adequate process and can be applied to a wide range of situations [4]. We have defined four major design modules for the our software system as shown in figure 1. These are described in what follows:

- *Definition of requirements Module:*

  This module inputs applications requirements, relevant operational and business-related data and network physical topology. Then, it identifies the Erlang traffic generated at each network node as well as cross traffic between nodes, over the WAN inter-node links.

- *Topological design Module:*

  This module uses the requirements and services statistics from the previous module, to generate the shortest path network topological design and links data bandwidth.

- *Cost analysis Module:*

  In this module, an analysis of the network links cost is performed based on an understanding of the network requirements and on the proposed WAN traffic, enterprise access locations, and various available carrier communication technologies. Also, it selects the minimum cost network design.

- *Design Report Module*

  Based on cost analysis, this module generates the statistics of the optimum (minimum cost) WAN design of the enterprise network It displays various output data such as: the shortest path for the network graph (links between WAN cities), No. of channels required between cities, bandwidth matrix between cities, the computed overall WAN minimum cost and the selected link technologies sorted by their costs.

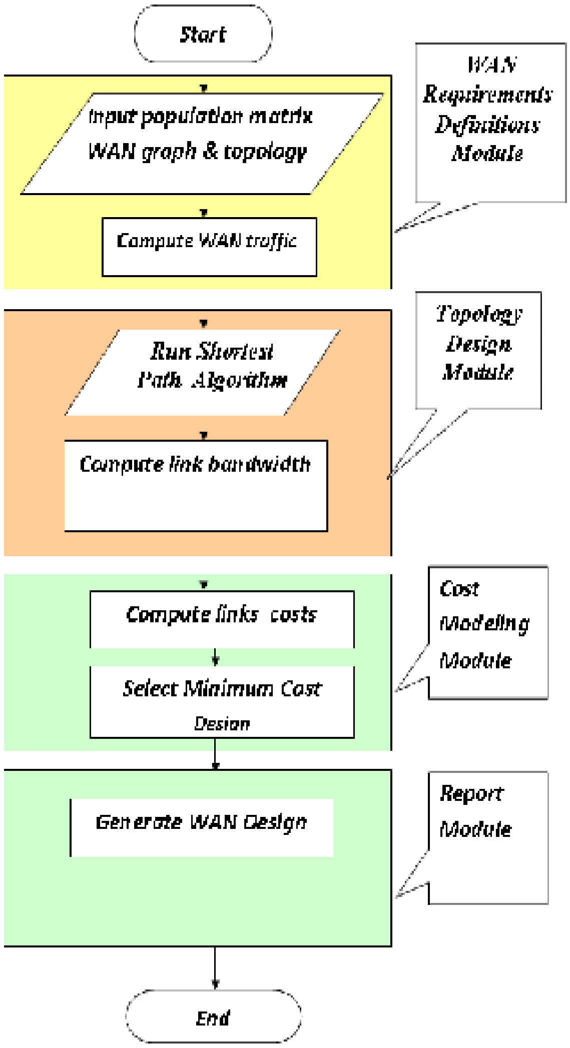

Figure 1 WAN Software System Modules

III REQUIREMENTS DEFINITION MODULE

In this section, we discuss the system requirements definition module (RDM) developed to translate an organization's overall communication traffic needs and desires into quantifiable design criteria. The module basic assumption is that the future WAN will not be just a transport network but also a multifunctional shared resource for various network-based applications [3]. 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.

The RFD uses broad averages of these applications traffics, 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 (node) in the network to all other service locations. The steps taken for the traffic analysis are as follows:

Total traffic (TT) for any city is a function of the following variables:

$TT= F_1(C, P, CC, CL, N) + F_2(R, P, CR, RL.N)$ (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
RL: Residential call duration (in hours) per day.

Service call in Equation (1) can be an Internet session, a business transaction or a multimedia call [5]. The call duration is computed based on the type of service.

The interchange of city traffic between City A and City B is proportional to their population ad 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 cities of the case study.

The cities of the kingdom of Saudi Arabia are used as a case study for this research.

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IV. Topological Design Module

In the topological design module, we aim toward finding 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.

In our case study, Dijkstra's algorithm was applied by this module, to determine the shortest path network topology. Afterwards, based on the traffic matrix, and the shortest path topology; the traffic carried by the various links of the shortest path network is then estimated.

V. Cost Analysis Module

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 evaluated by the cost analysis module of the software system, 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) [14].

The general link technology architecture used in our cost analysis module is shown in Figure 2. The cost for each ink 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.

Based on the national carrier price list, the cost analysis module implements various mathematical relationships developed for the cost of each transmission technology. The details of these relations are given in reference [4]. The computational results of these relations are used as input for the final design module where the minimum cost network design is presented.

In what follows, we give a sample of the implemented relations for VSAT and ATM technologies link costs respectively.

Very Small Aperture Terminal (VSAT)

Recent advances in technology have given a new thrust to the satellite communication industry by deploying low cost very small aperture terminal (VSAT) network for data, voice, and video communication. [12, 13] A VSAT system consists of a satellite transponder, central hub or a master earth station, and remote VSATs. A VSAT is defined as a small earth station with antenna diameter typically less than 1.8m and is suitable for easy installation on customer premises to provide a wide range of WAN telecommunication services with a large hub station or another VSAT. The two access alternatives for VSATs at STC are: Permanent assigned multiple accesses (PAMA) and demand assigned multiple accesses (DAMA). In a PAMA network, VSATs are pre-allocated a designated frequency. PAMA solutions use the satellite resources constantly. On the other hand, in the DAMA network, VSATs are allocated a designated frequency channel based on its demand for service. Equivalent of the terrestrial dial up -line solutions..

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

$$\mathbf{COST_{DAMA} = (IA_{DAMA} * m + SC_{DAMA} * n * m) + (DS_{DAMA}(rate) * m * t + PS_{DAMA}(rate) * t)} \quad (3)$$

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*

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

$$\mathbf{COST_{PAMA} = (IA_{PAMA} * m + SC_{PAMA}(rate, mode) * n * m)} \quad (4)$$

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*

Asynchronous Transfer Mode (ATM)

ATM is a packet switching protocol that encodes data into small fixed-sized cells (cell relay) and provides data link layer services that run over physical links [9,10]. ATM uses a connection-oriented model and establishes a virtual circuit between two endpoints before the actual data exchange begins. A key ATM concept is the traffic contract. When an ATM circuit is set up each switch is informed of the traffic class service of the connection. There are four basic ATM service types namely: CBR - Constant bit rate: a constant Peak Cell Rate (PCR) is specified, VBR - Variable bit rate: an average cell rate is specified, ABR - Available bit rate: a minimum guaranteed rate is specified and UBR - Unspecified bit rate: traffic is allocated to all remaining transmission capacity.
The cost of an ATM link $COST_{ATM}$ is:

$$\mathbf{COST_{ATM}} = a\,(\mathbf{IA}_{ATM}(rate) + \mathbf{SA}_{ATM}(rate)\ X\ n) + b\,(\mathbf{IC}_{ATM} + \mathbf{SC}_{ATM}(\text{rate, service type, location}) * n) \qquad (5)$$

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*

VI. Design Report Module

In this module, the software outputs various results related to the optimum (minimum cost) WAN topology of the enterprise network, based on the estimated WAN traffic, enterprise access locations, and various communication technologies.

The module presents various values, and makes comparisons of the various cost results as a function of the network variables. The cities of the kingdom of Saudi Arabia are used as a case study for this research as shown in figure 3. Some samples of the software system outputs are shown in figure 4 and figure 5, for the following input values: N = 7, C = .15, CC = 1, CL = 5, R = .85, CR = 1 and RL = .5

VII. Conclusion

This research work built a software system that implements quantitative and business-oriented mathematical cost and topology models for a WAN design. 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 modular software system that evaluates distance-insensitive tariffs, creates the WAN topological design, and performs the selection of appropriate WAN transmission technologies. As a case study, the system was applied on the Saudi network, to ease the daunting task of designing a large-scale Saudi WAN, and to minimize its required financial investment.

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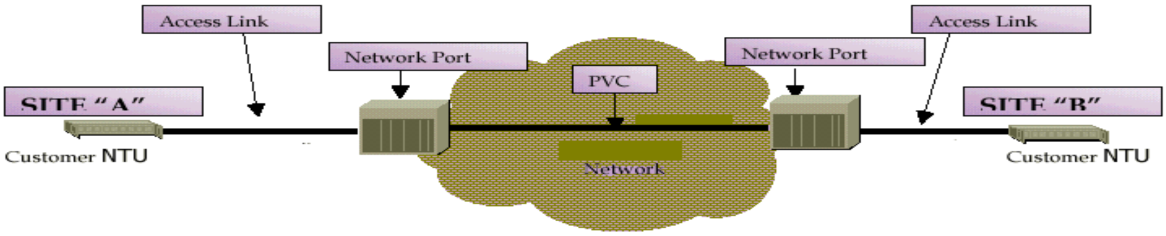

Fig. 2 Technology Architecture

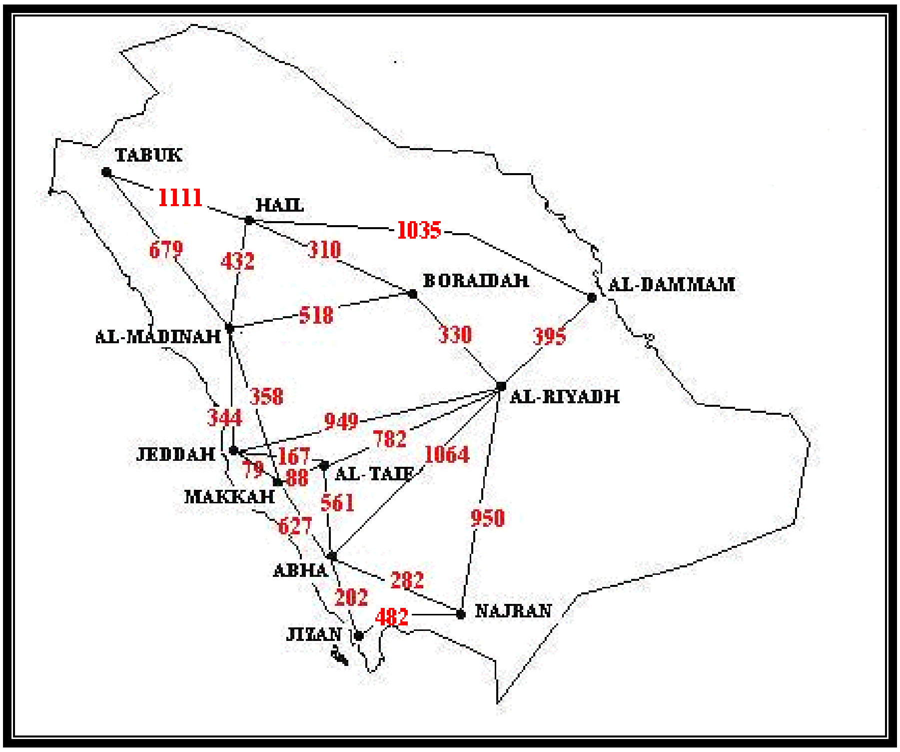

Figure 3 Case Study Cities and Links Map

LINK	TRAFFIC (ERLANG)
RIYADH – TAIF	6751
TAIF – MAKKAH	5869
MAKKAH- JEDDAH	3723
RIYADH – GASSIM	2457
GASSIM – MADINAH	152
RIYADH – DAMMAM	939
GASSIM – HAIL	29
MADINAH – TABUK	120
RIYADH – ABHA	295
RIYADH – NAJRAN	156
ABHA –JAZAN	91

Figure 4 Software system output sample for estimated Link Traffic over shortest Path Network

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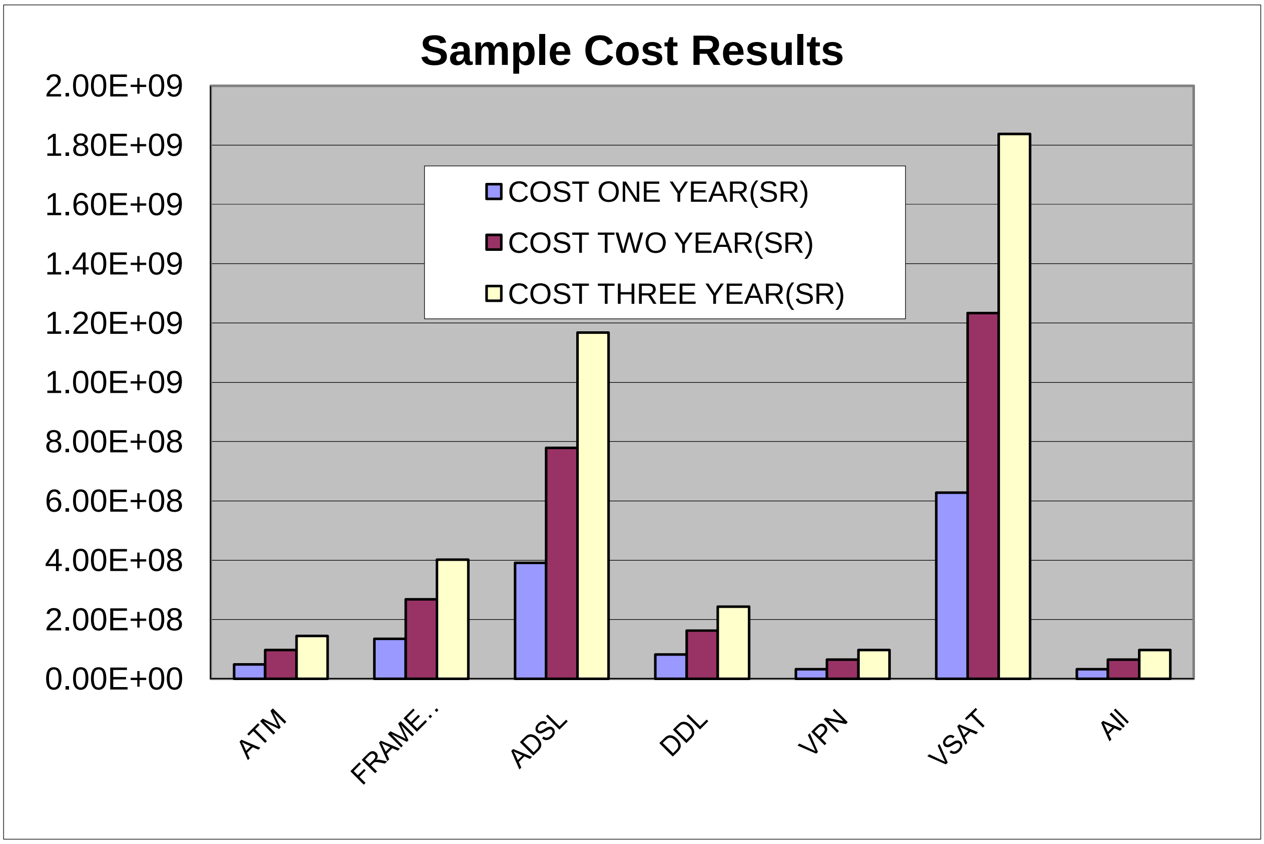

THE MINIMUM COST BETWEEN CITIES: (LINKS MAY TAKE DIFFERENT TECHNOLOGIES)

FROM	TO	TECHNOLOGY	INSTALLATION COST	MONTHLY SUBSCRIPTION COST	MONTHLY COST	COST ONE YEAR	COST TWO YEARS	COST THREE YEARS
RIYADH	DAMMAM	VPN	3.000E+04	1.40000E+05	1.70000E+05	1.71000E+06	3.39000E+06	5.07000E+06
RIYADH	TAIF	VPN	1.500E+05	7.00000E+05	8.50000E+05	8.55000E+06	1.69500E+07	2.53500E+07
RIYADH	GASSIM	VPN	6.000E+04	2.80000E+05	3.40000E+05	3.42000E+06	6.78000E+06	1.01400E+07
RIYADH	ABHA	VPN	3.000E+04	6.30000E+04	9.30000E+04	7.86000E+05	1.54200E+06	2.29800E+06
RIYADH	NAJRAN	VPN	3.330E+04	5.87000E+04	9.20000E+04	7.37700E+05	1.44210E+06	2.14650E+06
MAKKAH	JEDDAH	VPN	1.385E+05	4.36700E+05	5.75200E+05	5.37890E+06	1.06193E+07	1.58597E+07
MADINAH	TABUK	VPN	6.000E+04	1.26000E+05	1.86000E+05	1.57200E+06	3.08400E+06	4.59600E+06
TAIF	MAKKAH	VPN	1.200E+05	5.60000E+05	6.80000E+05	6.84000E+06	1.35600E+07	2.02800E+07
GASSIM	MADINAH	VPN	6.000E+04	2.03000E+05	2.63000E+05	2.49600E+06	4.93200E+06	7.36800E+06
GASSIM	HAIL	VPN	3.000E+04	6.30000E+04	9.30000E+04	7.86000E+05	1.54200E+06	2.29800E+06
ABHA	JAZAN	ATM	1.000E+03	3.23000E+04	3.33000E+04	3.88600E+05	7.76200E+05	1.16380E+06
TOTAL MINIMUM COST			7.12800E+05	2.66270E+06	3.37550E+06	3.26652E+07	6.46176E+07	9.65700E+07

Fig. 5: Software system output sample for Cost vs. technologies

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