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Analysis, Modeling, and Design of a Reliable Wide Area Network Case Study for Tikrit University Intranet

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ABSTRACT

This work presents the analysis and modeling of communication network used for data transmission with multi-protocols in campus network. The designed network is based on the geographical location of communication nodes. (Colleges and centers). Network optimal backbone is first designed by Kruskal algorithm. It will be subject to reliability improvement by links addition. Tie-sets method is used to evaluate the network reliability. Communication nodes are modeled using local area network (LAN), server, links, router, switch, and Firewall. Intranet will be used as communication backbone mainly to connect different communication nodes with the Principal Communication Center (PCC) where the System Server (SS) is located. The connection of Intranet to the Internet is mad via the front-end system server (SS). Tikrit University Intranet (TUI) is taking as case study in the present research. Tikrit University sites are grouped into master communication nodes. Each node is composed from several colleges, centers, and administrative sections.

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تحليل، نمذجة، وتصميم شبكة واسعة المساحة ذات موثوقية عالية دراسة لحالة شبكة الانترانت لجامعة تكريت

الخلاصة

يقوم هذا العمل بتحليل ونمذجة شبكة الاتصالات المستخدمة لنقل البيانات مع بروتوكولات متعددة في شبكة الحرم الجامعي .وتستند الشبكة المصممة على الموقع الجغرافي لعقد الاتصالات (الكليات والمراكز). تم تصميم العمود الفقري لشبكة الاتصالات باستخدام خوارزمية كروسكال .وسوف تخضع الشبكة بعد ذلك لتحسن الموثوقية عن طريق إضافة وصلات. تم نمذجة العقد الاتصالات باستخدام شبكة المنطقة المحلية (LAN)، الخادم، وصلات، جهاز التوجيه، التبديل، وجدار الحماية .سيتم استخدام الشبكة الداخلية باعتبارها العمود الفقري الاتصالات أساسا لتوصيل العقد التواصل المختلفة مع مركز الاتصالات الرئيسي (PCC) حيث يقع ملقم النظام (SS). اتصال الإنترانت بالإنترنت عن طريق خادم النظام الرئيسي (SS). تم دراسة الحالة الخاصة لشبكة الانترانت لجامعة تكريت. تم تصميم الشبكة باعتبار الجامعة مكونة من عدة عقد اتصالات رئيسية تحتوي كل واحدة منها على عدة عقد ثانوية.

1. INTRODUCTION

As data communication enters the new century, powerful driving forces, new functions are compelling with new Internet protocols to make dramatic changes in their infrastructure. Most networks are built to accommodate the needs of a single organization or group. Internetworking is a technology that accommodates multiple, diverse, underlying hardware by providing the means of interconnecting heterogeneous networks [1].

A Wide Area Network (WAN) generally covers a large geographical area, and consists of a number of interconnected switching nodes. WANs are now an essential part of most companies computing infrastructures. WANs directly connect smaller branch offices with headquarters, enabling them to perform big-office tasks. The ability to design and simulation of WANs enhances the design of computer networks concepts.

The aim of this work is to develop an analysis procedure based on the design of reliable communication network step by step. This design procedure fit perfectly

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with the design of any Intranet or more generally any WANs.

Two main modules are presented in this paper. The first is the analysis and design of a reliable communication network module. Kruskal algorithm is used for the design of communication backbone [2]. Addition of redundant links is made to increase network reliability, which is calculated using tie-sets method used for its simplicity and accuracy for small networks [3]. The second module concerns the modeling of communication nodes.

Intranet demands better quality of services (QoS) in computer communication networks. Two of the most commonly used QoS metrics are: network flow and network reliability [4]. In network flow, typically capacity/ bandwidth is computed between an (*s*, *t*) node pair in the network. On the other hand, network reliability metric calculates the probability that the system operates successfully under certain environmental conditions [5]. Failure probability of a system (in general) considering random variables at the input is the key principal of reliability analysis [6]. Many reliability evaluation measures for communication networks exist as State Space Enumeration method [7], Graph Reduction Technique [8], Tie- Sets [3], Cut-Sets [9], genetic algorithms [10], and Monte Carlo [11]. In this work backbone and improved network reliability is calculated using tie set method.

Tikrit University Intranet (TUI) is taking as case study in the present research. TUI covers the entire Tikrit university campus using mesh networking technology. This network will provide access to Web pages, Email, course materials, and library resources for users across Tikrit University, using desktops, mobile laptops, or smart phones.

Tikrit University is one of the largest public universities in Iraq, and is located over three main campuses. The major campus, Al-Qadisya, has over (18000) students studying in (20) colleges, spanning an area of about $15\ \mathrm{km}^2$. Tikrit University is currently without any network connectivity, and with old, communication infrastructure.

This paper is organized as follows. Second section is the study of nodes modeling and network representation by graph theory. The modeling, configuration and selection of equipment to be deployed to ensure maximum network performance are achieved. In section three, a reliability study is conducted to design a fully reliable network based on real locations of main activities (colleges and centers). In each section the case of TUI is outlined. Finally, a brief conclusion is given in section five.

2. COMMUNICATION NETWORK MODEL

2.1. Problem Definition and Modeling

Computer networks can be modeled by a graphical representation. A graph represents a connected communication network with (n) nodes (or vertices), and (l) Links (or edges). p_i, is the probability that a node (i) is up. Implementing nodes with redundant materials will make the probability $p_i = 1$ (perfect nodes). p_{ik} represents the probability that the link between node (i) and node (k) is up. Different links can have equal of different probabilities based on used materials (links types and fabrication methods). The graph G = (N, L), where *N* is a set of nodes, and L is a set of directed links [3].

Network topology is related directly to the geographical spreading of activities and building. For the case study of TUI, colleges and centers located closely, will be part of the same communication node.

Colleges, research centers, and administrative buildings in the major campus Al-Qadisya can be distributed geographically into (8) master communication nodes as shown in table 1. PCC is located in node (1) near the presidency of the University building. The two remaining campus outside Al-Qadisya can be connected to TUI by satellite or fiber optical link and they are out of focus of the present work. Each master node consists of many smaller nodes included inside (sub-node). For example, node (3) is located in the college of Engineering site. College of Computer and Mathematics, Internal housing for female students, restaurants complex and college of Engineering are part of this node (3).

The graphical representation of communication network is accomplished via matrix notation. The distance matrix A is a $(n \times n)$ matrix, where each element (a_{ik}) represents the distance between node (*i*) and node (*k*) in the network. Diagonal elements are equal to zero $(a_{ii} = 0)$. For the case study of TUI, A is given in (1) where element are distances in km. The distance matrix is in fact the cost matrix because link cost is logically related to the distance between the terminating nodes.

Table 1
Nodes geographical locations.

Node	Location of the master node
1	Presidency of the university
2	College of education
3	College of engineering
4	College of science
5	College of law
6	College of dentistry
7	College of agriculture
8	College of petroleum engineering

$$A=\begin{bmatrix} 0.0 & 0.4 & 0.4 & 1.1 & 1.5 & 1.7 & 2.5 & 2.9 \\ 0.4 & 0.0 & 0.8 & 1.5 & 1.9 & 2.1 & 2.9 & 3.3 \\ 0.4 & 0.8 & 0.0 & 0.7 & 1.1 & 1.3 & 2.1 & 2.5 \\ 1.1 & 1.5 & 0.7 & 0.0 & 0.4 & 0.6 & 1.4 & 1.8 \\ 1.5 & 1.9 & 1.1 & 0.4 & 0.0 & 0.2 & 1.0 & 1.4 \\ 1.7 & 2.1 & 1.3 & 0.6 & 0.2 & 0.0 & 0.8 & 1.2 \\ 2.5 & 2.9 & 2.1 & 1.4 & 1.0 & 0.8 & 0.0 & 0.4 \\ 2.9 & 3.3 & 2.5 & 1.8 & 1.4 & 1.2 & 0.4 & 0.0 \end{bmatrix} \quad (1)$$

Matrix P $(n \times n)$ is the connectivity matrix where element (p_{ik}) are the probabilities of links (up), and can have three possible ranges of values:

$$P\begin{cases} 0\ if\ no\ link\ between\ (i) and\ (k) \\ p_{ik}\ if\ \ link\ between\ (i) and\ (k) \\ 1\ for\ the\ diagonal\ elements \end{cases} \quad (2)$$

Indeed, the diagonal elements represent the probability of nodes considered as perfect in this work. If no link between two nodes, this implies a null probability.

2.2. Master Nodes Model

The localization of master nodes depends on the geographical location and expected load from each unit. Generally, activities located nearby are part of one master node. In the case study of TUI, each master communication node is composed by several sub-nodes. Sub-node is the network of one administrative or scientific unit (college, scientific center, or administrative section). Fig. 1 shows the internal design of master node number (3) located in the college of Engineering. Four sub-nodes are present. (3-1) represents the sub-node of College of Engineering. (3-2) is the sub-node of college of Computer and athematic. The internal housing for female student's sub-node is given in (3-3). Finally, the sub-node representing restaurants complex is given in (3-4). Each sub-node is built by many Ethernets, one for each department. The number of Ethernet depends on the departments or sections number in each college or unit. For example, the sub-node of college of Engineering (3-1) must comprised (6) Ethernets representing one Ethernet for each department plus the administrative Ethernet in the deanship. In this research an average of four (4) Ethernets is considered for each sub-node.

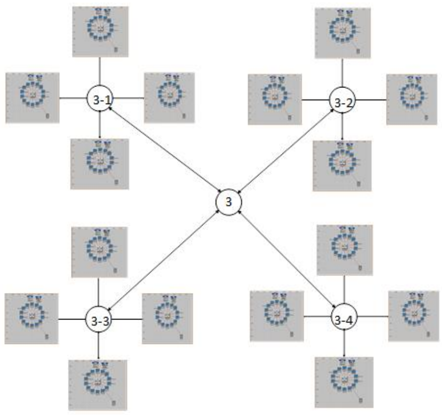


Fig. 1. Master node 3, located at college of engineering.

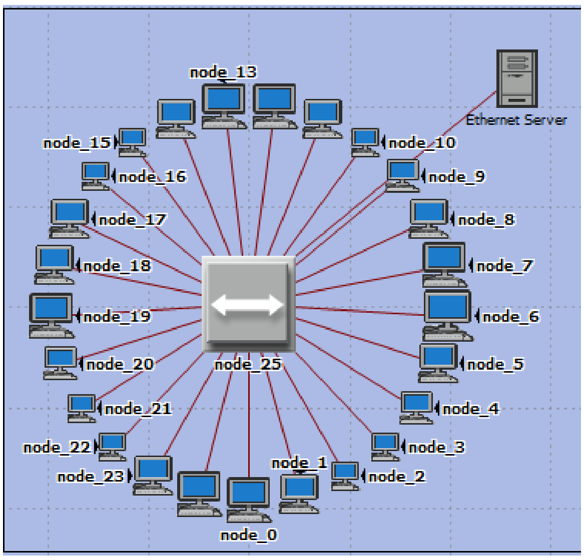


Fig. 2. One Ethernet design.

Ethernets are designed with a local server as in the Fig. 2**.** Local servers are connected via switch to build one sub-node. Sub-nodes are connected together via switches to build the master node. A master node server is connected to the TUI using a router. Each master node can be a standalone network or part of TUI. The connectivity is made only server-to-server. This design procedure is a very important for security matter by providing firewall in Demilitarized Zone (DMZ) for each master node.

3. BACKBONE DESIGN AND RELIABILITY STUDY

3.1. Backbone Design

A connected graph with the smallest number of arcs is a spanning tree. In general, a complete network (all edges possible) with n nodes will have n^{n-2} spanning trees, each with $e_s = (n-1)$ edges (arcs).

The length matrix (A) gives the length of each possible links in the network. To find the network backbone which is the best spanning tree a procedure based on Kruskal algorithm is developed [12]:

1- Create a forest F (a set of trees), where each node in the graph is a separate tree
2- Create a set S containing all the edges in the graph represented by matrix A as in the Table 2.
3- list links in increasing order
4- While S is nonempty and F is not yet spanning:
- Remove an edge with minimum weight from S, for all (i,k), minimum value of a_{ik}
- If that edge connects two different trees, then add it to the forest, combining two trees into a single tree
- Otherwise discard that edge.

At the termination of the algorithm, the forest forms a minimum spanning forest of the graph. If the graph is connected, the forest has a single component and forms a minimum spanning tree.

After application of Kruskal algorithm based on matrix A given in (1) of TUI, the best spanning tree is found (backbone) with 7 edges as in the Table 2. Fig. 3 shows the connected backbone topology.

3.2. Reliability Improvement

To improve the reliability of TUI, new links must be added to the basic communication backbone. A wired strategy is adapted for the TUI in the major campus instead of wireless for technical and economical raisons. The designed communication network can be used for additional purposes out of the scope of this paper like CCTV and other supporting services.

Addition of new link to the backbone such that each node must have at least 2 links connected to it to have an alternate route in case of failure of link connected to it. Many candidate improved topologies are proposed. The choice of best topology is made based on the reliability of the network as major factor of QoS, and the cost which is related to the distance of added links. Fig. 3 shows that there are two singular nodes (node 2 and node 8) have only single connection each one. The added links must be connected to these nodes to resolve the problem of single connection. Three logical candidate topologies are proposed in Fig. 4.

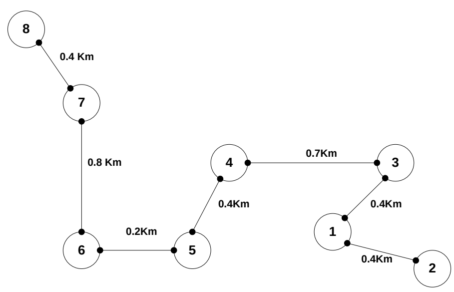
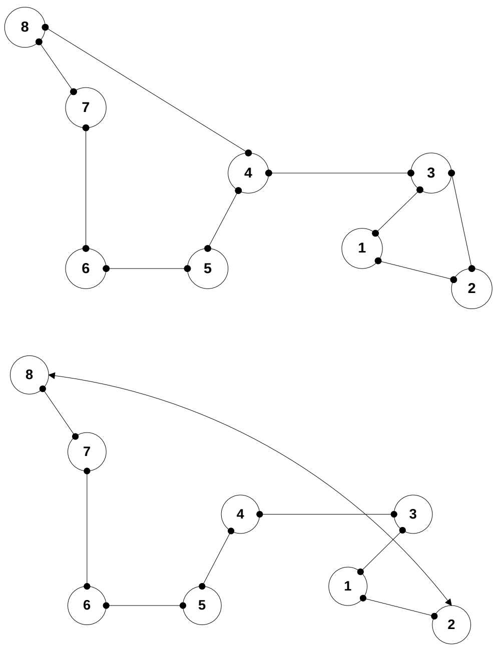
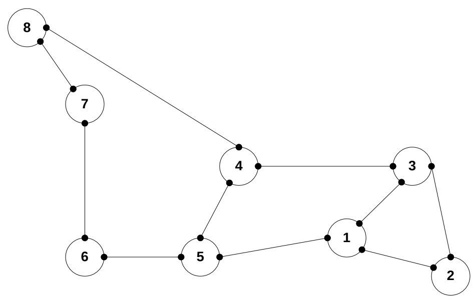


Fig. 3. Communication backbone of TUI.



4-1: Topology T_1, 4-2: Topology T_2



4-3: Topology T_3

Fig. 4. Candidate topologies.

$X_2 = l_{84}, l_{43}, l_{32}, l_{21}$

$X_3 = l_{87}, l_{76}, l_{65}, l_{54}, l_{43}, l_{31}$

$X_4 = l_{87}, l_{76}, l_{65}, l_{54}, l_{43}, l_{32}, l_{21}$

Table 2
Kruskal Algorithm table.

S: All edges of TUI	F: the forest
$a_{56} = 0.2,$	
$a_{12} = a_{13} = a_{45} = a_{78} = 0.4,$	
$a_{46} = 0.6,$	
$a_{34} = 0.7,$	
$a_{23} = a_{67} = 0.8,$	$L_1 = 5 - 6$
$a_{57} = 1,$	$L_2 = 1 - 2$
$a_{14} = a_{35} = 1.1,$	$L_3 = 1 - 3$
$a_{68} = 1.2,$	$L_4 = 4 - 5$
$a_{36} = 1.3,$	$L_5 = 7 - 8$
$a_{47} = a_{58} = 1.4,$	$L_6 = 3 - 4$
$a_{15} = a_{24} = 1.5,$	$L_7 = 6 - 7$
$a_{16} = 1.7,$	
$a_{48} = 1.8,$	7- edges only
$a_{25} = 1.9,$	
$a_{26} = a_{37} = 2.1,$	
$a_{17} = a_{38} = 2.5,$	
$a_{18} = a_{27} = 2.9,$	
$a_{28} = 3.3,$	

where, l_{ik}, is the link between node (n_i) and node (n_k), replaced in the calculation by the corresponding link probability given in matrix C. for simplification suppose that all links with same probability $p = 0.9$ then Eq. (3) yields:

$$R_{81} = P(X_1 + X_2 + X_3 + X_4)$$

$$R_{81} = P(X_1) + P(X_2) + P(X_3) + P(X_4) - \{P(X_1X_2) + P(X_1X_3) + P(X_1X_4) + P(X_2X_3) + P(X_2X_4) + P(X_3X_4)\} + \{P(X_1X_2X_3) + P(X_1X_2X_4) + P(X_1X_3X_4) + P(X_2X_3X_4)\} - \{P(X_1X_2X_3X_4)\}$$

Using tie set method, the two terminals reliability is calculated for each pair of nodes given that the destination node is always (n_1). This is justified by the fact that the

where $P(X_iX_k)$, is the joint probability of tie set X_i, and X_k.

$$R_{81} = p^3 + p^4 + p^6 + p^7 - \{p^5 + p^7 + p^9 + p^9 + p^8 + p^8\} + \{p^9 + p^9 + p^9 + p^9\} - p^9$$

PCC is located in node (n_1). For every candidate topology, the average reliability is calculated as a mean of comparison as indicated at the end of Table 3.

Tie set method is based first on finding the groups of edges that form a minimum path between the source node (n_s) and the destination (n_d). The term minimal implies that no node or edge is traversed more than once (loop free). If there are (m) tie sets between (n_s) and (n_d), then the reliability is given by the expansion of (3) with respect to probability theory [13]:

$$R_{st} = P(X_1 + X_2 + \dots + X_m) \tag{3}$$

where X_i is the tie set number (i).

For example, the reliability R_{81} between node n_8 and n_1 (commodity 8-1) is calculated based on available tie sets for each topology. Topology T_1 gives 4 tie sets for this commodity as:

$X_1 = l_{84}, l_{43}, l_{31}$

$R_{81} = 0.8525.$

Table 3
Network reliabilities and costs.

Commodity	T1 reliability	T2 reliability	T3 reliability
2-1	0.9810	0.9478	0.9493
3-1	0.9810	0.9478	0.9571
4-1	0.8829	0.9110	0.9847
5-1	0.8525	0.8890	0.9853
6-1	0.8374	0.8817	0.9973
7-1	0.8374	0.8890	0.9845
8-1	0.8525	0.9110	0.9501
Average	0.8892	0.9110	0.9726
Additional cost in km	2.6	3.3	4.1

For the case study of TUI the application of (3) is repeated for all 8 commodities, and for each topology (T_1,T_2, and T_3). Table 3 summarizes results concerning the average reliability and the additional costs introduced by the improvement of the original topology (backbone). Additional costs are found by matrix (1).

Table 3 shows that T_3 is better in reliability (0.9726) but with a higher cost than the other two topologies. T_3 seems to be the best compromise between higher reliability with acceptable cost. In the three cases we have an improvement in reliability comparing to the backbone reliability which is equal to (0.731) for the commodity with destination n_1.

4. CONCLUSIONS

Four steps must be followed to ensure optimal solution for a communication network. Technical specifications, design, simulation, and implementation. The present research focused into the design procedure which is based on the specifications. Simulation scenarios must be employed to validate expected results before implementation of real network. The procedures formulated previously contribute to the design of reliable networks which can be used as background for any computer network or communication system. Results collected are based on a real case study but can be used for any similar network.

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