RELIABILITY AND COST ANALYSES OF THE HYPERCUBE AND MESH COMMUNICATION DESIGNS IN SUPPLY CHAIN MANAGEMENT SYSTEMS BETWEEN COLLABORATORS

Suresh Chalasani, University of Wisconsin-Parkside, chalasan@uwp.edu
Marwan Wafa, University of Wisconsin-Parkside, wafa@uwp.edu

ABSTRACT

Global competition and technological innovation have been key drivers for change in how organizations do business. The implementation of Supply chain management systems (SCMs) based on business-to-business (B2B) electronic commerce have been tested by corporations such as Cisco and Seven Eleven Japan. Although hardware/software architectures for such implementations are widely studied, there has been little research on enhancing the reliability of the supply chain management systems. This study evaluates two topologies for reliable communications between collaborators in an SCM system.

Keywords: Supply chain management systems, Reliability Analysis, B2B Systems, Mesh designs, Hypercubes

INTRODUCTION

The real challenge facing businesses in their quest to become web-enabled is not building a web-store, but creating an efficient, responsive supply chain linking customers, suppliers, factories, distributors, and other trading partners. The success of a company's e-business strategy can be measured by the effectiveness with which the company delivers high quality and customized products in the shortest possible time and at the lowest cost. In recent years, several companies have implemented one form of supply chain management (SCM) or another. Examples of e-businesses include Cisco systems, Seven Eleven Japan, Dell, Wal-Mart and Motorola (11, 14, 15, 16).

In this paper, the technological aspects of supply-chain integration into the business-to-business (B2B) e-commerce systems are discussed. Specifically, the information system architecture required for successful supply-chain management systems is analyzed. Although supply chain management systems are being implemented, no studies have yet been conducted to investigate the reliability of the SCM systems (12, 16). Reliability studies are crucial in facilitating smooth operations for any system by reducing or eliminating outages (3, 4). Two models for designing Virtual Private Networks (VPN) are introduced. The two conceptual designs for networks connecting the collaborators in an SCM system are the hypercube and the mesh communication designs. A cost and reliability comparison between these two models is presented.

WHAT ARE THE FUNDAMENTALS OF SUPPLY CHAIN?

A supply chain is a network of collaborating partners who collectively engage in activities such as procurement and transformation of materials into products, and distribution of products to customers. Figure 1 shows a supply chain with two suppliers, one manufacturer and two distributors servicing customers. The widespread use of the Internet has prompted companies to manage their supply chains using the Internet as the enabling technology resulting in improved supply chains that are managed collaboratively by the partners in the chain. Internet supply chains can reduce the overall cost of managing the supply chains, thus allowing the partnering companies to spend more dollars and effort on innovative research and product development.

Internet supply chains also allow smaller companies to compete well without massive physical infrastructures.

In this paper, we focus on the communication and reliability aspects of B2B supply chain management systems. In recent years, other research studies have been conducted on the design of supply chain management systems (12, 16, 9, 10, 20). Also, security aspects of supply chain management systems have been addressed by academic researchers (5, 19) as well as industrial leaders via products such as SiteMinder (17). Software architectures for building e-commerce systems and SCM systems have been developed by other researchers (6). However, very little research has been conducted on the communication topology designs between collaborating partners in an SCM system. In this paper, we propose the use of hypercube and mesh designs for connecting partners in an SCM system and study the reliability and cost aspects of these designs. It is estimated that the Internet traffic is growing at a rate of 15% to 25% every 6 months (13). If this trend continues at the same rate in the future, SCM systems without robust communication designs may not be able to operate without significant failures. Hence the need for designing robust communication structures for SCM systems.

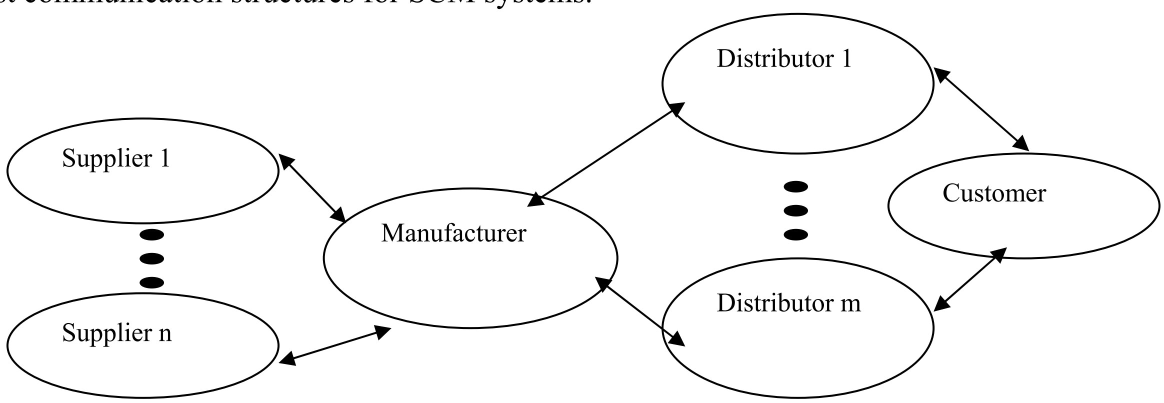

Figure 1: Collaboration between suppliers, manufacturer, distributors and the customer in an SCM system.

DESIGNS FOR COLLABORATION BETWEEN TRADING PARTNERS IN AN SCM SYSTEM

For the purpose of this paper, we refer to each collaborator (i.e. supplier, manufacturer, and distributor) in the SCM system as a node. An SCM system comprises of several nodes, some of which are supplier nodes, some are manufacturer nodes and some others are distributor nodes. These different nodes are often connected together via a secure Virtual Private Network (VPN). Providers such as Sprint (18) or Avaya Communications (2) offer Virtual Private Networks to companies.

This paper proposes designs for configuring the VPNs for SCM systems with the objective of enhancing reliability of the VPN system. This is achieved by increasing the ability of the system to maintain communication between different nodes even when failures occur. There are two models for designing Virtual Private Networks (VPN): the hypercube and the mesh. A cost and reliability comparison between these two models is presented.

HYPERCUBE DESIGN FOR SCM SYSTEMS

In the hypercube design, each node is either a trading partner (a collaborator) or a network component (such as router). A hypercube consists of $P = 2^p$ nodes. Each node is given a unique number from 0 to $(2^p - 1)$. Each node is assigned a unique p-bit binary number. For example, in a hypercube with P=8 nodes, nodes are numbered from 0 to 7. The 8 nodes are numbered as 000, 001, 010, 011, 100, 101, 110, 111.

Definition 1: In the hypercube design of SCM systems, two nodes are connected by a link if and only if their binary numbers differ in exactly 1 bit.

Example: An 8-node hypercube is shown below. Node 000 is connected by a link to nodes 001, 010 and 100. In this example, there are two suppliers S1, and S2 as shown in Figure 2. These two suppliers are at nodes 0 and 6, while the two manufacturers M1 and M2 are at nodes 5 and 2. Table 1 shows the distinct communication paths available between the suppliers and manufacturers. Between supplier Si and manufacturer Mj, we only consider those communication paths that do not involve other suppliers and manufacturers.

Definition 2: Two paths in a hypercube are said to be distinct as long as they differ in at least one node.

Proposition 1: The minimum distance between nodes X and Y in a hypercube with $P = 2^p$ nodes is the number of bits that differ between X and Y.

Proof: Proof omitted due to space constraints.

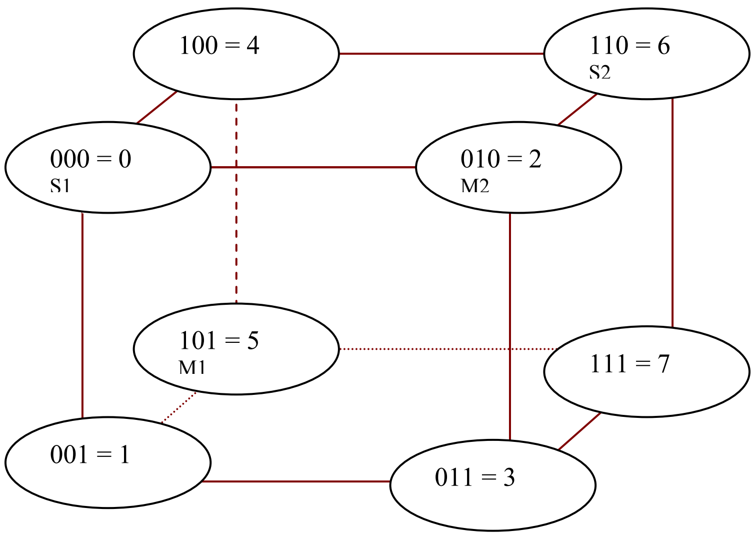

Figure 2: An 8-Node Hypercube System with Two Suppliers (S1, S2) and Two Manufacturers (M1, M2)

Proposition 2: There are n distinct paths between any two given nodes X and Y in a hypercube with $N = 2^n$ nodes.

Proof: Proof omitted due to space constraints.

Table 1: Distinct paths between suppliers S1 and S2 and manufacturers M1 and M2

Supplier Manufacturer Pair	Distinct Paths
S1 to M1	(S1) 0 → 4 → 5 (M1) (S1) 0 → 1 → 5 (M1)
S1 to M2	(S1) 0 → 2 (M2) (S1) 0 → 1 → 3 → 2 (M2)
S2 to M2	(S2) 6 → 2 (M2) (S1) 6 → 7 → 3 → 2 (M2)
S2 to M1	(S2) 6 → 4 → 5 (M1) (S2) 6 → 7 → 5 (M1)

Proposition 3: If there are $P = 2^p$ collaborating partners in an SCM system, it is possible to place these $P = 2^p$ collaborating partners in a hypercube with $2^{(p+1)}$ nodes so that at least p distinct paths exist between any supplier and manufacturer pair with the following properties:

- these distinct paths between a supplier Si and manufacturer Mj do not involve any other supplier or manufacturer, and

- any pair of distinct paths overlap in at most two nodes (other than the nodes Si and Mj).

Proof: Omitted due to space constraints.

Based on proposition 3, we infer that hypercube design provides a robust structure for secure and reliable communication between suppliers and manufacturers. If each link in the hypercube has a bandwidth of B and the price for each bandwidth unit is Q, then the total cost of implementing a virtual private network VPN with the hypercube structure for $P = 2^p$ collaborating partners in an SCM system is computed as follows:

Total cost = Total number of links * B * Q = $(p+1) * 2^p * B * Q$

Where: B = Bandwidth, Q = Cost of leasing the Bandwidth, and
P ($=2^p$) Number of collaborators in the SCM system.

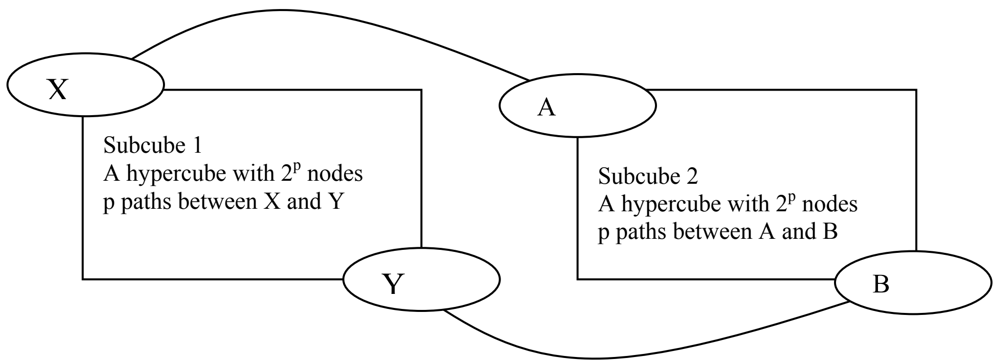

Figure 4: Distinct Paths Between Nodes X and Y in a $2^{(p+1)}$ Node Hypercube

Example: If there are 16 suppliers and manufacturers, we will need a hypercube with 32 nodes (i.e. 2*16). In this hypercube, there are 16*5 = 80 links. Suppose the bandwidth required on each link is 50 Mb/sec. If it costs $100/month for a bandwidth of 10 Mb/sec on each link, total cost of this Virtual Private Network (VPN) is equals 80 * $100 * 5 = $40,000/month.

Definition 3: For the purposes of this paper, we define the reliability of a VPN design for the SCM system to be the maximum number of distinct path failures that can be tolerated between a supplier Si and a manufacturer Mj before the communication breaks down between Si and Mj.

Proposition 4: The reliability of the SCM system with $P = 2^p$ collaborating partners in a hypercube VPNwith $2^{(p+1)}$ nodes is p.

Proof: From proposition 3, it follows that there are p distinct paths between any pair of collaborating partners in a hypercube VPN with with $2^{(p+1)}$ nodes. All these p paths should fail before communication between the pair breaks down completely. Hence, from definition 3, the reliability of the hypercube design is p.

Example: If there are $16= 2^4$ suppliers and manufacturers, we will need a hypercube with 32 nodes (i.e. 2*16). In this hypercube, the reliability is 4 because there are four distinct paths between any supplier-manufacturer pair.

MESH DESIGN FOR SCM SYSTEMS

In the mesh design, each node is either a trading partner (a collaborator) or a network component (such as router). A mesh design consists of PxP nodes arranged in a square array. Each node is given a unique number from 0 to P^2-1. Each node is assigned a unique two-dimensional number (a, b). For example, in a mesh with P=16 nodes, nodes are numbered from 0 to 15.

Each node is also given a unique two-dimensional address ranging from (0,0) to (3, 3). A node (i, j) is connected to four other nodes: (i+1 mod P, j) , (i-1 mod P, j), (i, j+1 mod P) and (i, j-1 mod P). Here "mod" stands for the modulo operation; in other words, x mod y returns the remainder when x is divided by y. For example, node (0, 0) is connected to (1, 0) and (0,1). In addition, it is also connected to nodes (-1 mod 4, 0) and (0, -1 mod 4), which are nodes (3, 0) and (0, 3) respectively.

Proposition 5: If there are of P collaborating partners in an SCM system, it is possible to place these P collaborating partners in a PxP mesh with P^2 nodes so that at least (P-1) distinct paths exist between any supplier and manufacturer pair with the following properties:

- these distinct paths between a supplier Si and manufacturer Mj do not involve any other supplier or manufacturer, and
- any pair of distinct paths overlap in at most 2*(P-1) nodes (other than the nodes Si and Mj).

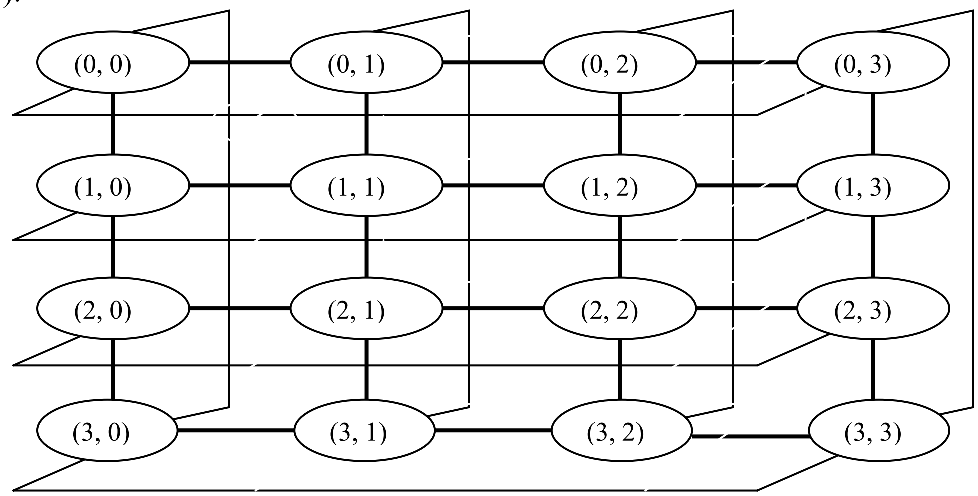

Figure 5: A 4x4 mesh consisting of 16 nodes

Proof: Omitted due to space constraints.

Based on proposition 5, we infer that the mesh design provides a robust structure for secure and reliable communication between suppliers and manufacturers. If each link in the mesh has a bandwidth of B and the price for each bandwidth unit is Q, then the total cost of implementing a virtual private network VPN with the mesh structure for $P = 2^p$ collaborating partners in an SCM system is computed as follows:

Total cost = Total number of links * B * Q = $2^p * 2^p * 2 * B * Q$

Where: B = Bandwidth, Q = Cost of leasing the Bandwidth, and
P ($=2^p$) Number of collaborators in the SCM system.

Example: If there are 16 suppliers and manufacturers, we will need a mesh with 256 nodes. In this mesh, there are 256*2 = 512 links. Suppose the bandwidth required on each link is 50 Mb/sec. If it costs $100/month for a bandwidth of 10 Mb/sec on each link, total cost of this Virtual Private Network (VPN) equals 512 * $100 * 5 = $256,000/month.

Proposition 6: The reliability of the SCM system with $P = 2^p$ collaborating partners in a mesh VPN with 2^px 2^p nodes is (P-1).

Proof: From proposition 5, it follows that there are (P-1) distinct paths between any pair of collaborating partners in a mesh VPN with with $P=2^p$ nodes. All these (P-1) paths should fail before communication between the pair breaks down completely. Hence, from definition 3, the reliability of the mesh design is (P-1).

Example: If there are $16= 2^4$ suppliers and manufacturers, we will need a mesh with 256 nodes. In this mesh, the reliability is 15 because there are 15 distinct paths between any supplier-manufacturer pair.

COMPARISON BETWEEN THE HYPERCUBE DESIGN AND THE MESH DESIGN

In this section we present a comparison between the mesh and the hypercube designs. The following table (Table 3) summarizes the reliability and cost of the hypercube and the mesh VPN designs as the number of collaborating partners in the SCM system (P) varies. In Table 3, B denotes the bandwidth and Q denotes the cost of leasing the bandwidth.

Table 3: A comparison Between the Mesh and the Hypercube Designs.

P = # partners	Cost of hypercube	Monthly cost B=10Mb/sec, Q=$10/mon	cost per partner	Reliability of hypercube	Cost of the mesh design	Monthly cost B=10Mb/sec, Q=$10/mon	cost per partner	Reliability of mesh
4	12*B*Q	$1200	$300	2	32*B*Q	$3200	$800	3
8	32*B*Q	$3200	$400	3	128*B*Q	$12,800	$1600	7
16	80*B*Q	$8000	$500	4	512*B*Q	$51,200	$3200	15
32	192*B*Q	$19,200	$600	5	2048*B*Q	$204,800	$6400	31
64	448*B*Q	$44,800	$700	6	8192*B*Q	$819,200	$12,800	63
128	1024*B*Q	$102,400	$800	7	32768*B*Q	$3,276,800	$25,600	127

From Table 3, it is inferred that the hypercube design offers a significant cost savings over the mesh design. The cost per each trading partner increases logarithmically as the number of trading partners increases. On the other hand, for the mesh design cost increases linearly as the number of trading partners increases. If cost is of primary concern, then the mesh design may become prohibitively expensive as the number of trading partners increases beyond 64.

On the other hand, the mesh design offers significantly higher reliability over the hypercube design. For example, for an SCM system with 16 collaborators 15 paths should completely fail before the communication between a pair of collaborators fails completely in the mesh design, while in the hypercube design only four path failures can force complete communication failure between a supplier-manufacturer pair.

Definition 4: The reliability-cost metric (RCM) to be the cost of a VPN design per partner divided by its reliability.

The smaller the RCM is for a VPN design, the higher is its ability to provide a high reliability at a reasonable cost.

Proposition 7: The RCM for an SCM system with $P = 2^p$ collaborating partners in a hypercube VPN with $2^{(p+1)}$ nodes is **((p+1) * B * Q)/p,** where B is the unit bandwidth and Q is the cost of leasing the bandwidth.

Proof: Omitted due to space constraints.

Table 4: A Comparison of reliability-cost metrics between the mesh and the hypercube designs

P = # partners	p	RCM for hypercube	RCM for the mesh design
4	2	1.5*B*Q	2.67*B*Q
8	3	1.33*B*Q	2.29*B*Q
16	4	1.25*B*Q	2.13*B*Q
32	5	1.2*B*Q	2.06*B*Q
64	6	1.17*B*Q	2.03*B*Q
128	7	1.14*B*Q	2.02*B*Q

Proposition 8: The RCM for an SCM system with $P = 2^p$ collaborating partners in a mesh VPN with $2^p x 2^p$ nodes is **(P *2 * B * Q)/(P-1),** where B is the unit bandwidth and Q is the cost of leasing the bandwidth.
Proof: Omitted due to space constraints.
In Table 4, a comparison is made between the reliability-cost-metrics of the hypercube and mesh designs. Once again, B denotes the bandwidth and Q denotes the cost of leasing the bandwidth.

From Table 4, we conclude that the RCM for the mesh is within two times that of the hypercube design.

CONCLUSIONS

In this paper, we studied two different designs for communication networks (Virtual Private Networks) of a supply-chain management system: the mesh design and the hypercube design. These two designs are significantly different from one another. Using thorough analysis, we studied both the reliability and the cost of these designs. We also studied the Reliability-Cost metric (RCM) for evaluating different VPN designs for the SCM systems. The RCM metric for the mesh design is within two times the RCM metric for the hypercube designs.

REFERENCES

1. Allamaraju, S. et al. (2001). *Professional Java E-Commerce,* Wrox Press.
2. Avaya communications (http://www.avaya.com/).
3. Boppana, R.V. and Chalasani, S. (1999). Fault-Tolerant Communication with Partitioned Dimension-Order Routers, IEEE Transactions on Parallel and Distributed Systems, (10), 1026-1039.
4. Chalasani, S. and Boppana R.V. (1997), Communication in Multicomputers with Nonconvex Faults, IEEE Transactions on Computers, (5), 612-622.
5. Chalasani, S. and Wafa, M. (2002), Reliable Technologies for B2B E-Commerce Based Supply Chain Management Systems, Proceedings of the 38th Annual MBAA Meeting (38th), Chicago, IL.
6. Chalasani, S. (2002), Medical Information Systems on the Internet, Invited Paper, Proceedings of the International Conference on Advances in Infrastructure for Electronic Business, Education, Science, and Medicine on the Internet (SSGRR 2002), L'Aquila, Italy.
7. Chalasani, S. and Boppana, R.V. (2002), Software Architectures for E-Commerce Computing Systems with External Hosting, Proceedings of the International Conference on Information Technology: Coding and Computing (sponsored by IEEE Computer Society), Las Vegas, NV.
8. Burrows, P. (2001), Where is the Upside: HP-Compaq will lead in PCs but not in costs or technology, Business Week, 40-43.
9. Don Estes (2000), Adopting XML For B2B E-Commerce, Research Note, http://www.cutter.com/research/2000/crb000718.html.
10. Gonsalves, A. (2002), Integration Projects Take Aim At Partner Collaboration, Information Week, (1), 2002.
11. Grosvenor, F. and Austin, T. (2001), Cisco's eHub Initiative, Supply Chain Management Review, (8).
12. Hewitt, F. (2001), After Supply Chains, Think Demand Pipelines, Supply Chain Management Review, (3), 2001.
13. Internet Domain Survey 2001: http://www.isc.org/ds/WWW-200107/index.html.
14. Lee, H. and Whang, S. J. (2001), Demand Chain Excellence: A Tale of Two Retailers, Supply Chain Management Review, (3).
15. Porter, M.E. (2001), Strategy and the Internet, Harvard Business Review, (3).
16. Pyke et al., D. (2001), e-Fulfillment: It's Harder Than It Looks, Supply Chain Management Review, (1).
17. SiteMinder 2003, Netegrity's SiteMinder, http://www.netegrity.com/products/index.cfm?leveltwo=SiteMinder.
18. Sprint (http://www.sprintbiz.com/bsgpromo/ip2.html).
19. RosettaNet 2003, Rosetta Net Home Page, http://www.rosettanet.org/.
20. Venkatraman, N. (2001), Strategic eBusiness – Challenges for Competitive Success, General Management Review (2).