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Abstract

Two major approaches for providing connectionless service for ATM networks are connection based and server based. In the connection based approach, the connection oriented service of ATM is used to interconnected pairs of ATM end systems. The end systems are then responsible for providing a connectionless service to various other end systems via ATM connections. In the server based approach, connectionless servers in the ATM networks directly provide a connectionless service. An end system may send all its packets to one connectionless server where each packet is individually routed to other connectionless servers en route to the destination. This paper examines analytically the resource requirements for these two approaches. Specifically, it finds the number of ATM connections, connection set-up rate and required number of connectionless servers.

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1 Introduction

Connectionless networks such as Ethernet currently makes up a large portion data networks in existence. Internetworking these networks is expected to be one of the major applications of the emerging Asynchronous Transfer Mode (ATM) networks. However, ATM was designed for connection oriented services such as voice and video. As such, adaptations are necessary to provide connectionless service on ATM. [1]-[11].

There are two main approaches to providing connectionless datagram service in ATM networks. The first is called the connection based approach. The ITU also calls this the indirect approach since the ATM network is only indirectly providing connectionless service. This approach uses ATM connections to interconnect pairs of ATM end systems. The example in Figure 1(a), shows the interconnection of four ATM end systems (LAN's `A` through `D`'s interworking units). In this approach, a separate connection is required for each destination ATM end system. When an end system has a packet to deliver to a destination end system for which it has no open connection, a new connection is set-up. Subsequent packets to the same destination may use the same connection. The connection may be torn down after some idle time.

A second approach, called the server based approach, is based on the deployment of connectionless servers (CLS) throughout the network, forming a virtual connectionless network overlayed on the connection-oriented ATM network [12][13]. A CLS may be an ATM switch with connectionless server functionality built in or it may be an external device attached to a switch with a bidirectional link between itself and the switch. A CLS maintains ATM connections to other CLS's and ATM end systems. Datagrams are routed to other connectionless servers en route to the destination end system. As shown in the example configuration in Figure 1(b), an ATM end system only needs an open connection to a nearby connectionless server in order to send datagrams to any number of destinations. The ITU refers to this as the direct approach since connectionless service is directly provided by ATM.

The connection and server based approaches require different sets of resources. The server approach may require significantly fewer connections than the connection approach since end systems only need one connection (to a CLS) instead of one for each destination. Using switched connections for the connection approach adds to the call processing burden. The server approach requires fewer connection set-ups and tear-downs since the connections between CLSs may be permanent rather than switched. With connection set-up times in ATM switches as long as 10 msec.[1], the fewer number of connection set-ups required may be a significant advantage of the server approach. However, the server approach requires CLSs to be deployed.

Whether the advantages of the server approach will be enough to outweigh its disadvantages (the necessity of connectionless server deployment) is dependent on the network

[1](*e.g.*, FORE ASX-200 ATM switch)

environment. In local and customer premises networks, VPI/VCI's may be freely allocated to the end systems although some ATM switches may only be able to switch a limited number of VC's. A limitation on the number of VC's switches can support may not be a significant factor in small ATM networks, but in large, public ATM networks, limitations on the number of VC's and the amount of SVC call processing switches can support may make the server approach more attractive than the connection based approach.

This paper investigates the resource utilization of the connection based and server based approaches. In Section 2, the analytical model used for the evaluation is described. Section 3 shows how the connection usage and set-up processing rate is determined for the connection based approach. Section 4 shows an analysis of the server based approach examining different topologies used for interconnecting the CLSs. Numerical results comparing the connection and server based approaches are shown in Section 5. Section 6 summarizes some of the key results.

2 Model

The number of connections used by the two connectionless service approaches, the rate of connection set-up/tear-downs of the connection based approach, and the number of CLSs needed by the server based approach will be found analytically. The assumptions used in modeling are as follows.

For the connection based approach, it is assumed that an ATM connection will be set-up when a (TCP) conversation[2] begins between a pair of ATM end systems for which no connection is currently open. A single connection may carry more than one conversation between a pair of end systems. The connection is torn down when there are no longer any conversations alive to use it.

For the server based approach, it is assumed that a single ATM connection is opened and used between an end system and a CLS if the end system has any live conversations. The CLSs are assumed to maintain permanent connections between each other. An end system is attached to only one CLS. The N ATM end systems are assumed to be evenly distributed over the M CLSs. Conversations arrive to a CLS from neighboring CLSs and from its own attached end systems. An ample number, M, of CLSs should be utilized so that each CLS does not have to support an excessive number of conversations.

The conversations are independently generated at each end system according to a Poisson process with mean rate λ per minute. Conversation durations are assumed to be exponentially distributed with mean β minutes. For the analysis presented in this paper, packet level performance (queueing delay, retransmissions) is assumed to have a negligible effect on the durations of conversations. The destination end systems of the conversations are chosen independently with either an equal probability for each end system (a uniform

[2] A *conversation* is a series of packets between two hosts such as during a file transfer or telnet session.

case) or with a small number of end systems receiving proportionately more conversations than others (a nonuniform, or "hot spot" case). Given N ATM end systems, let H $(0 \leq H \leq N)$ be the number of hot spot destinations. Let α $(H/N \leq \alpha \leq 1)$ be the portion of conversations destinated to the H hot spot end systems. In the uniform case, $\alpha = H/N$. The particular set of hot spot destinations may vary from one source to another.

The notation below will be used in the analysis to follow.

N	Number of end systems
M	Number of connectionless servers
β	Mean time duration of a conversation
λ	Mean conversation arrival rate from a single end system
λ'_i	Mean conversation arrival rate at a CLS i from its attached end systems
λ_i	Mean total conversation arrival rate at CLS i including conversations routed from other CLSs
Q_D	Desired $90th$-percentile number of conversations at the most congested CLS
$p_{i,j}$	Probability that a conversation originating from an end system attached to CLS i will traverse CLS j
C_H,C_M,C_R	Number of connections utilized by the hypercube, Manhattan Street Network, and dual ring CLS topolog
C_I	Number of connections utilized by the connection based approach
$F_C(k)$	Probability of k connections in the network using the connection based approach
$F_S(k)$	Probability of k simultaneous conversations at a CLS using the server based approach
Δ_t	Savings in number of ATM connections per CLS when the CLSs are connected using topology t, $t \in \{H, M, R\}$
δ_t	Savings in connection set-up rate per CLS when the CLSs are connected using topology t

3 The Connection Based Approach

Since the arrival process of conversations is assumed to be Poisson and destinations are chosen independently, the arrival process of conversations from one source to a particular destination is Poisson with a mean rate of $\lambda\alpha/H$ for hot spots and $\lambda(1-\alpha)/(N-H)$ otherwise. With exponentially distributed conversation durations, the probability distribution of the number of conversations utilizing a single ATM connection is equivalent to the probability distribution of busy servers in an M/M/∞ queue. The state distribution of an M/M/∞ queue with an arrival rate of λ^* and a service time of β^* is [15]

$$P(k) = \frac{(\lambda^*\beta^*)^k}{k!}P(0) \tag{1}$$

$$P(0) = e^{-\lambda^*\beta^*} \tag{2}$$

Thus, the probability that a connection is not open to a particular hot spot destination, D_h, or a particular non-hot spot destination, D_l, is found using Eq. (2) as

$$\begin{aligned} D_h &= e^{-\alpha\lambda\beta/H} \\ D_l &= e^{-(1-\alpha)\lambda\beta/(N-H)} \end{aligned} \tag{3}$$

The probability, $f_c(k)$, that a single source end system will have k connections open is given by

$$f_c(k) = \begin{cases} \sum_{j=0}^{k} \binom{H}{j} (1-D_h)^j D_h^{H-j} \\ \quad \times \binom{N-H}{k-j} (1-D_l)^{k-j} D_l^{N-H-(k-j)} & ,0 \le k \le H \\ \sum_{j=max(0,k-(N-H))}^{H} \binom{H}{j} (1-D_h)^j D_h^{H-j} \\ \quad \times \binom{N-H}{k-j} (1-D_l)^{k-j} D_l^{N-H-(k-j)} & ,H < k \le N \end{cases} \tag{4}$$

The probability, $F_C(k)$, that the total number of connections in the network using the connection based approach is k, is found as

$$F_C(k) = \sum \Pi_{i=1}^{N} f_c(k_i) \tag{5}$$

where $k = \sum k_i$ and the summation in Eq (5) is over all combinations of k_i's such that $k = \sum k_i$. Directly computing $F_C(k)$ from Eq (5) is computationally intractable except for very small values of N or k.

For large N, the total number of network connections may instead be approximated as the number of busy servers in an M/G/∞ system. Customer arrivals model ATM connection set-ups and the service times model ATM connection durations. The arrival process of ATM connection set-ups in the network is Poisson with mean rate $N\lambda_C$ where

$$\lambda_C = \lambda(\alpha D_h + (1-\alpha)D_l) \tag{6}$$

The service time of the M/G/∞ system is equal to the connection duration. In steady state, the state distribution of an M/G/∞ model is given by Eqs. (1) and (2) with λ^* replaced by $N\lambda_C$ and β^* replaced by the mean of the connection time distribution [15].

4 The Server Based Approach

Many topologies may be used to interconnect the CLSs [14]. This section explores how a few of them may be analyzed. Let $p_{i,k}$ denote the probability that a conversation originating from an end system attached to CLS i will traverse CLS j, whether CLS j is a final destination or an intermediate hop. The average total conversation arrival rate to CLS i is given by

$$\lambda_i = \lambda' + \sum_{j \neq i} p_{j,i} \lambda', \tag{7}$$

where λ' is the mean arrival rate of conversations to a CLS from its attached end systems.

In networks where each node, where a node represents a CLS, in the network has an equal mean load, (*i.e.*, $\lambda_i = \lambda_{CLS}$), the mean conversation arrival rate may also be calculated based on the mean path length. If the mean path length for a conversation is $\overline{L}$ links, then conversations traverse $\overline{L}+1$ nodes on average. For such networks, the conversation arrival rate at a CLS may be given by

$$\lambda_{CLS} = (\overline{L}+1)\lambda' \tag{8}$$

The number of simultaneous conversations at a CLS is equivalent to the number of busy servers in an M/M/∞ queue with an arrival rate of λ_{CLS} and a service time of β. The probability, $F_S(k)$, of k active conversations at a CLS is found using Eqs. (1) and (2).

For many networks, $p_{i,j}$, and thus λ_{CLS}, may only be calculated numerically. However, some networks have a regular form that is amenable to analytical evaluation. In each of the networks analyzed, n-cube, Manhattan Street Network, and dual ring, a node in the network is used to represent a connectionless server. The number of connections needed to connected M nodes and the expected arrival rate of conversations to a CLS, based on Eq. (8), is analyzed. The minimum number of CLSs needed to obtain a given target λ_{CLS} may then be found numerically. The number of CLSs and the connections between them may then used to compare the server based approach to the connection based approach.

The scalabilitieso f the topologies are also analyzed. Scalability is the increase in a network's capacity as more CLSs are added, or alternatively, the decrease of the load on each CLS as more nodes are added. We use the latter definition to compare the topologies for connectionless servers.

4.1 n-cube

An analysis of n-cube performance for connectionless servers is shown below. The analysis below is an extension of the hypercube ($n = 2$) analysis presented in [16].

We begin the analysis with a methodology to construct a partial n-cube with an arbitrary number of nodes. The number of nodes, M_H, in a complete n-cube of degree r is

n^r. If M_H is not an integer power of n, then a number of small, complete n-cubes may be connected together to form a partial n-cube. For example, Figure 2 shows a partial hypercube containing 14 nodes. The largest cube contains 2^3 nodes and the smaller cubes contain 2^2 and 2 nodes. This construction permits a much smoother growth of the partial n-cube network than if only complete n-cubes are considered.

To determine the composition of a partial n-cube, it is necessary to first find the maximum number of complete n-cubes of degree r that may be built using M_H or fewer nodes,

$$H'(r, n, M_H) = \lfloor \tfrac{M_H}{n^r} \rfloor \quad , n \leq M_H, 0 \leq r \leq R \tag{9}$$

where $R = \lfloor log_n M_H \rfloor$ ($\lfloor x \rfloor$ is the largest integer less than or equal to x) is the highest degree complete n-cube that can be built from M_H nodes. Node addresses contain $R^+ = \lceil log_n M_H \rceil$ ($\lceil x \rceil$ is the smallest integer greater than or equal to x) dimensions, $A_{R^+}, \ldots, A_1$ ($0 \leq A_i \leq n-1$). If M_H is an integer power of n, then $M_H = n^R$ and $R^+ = R$, otherwise, $M_H > n^R$ and $R^+ = R+1$. In the example of Figure 2, $n = 2$ (a binary hypercube), $R = 3$ (the degree of the largest complete hypercube contains $n^R = 2^3$ nodes) and $R^+ = 4$.

The composition of the partial n-cube will be such that the maximum number of larger complete cubes are constructed. As such, the M_H nodes are first decomposed into n-cubes of degree R. The remaining nodes are then decomposed into complete n-cubes of degree $R-1$, then $R-2$ and so forth. There may be between 0 and $n-1$ cubes of degree r in the partial n-cube. The number of complete n-cubes of degree r ($0 \leq r \leq R$) that will compose the M_H node partial n-cube is

$$H(r) = H'(r, n, M_H - \sum_{s=r+1}^{R} n^s H(s)) \tag{10}$$

Having described a methodology for constructing a partial n-cube for an arbitrary number of nodes, we will next investigate the number of connections required. There are three types of connections: those connecting nodes within the same complete n-cube, those connecting nodes in different complete n-cubes of the same degree, r, and those connecting nodes in complete n-cubes of different degrees. These three will be examined in turn.

First, within a complete n-cube of degree r, nodes are connected when their addresses differ in only one of the r dimensions. Since each dimension takes one of n values, a node is connected to $r(n-1)$ other nodes in the same cube. The total number of connections within a complete n-ary cube of degree r is

$$c(r, n) = \frac{1}{2} n^r r(n-1) \tag{11}$$

Second, between the $H(r)$ complete n-cubes of degree r, a node in one n-cube is connected to exactly one node in each of the other n-cubes. Third, between complete n-cubes of different degrees, a node will be connected to exactly one node in each of the higher degree n-cubes. [3] Thus, the number of connections from all complete n-ary cubes of degree r to other complete n-ary cubes of degree greater than or equal to r in the partial n-cube is

$$c^{+}(r,n) = n^{r}\left\{\frac{H(r)(H(r)-1)}{2} + H(r)\sum_{s=r+1}^{R} H(s)\right\} \tag{12}$$

Combining Eqs. (11) and (12), the total number of connections in the partial n-cube is

$$C_H = \sum_{r=0}^{R}\left\{H(r)c(r,n) + c^{+}(r,n)\right\} \tag{13}$$

The final step in the analysis of n-cubes is determining the expected arrival rate of conversations to a CLS. As described by Eq. (8), the mean conversation arrival rate may be determined based on the expected number of CLS's that a conversation will traverse.

For a conversation that originates and terminates at nodes in any of the $H(r)$ n-cubes of degree r, the probability that a conversation traverses j hops, where a hop is a connection between two CLS's, is

$$L_H(j,r) = \begin{cases} \frac{1}{H(r)}\left(\frac{1}{n}\right)^{r} & ,j=0 \\ \frac{H(r)-1}{H(r)}\binom{r}{j-1}\left(\frac{n-1}{n}\right)^{j-1}\left(\frac{1}{n}\right)^{r-(j-1)} & \\ \quad + \frac{1}{H(r)}\binom{r}{j}\left(\frac{n-1}{n}\right)^{j}\left(\frac{1}{n}\right)^{r-j} & ,1 \le j \le R^{+} \end{cases} \tag{14}$$

The $j = 0$ case represents conversations where the source and destination end systems are attached to the same CLS. The first term in the $1 \le j \le R^{+}$ case is the probability of j hops with the source and destination nodes in different n-cubes of degree r. The second term represents the case where they reside in the same n-cube. The mean number of hops in r-degree n-cubes is denoted by

$$\gamma_H(r) = \sum_{j=1}^{r} jL_H(j,r) \tag{15}$$

The analysis of the mean number of hops between cubes of different degrees will focus on the number of hops within cubes of degree R. These cubes, which are the largest in the partial n-cube, are referred to here as *primary cubes* while all n-cubes of degree less than R

[3] For the purposes of counting connections, a connection between a node in an r_1 degree n-cube and a node in an r_2 degree n-cube will be counted by the the node in the lesser degree n-cube.

are referred to as *secondary cubes.* We focus on the primary cubes because they have larger diameters (the longest path length), hence longer mean path length and, following Eq. (8), the loads on each node should be greater. Thus, analysis of loads in the primary n-cubes should provide performance measures for the most congested connectionless servers.

Let Ψ denote the degree of the largest secondary cube. For conversations that originate from a node in a primary cube and terminate at a node in a secondary cube (or vice versa), the mean number of hops that will be traversed within the primary cubes, γ_Ψ, may be determined by examining the probability of each (address) dimension being traversed in the primary cube.

The number of values each address dimension in n-cubes of degree Ψ or less may take are

$$\begin{array}{ll} A_{R+} \ldots A_{\Psi+2} & : 1 \\ A_{\Psi+1} & : H(\Psi) \;\; \text{if} \sum_{r=0}^{\Psi-1} H(r) = 0 \\ & : H(\Psi) + 1 \;\; \text{otherwise} \\ A_\Psi \ldots A_1 & : n \end{array}$$

If we assume that the routing algorithm randomly chooses the order in which the address dimensions are traversed, then γ_Ψ may be given by

$$\gamma_\Psi = \gamma_H{}'(R)\frac{1}{R}\left(\frac{1}{2}(\Psi+1) + (R-\Psi-1)\right) + 1 \tag{16}$$

$$\gamma_H{}'(R) = \sum_{j=1}^{R} j \binom{R}{j} \left(\frac{n-1}{n}\right)^j \left(\frac{1}{n}\right)^{R-j} \tag{17}$$

Eq. (16) weighs the mean path length in a primary cube ($\gamma_H{}'(R)$) by the expected number of dimensions that will be traversed in a primary cube. The $\frac{1}{2}(\Psi+1)$ term on the right hand side of Eq. (16) is the mean number of dimensions $A_{\Psi+1} \ldots A_1$ that may be traversed within a primary cube. The next term represents the dimensions $A_R \ldots A_{\Psi+2}$ that can *only* be traversed in a primary cube. The final "+1" term on the r.h.s. of Eq. (16) represents the fact that A_{R+} must change in any path between primary cubes and secondary cubes.

Combining Eqs. (8) (15) and (16), the mean conversation arrival rate to a connectionless server in a primary n-cube is

$$\lambda_{H_p} = (\gamma_H(R)+1)\left(\frac{M_H}{M_H}\right)^2 \lambda \frac{N}{M_H} + (\gamma_\Psi + 1)\frac{2M_H(M_H - M_P)}{{M_H}^2}\lambda\frac{N}{M_H}\frac{M_H - M_P}{M_P} \tag{18}$$

where $M_P = n^R H(R)$ is the number of nodes in the primary cubes. The first term on the right hand side of Eq. (18) represents conversations that originate and terminate in primary cubes and the second term represents conversations that traverse both primary and secondary cubes.

The scalability of n-cubes is the best of the topologies considered here. The conversation arrival rate to a connectionless server from its attached end systems declines at a rate of $1/M_H$ since $\lambda_i' = \lambda N/M_H$. The diameter, or the maximum path length, is an obvious upper bound of the mean path length. Since the diameter of an n-cube is $log_n M_H$, the conversation arrival rate to a CLS behaves as $\lambda_{H_p} \sim log M_H/M_H$ as an upper bound for large M_H.

4.2 Manhattan Street Network

A Manhattan Street Network (MSN) is a mesh connected topology designed for metropolitan area networks. Its usefulness as a CLS topology is investigated below.

Modeled after the alternating one-way streets found in the city of Manhattan, each node has one connection going either north or south and one connection going either west or east. Thus, the number of connections in a Manhattan Street Network with M_M nodes is simply

$$C_M = 2M_M \tag{19}$$

The average number of links traversed in a Manhattan Street Network of size $M_M = M_1 \times M_2$ assuming a uniform source and destination distribution is given in [17]. The analysis is easily modified to include scenarios in which the source node may also be the destination node. The average number of links traversed is

$$\gamma_M(M_1, M_2) = \begin{cases} 1 & , M_1 = M_2 = 2 \\ \frac{M_M/4(M_1+M_2+4)-M_2-4}{M_M} & , M_1/2 \text{ is even}, M_2/2 \text{ is odd} \\ \frac{M_M/4(M_1+M_2+4)-4}{M_M} & , M_1/2 \text{ is even}, M_2/2 \text{ is even} \\ \frac{M_M/4(M_1+M_2+4)-M_1-M_2-4}{M_M} & , M_1/2 \text{ is odd}, M_2/2 \text{ is odd} \end{cases} \tag{20}$$

where M_1 and M_2 are assumed to be even integers.

From Eqs. (8) and (20), the mean conversation arrival rate at a connectionless server is

$$\lambda_M(M_1, M_2) = (\gamma_M(M_1, M_2) + 1)\lambda \frac{N}{M_M} \tag{21}$$

The diameter of a square MSN is $\sqrt{M_M}$ when $\sqrt{M_M}/2$ is even and $\sqrt{M_M} + 1$ when $\sqrt{M_M}/2$ is odd [17].

The mean path length, γ_M, in square Manhattan Street Networks networks, $M_1 = M_2$, grows at a rate of $O({M_M}^{1/2})$. Substituting ${M_M}^{1/2}$ for $\gamma_M(\sqrt{M_M}, \sqrt{M_M})$ into Eq. (21), it can be seen that the conversation arrival rate to a CLS behaves as $\lambda_M \sim 1/\sqrt{M_M}$ for large M_M.

4.3 Bi-directional Ring

Bi-directional (or dual counter rotating) rings may also be used to connect the CLSs. The number of connections required M_R nodes is

$$C_R = 2M_R \tag{22}$$

Assuming a uniform destination distribution and letting $M_R' = \lfloor M_R/2 \rfloor$, the probability that the number of links to a destination is l is given by $L_R(l) = 1/M_R$ if $l = 0$ and $L_R(l) = 2/M_R$ if $1 \leq l \leq M_R'$. If M_R is even, then $L_R(M_R' + 1) = 1/M_R$.

The mean number of links traversed for a conversation is

$$\gamma_R(M_R) = \begin{cases} = \sum_{l=1}^{M_R'} l \frac{2}{M_R} = \frac{M_R'(M_R'+1)}{M_R} & M_R \text{ is odd} \\ = \frac{M_R'+1}{M_R} + \sum_{l=1}^{M_R'} l \frac{2}{M_R} = \frac{(M_R'+1)^2}{M_R} & M_R \text{ is even} \end{cases} \tag{23}$$

From Eqs. (8) and (23), the mean conversation arrival rate is

$$\lambda_R(M_R) = (\gamma_R(M_R) + 1)\lambda \frac{N}{M_R} \tag{24}$$

The ring network is not scalable in the present context. As M_R increases, $\gamma_R(M_R) \sim M_R/4$ and $\lambda_R(M_R) \to \lambda N/4$. Thus, increasing M_R only affects an asymptotic reduction in $\lambda_R(M_R)$ making it ill equipped to handle heavy traffic loads or a large number of end systems.

4.4 Tree

Tree topologies are useful for environments where a high degree of locality exists. However, with a uniform destination distribution, as assumed in this paper, half of all traffic would be routed through the root node regardless of the number of leaf nodes. Thus, without locality, a tree's throughput is severely limited.

4.5 Topology comparison

Table 1 summarizes some of the characteristics of the n-cube, Manhattan Street Network, ring and tree topologies. The foremost consideration is the scalability of a topology. The scalability measures the ability of a topology to compensate for an increase in traffic load by adding more CLSs. The scalability in Table 1 is defined as the rate at which the conversation arrival rate to a single CLS declines as more servers are added. The ring and

	n-cube	MSN	Ring	Tree
Scalability $\lambda_{CLS}(M)$	$\sim logM/M$	$\sim 1/\sqrt{M}$	no	no
Diameter	$\lceil log_n M \rceil$	$\sqrt{M}$	$M/2$	$2log_n M$
Connections	$\frac{1}{2}(n-1)Mlog_n M$	$2M$	$2M$	$M-1$
Traffic Locality	helps	helps	required	required
Broadcasting	hard	hard	easy	easy

Table 1: Comparison of topologies for connectionless servers

tree topologies are not scalable. The MSN is somewhat scalable. The n-cube has the best scalability.

n-cubes also have the shortest diameters and do not depend on traffic locality for good performance. However, broadcasting is difficult to support and they also require more connections than any other topology.

Manhattan Street Networks have moderate diameters and are moderately scalable. Traffic locality would greatly improve performance. Broadcasting is difficult to support and the number of connections required is small.

Ring networks exhibit poor scalability, has a large diameter, and require traffic locality for acceptable performance. Its best assests are the small number of connections required and its ease of broadcasting support.

Tree topologies are limited by the throughput of the root node. Tree topologies are only appropriate for environments where there is a great deal of traffic locality.

In the following numerical examples, each CLS topology is characterized by the minimum number of CLS's, M_H, M_M and M_R for CLS topologies of hypercube, MSNs and rings, respectively, such that the probability that there are Q_D or fewer simultaneous conversations at a CLS is greater than 0.9, ($i.e.$, $\sum_{k=0}^{Q_D} F_S(k) \geq 0.9$).

Figure 3 shows the effect of Q_D on the number of CLSs required to support $N = 100,000$ end systems with $\lambda\beta = 0.1$ while satisfying the condition described above. (The product $\lambda\beta$, hereafter referred to as the load, is equal to the mean number of simultaneous conversations originating at an end system.) Ring networks are not able to support 100,000 end systems so the figure only shows the results for hypercubes (2-cubes) and Manhattan Street Networks. The figure shows that Q_D has a very significant effect on the number of CLSs necessary. When Q_D is small, Manhattan Street Networks may require twice as many CLSs as hypercubes. For the remainder of the numerical results, we assume that $Q_D = 1000$. For a CLS with a throughput of 155 Mbps, this corresponds to a mean of 150 Kbps per conversation.

Figure 4 shows the effect of the number of end systems on the number of CLSs needed. Two sets of graphs are shown: one for a conversation load of $\lambda\beta = 0.1$ and one for $\lambda\beta = 4.0$. Ring networks, which are unable to support more than 50,000 end systems with

$\lambda\beta = 0.1$, are not pictured. The MSN utilizes significantly more CLSs than the hypercube, particularly with the higher load of $\lambda\beta = 4.0$ and a large number of end systems. The figure also shows that there is only a minimal gain by using higher order cubes ($n > 2$). As such, of the n-cubes, only hypercubes ($n = 2$) will be considered from here on.

5 Numerical Results

Numerical results are presented below to compare connection based and server based approaches. The savings in the number of ATM connections possible using the server based approach is calculated. The rate of connection set-up required by the connection based approach is also determined.

The connection based approach is characterized below by minimum number of connections in the network, C_I, such that the probability of C_I or fewer connections is greater than 0.9, (*i.e.*, $\sum_{k=0}^{C_I} F_i(k) \geq 0.9$).

The server based approach is characterized by the minimum number of CLSs and connections such that the probability of 1000 or fewer simultaneous conversations at a CLS is greater than 0.9, as described in Section 4.5.

As the server based approach requires the deployment of additional equipment (connectionless servers) that the connection based approach does not, we find Δ defined as

$$\Delta_H = \frac{C_I - C_H}{M_H} \quad ; \quad \Delta_M = \frac{C_I - C_M}{M_M} \tag{25}$$

for hypercubes and Manhattan Street Networks, respectively. Δ is the average number of ATM connection savings per CLS. Similarly, we define δ_H and δ_M as the server based approach's savings in connection set-up rate per CLS for hypercubes and Manhattan Street Networks, respectively.

$$\delta_H = \frac{\lambda N(\alpha D_h + (1-\alpha) D_l)}{M_H} \quad ; \quad \delta_M = \frac{\lambda N(\alpha D_h + (1-\alpha) D_l)}{M_M} \tag{26}$$

Note that we've assumed that the server based approach utilizes permanent connections.

Figure 5 shows Δ_H and Δ_M as a function of the number of end systems for two values of $\lambda\beta$. The server based approach is more attractive in regions where Δ_H and Δ_M are large. The figure shows that the server based approach is marginally effective for the small value of $\lambda\beta$. For $\lambda\beta = 4.0$, Δ_H and Δ_M are significantly improved. The figure also reveals that the effectiveness of the server based approach decreases as the number of end systems increases. This is due to the poor scalability of the CLS topologies. Poor scalability is the result of the increased CLS-to-CLS traffic produced by large networks of connectionless servers which in turn requires more connectionless servers and ATM connections. The non-smooth decline in Δ_H is reflective of the uneven decline in λ_{CLS} as M_H is increased since we consider partial hypercubes where the number of nodes may not be a power of 2.

The effect of hot spot traffic and $\lambda\beta$ may be seen in Figure 6. The connection based approach may make better advantage of hot spots since one connection may multiplex many conversations with the assumption that the performance of switches, unlike CLSs, effectively does not limit the number of conversations. The number of CLSs in the server based approach is unaffected by hot spot traffic since the CLSs will have to process the same number of conversations regardless of the hot spot portion of traffic. This is a result of an assumption we made that each source has a different set of hot spot destinations. However, as the figure shows, in order to affect a significant reduction in the effectiveness of the server based approach, a very large portion of the conversations (α) has to be directed to a small population of destinations (H). While Δ_H dropped approximately a third with the high hot spot traffic scenario, Δ_H was still in the range of 100 – 160 for $\lambda\beta \geq 4$. Δ_M was not as significantly affected by α but was very low in any case.

The server based approach's savings in ATM connection set-ups, δ_H and δ_M, are shown in Figure 7 as a function of the conversation arrival rate, λ. The connection set-up rate is dependent on the individual values of λ and β as shown in Eq. (6) whereas the number of connections, and hence Δ, are only dependent on their product. The Manhattan Street Network topology is shown to perform poorly as the load is increased. δ_M rapidly approaches 0. δ_H declines much slower, particularly in the near uniform destination distribution case.

6 Conclusion

Connectionless service provides a means by which diverse data and LAN/MAN interconnection services can be realized. This paper investigated two approaches to providing such a service on ATM networks.

The server based approach, utilizing connectionless servers, was shown to have significant advantages over the connection based approach. The server based approach utilizes fewer ATM connections and does not require the significant connection set-up processing that the connection based approach does. Under the assumptions used in this paper, the server based approach shows the most advantages when using the hypercube topology to interconnect the connectionless servers, when the ATM end systems have conversations with many other end systems simultaneously, and the conversations transmit at low to moderate data rates.

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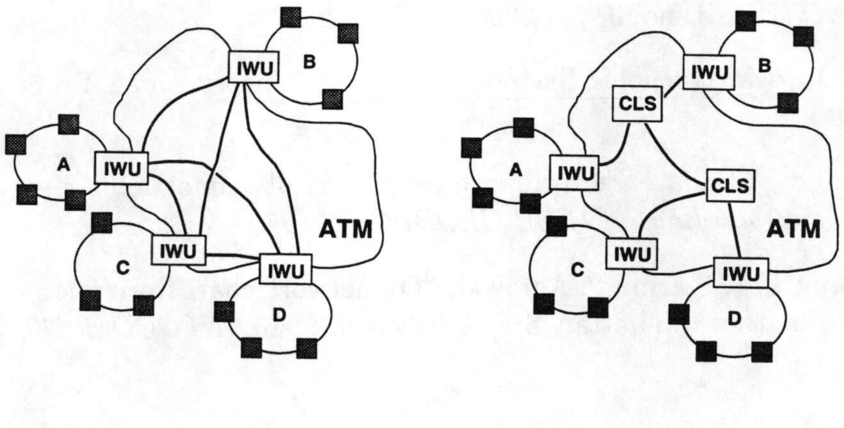

a) Indirect Connectionless Support b) Direct Connectionless Support

Figure 1: Connection based and server based connectionless service architectures

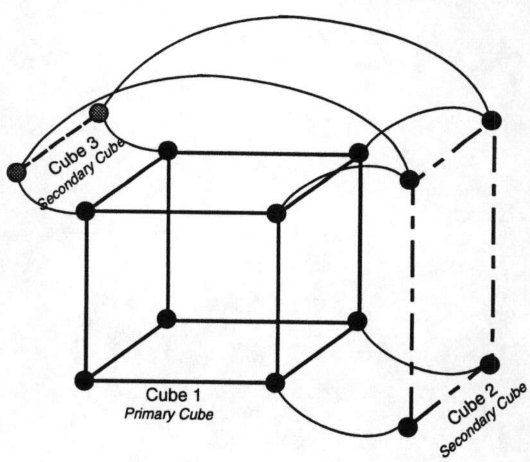

Figure 2: A partial 2-cube (*hypercube*) with 14 nodes is composed of 3 smaller complete 2-cubes.

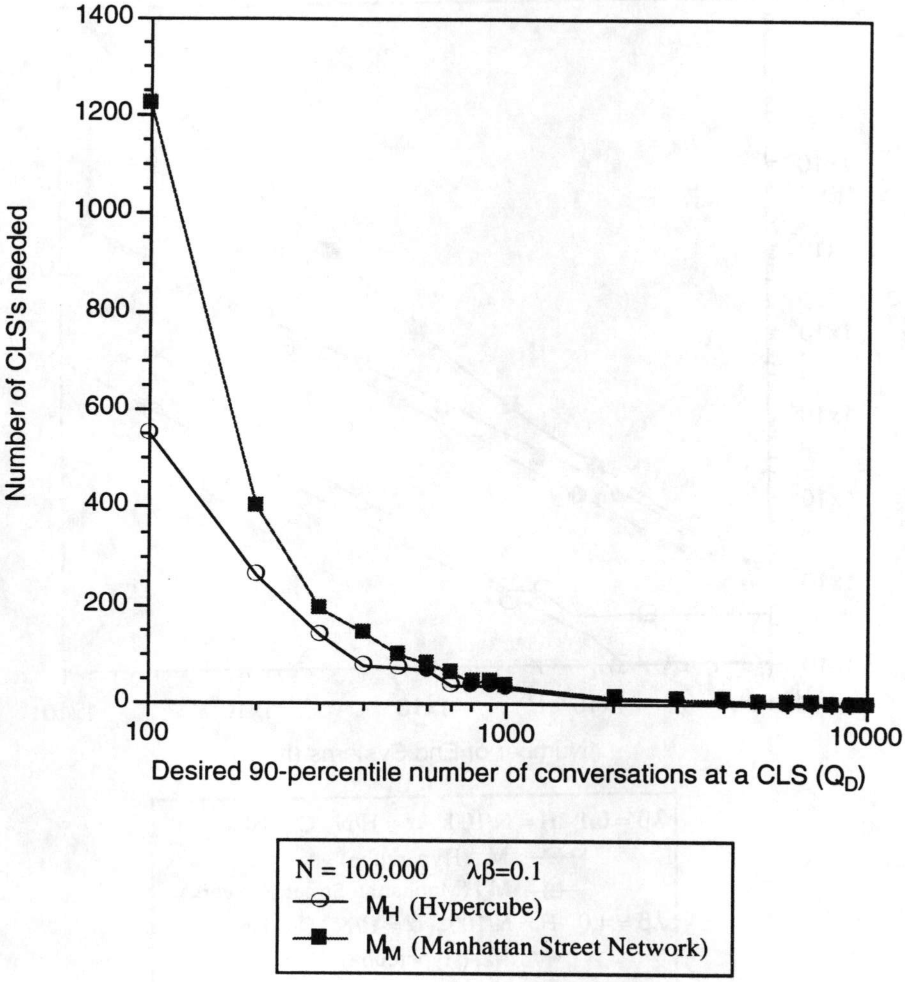

Figure 3: Number of connectionless servers as a function of the desired $90th$-percentile number of conversations at each (Q_D).

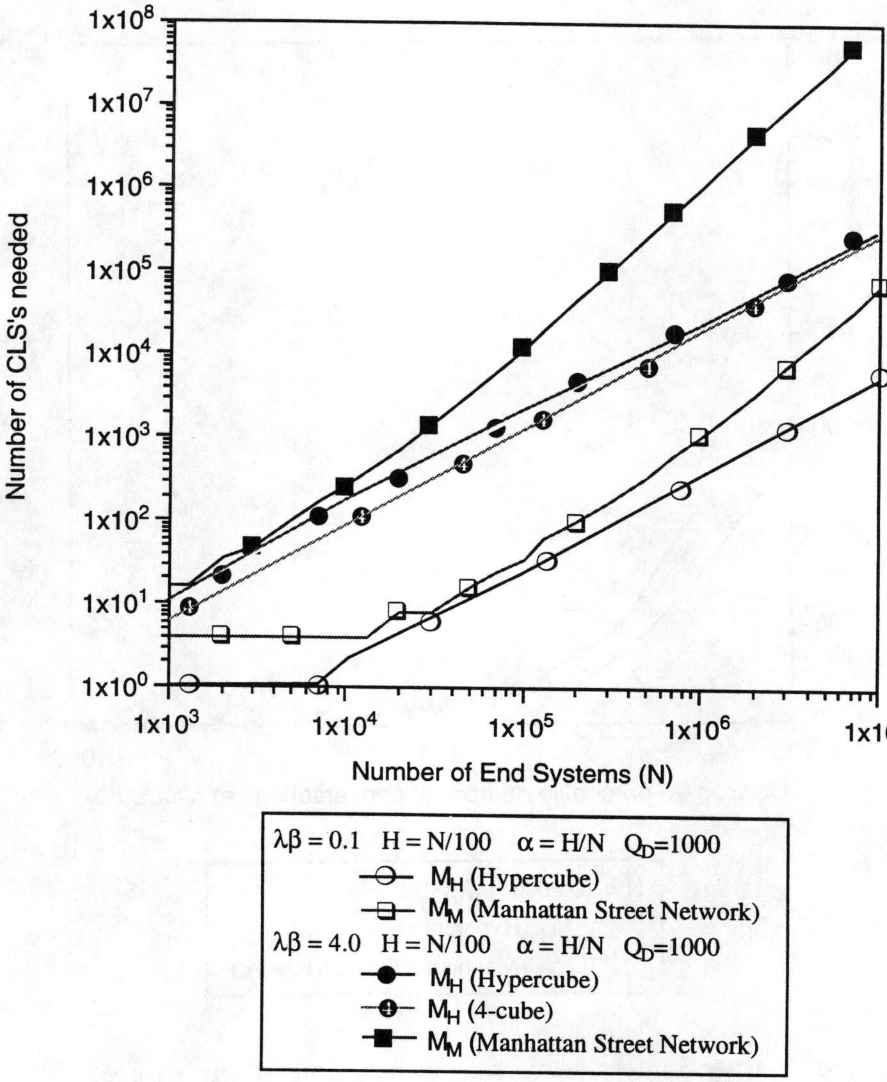

Figure 4: Number of connectionless servers as a function of the number of end systems.

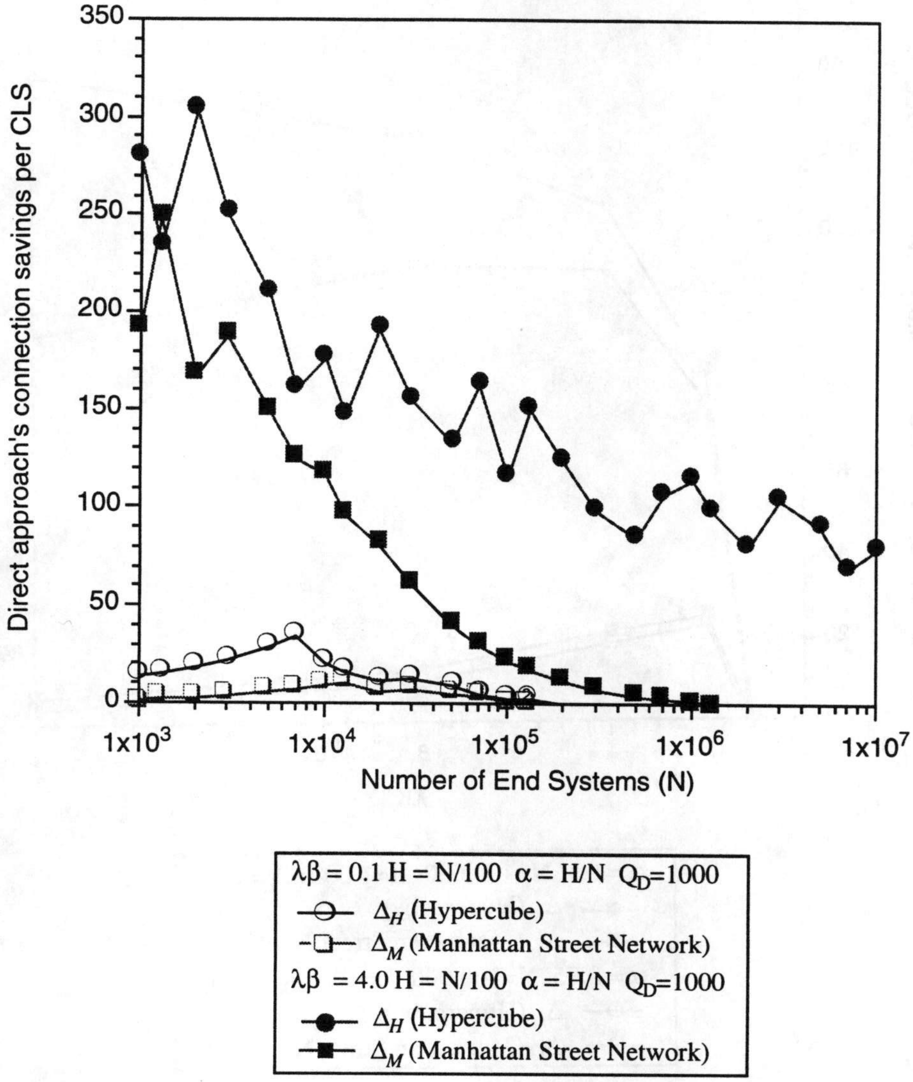

Figure 5: Cost factor for connectionless servers as a function of the number of end systems.

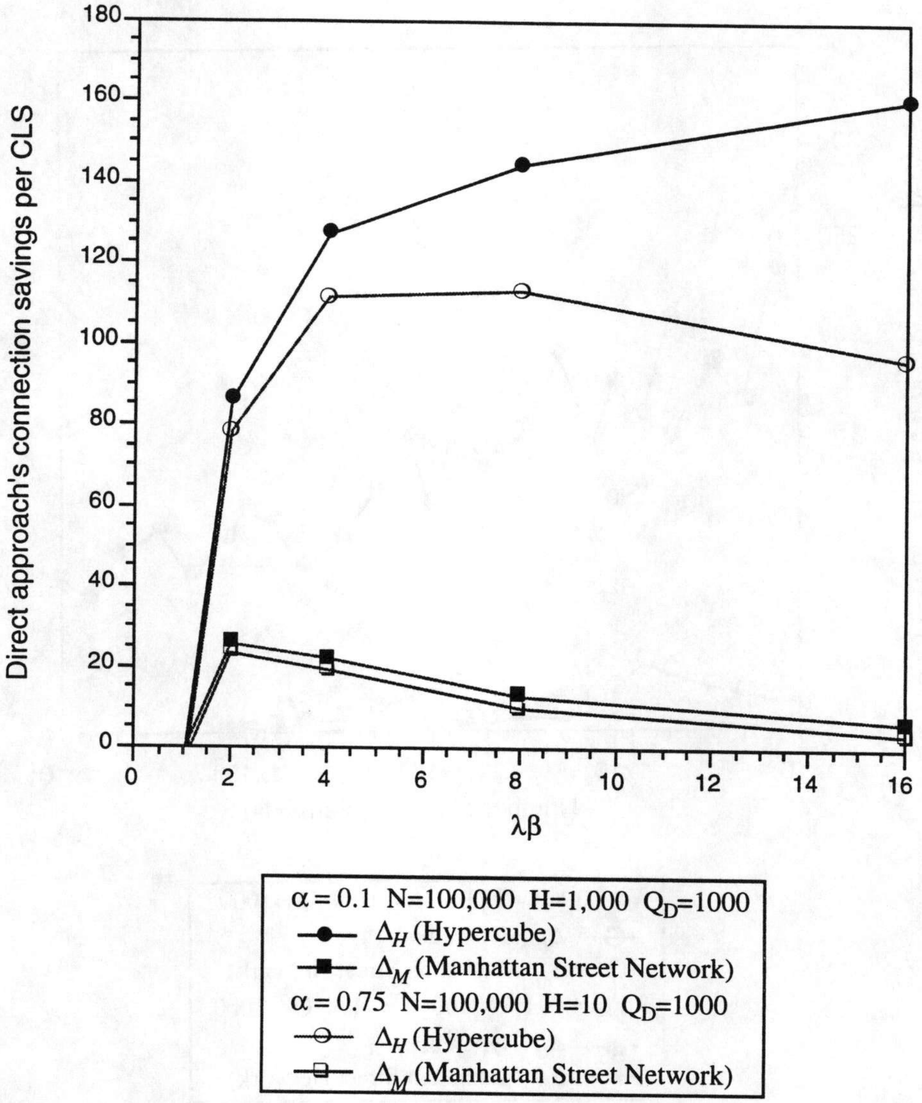

Figure 6: Server based approach's savings in number of open ATM connections as a function of $\lambda\beta$.

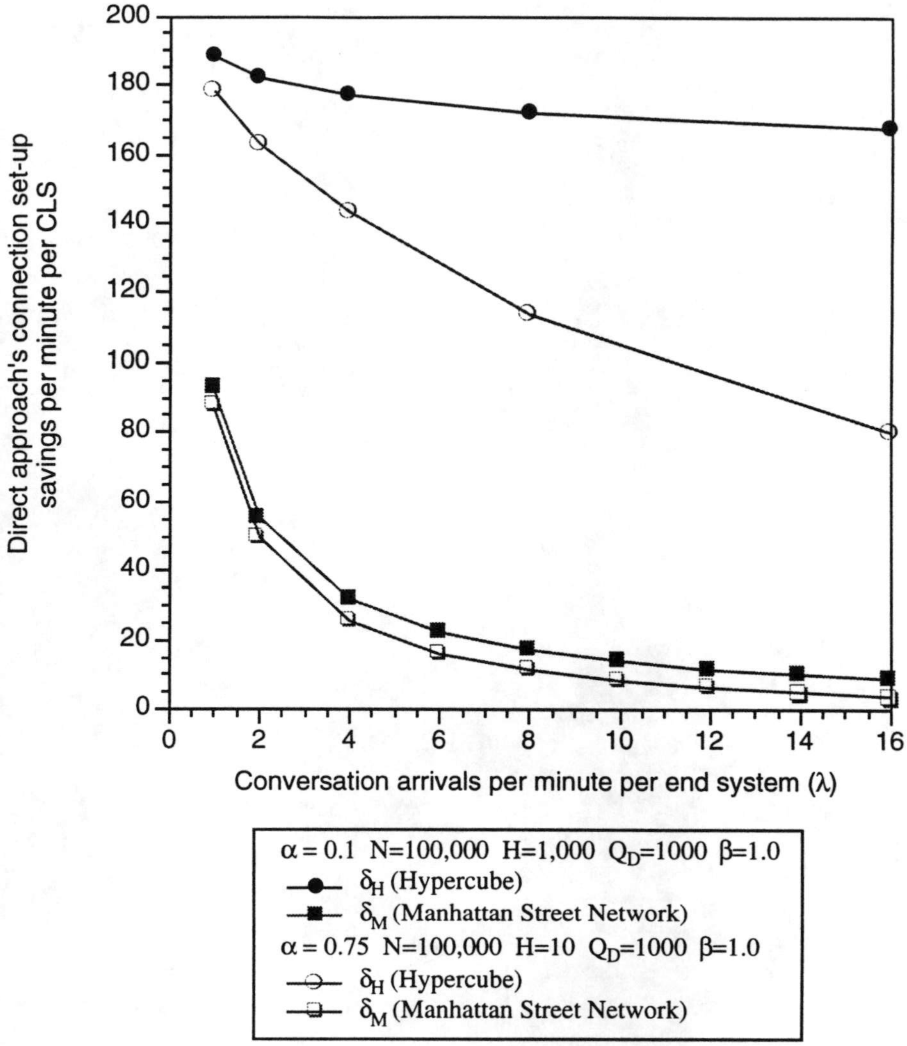

Figure 7: Server based approach's savings in ATM connection set-up rate as a function of λ.