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An Efficient and Implementation-Easy Ethernet Local Area Network with Applications *

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Abstract

With increasing requirements in the network bandwidth of LAN we must do our best to improve the required network bandwidth by using lower cost. This paper presents a mechanism for establishing an efficient LAN by using intelligent switching hubs of easy implementation and low delay, where an LAN structure is constructed based on a full tree that the leaves represent user stations, the internal nodes represent intelligent switching hubs and the links between any pair of nodes (or any pair of node and station) represent full-duplex communication connections. Such an LAN including implementation-easy and low-delay intelligent switching hubs has been shown that it can allows simultaneous communications to exist in different parts of the network, and can isolate certain user stations or networks so that the traffic congestion on an LAN can be reduced when more and more users add into the LAN. Moreover, since it is a tree structure and a switching network, it can provide more bandwidth for transmitting multimedia data by means of the priority scheme.

1 Introduction

Currently, Ethernet reigns as the mainstay of local area networks (LANs) in organizations around the world, because it has good reasons as follows [1]: (1) It is reliable, having a history of stability that keeps more than a decade. (2) It is economical, both in cost per connection and in choice of physical cabling. (3) It is flexible, supporting many different configurations and applications. However, Ethernet only delivers a finite amount of network bandwidth, which yields a challenge for network managers: the efficient and economical allocation and delivery of the right amount of bandwidth to the right location. The challenge of allocating and delivering limited bandwidth is exacerbated by an explosion in demand for it. To help network managers cope with the growing requirements for more LAN bandwidth, the networking industry has responded with a variety of internetworking devices that divide the network into smaller, more manageable segments, as well as with new technologies that provide inherently more bandwidth. Although these internetworking devices and technologies deliver more bandwidth, they also have their own limitations.

For network managers searching for more bandwidth, the variety of internetworking devices can be confusing. The choices range from wiring hubs to two-port bridges and routers, to multiport bridges and routers, to Ethernet switches, to new generations of intelligent switching hubs. Also, new technologies with inherently higher bandwidth, FDDI, which is available today, and ATM, which will be available in the near future, compound the complexity of the network manager's decision. Hubs are not an internetworking device in the purest sense, but they are essential because they simplify network management by centralizing the connection of devices to the network. However, they do not provide bandwidth or network segmentation. At the low end of the internetworking spectrum, two-port bridges and routers connect one segment to another in a linear fashion. This is a low-cost approach providing higher performance within the network segment, but it penalizes communications between networked devices on different segments. Further, a performance penalty will worsens as each bridge or router is traversed. Multiport bridges and routers eliminate much of the performance penalty of intersegmented traffic by connecting different segments in a star fashion, but they do not integrate with hubs. The result is that bandwidth never trickles downward from the hub to the desktop. Multiport bridges and routers are also expensive, both for the devices themselves and for the hubs that are needed to centralize management. Although related to intelligent switching hubs, Ethernet switches handle internetwork data differently from

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bridges and routers, which store and forward internetwork communications. Instead, Ethernet switches transmit data in such a way that the front end of a data packet leaves the switch before the back end enters the switch. Compared to other approaches, the cost is low and the throughput is high. Ethernet switches, though, sacrifice many of the features upon which network managers rely, such as subnetting, network redundancy via Spanning Tree, and packet error checking; however, these features can be found in intelligent switching hubs. Moreover, Ethernet switches are not well-suited to client/server applications, where more than one client need to simultaneously access a server. To do this, a connection providing more bandwidth than Ethernet must be used to connect the server. Today, that connection is FDDI. Given the limitations of these devices, many network managers are investigating the use of new technologies with inherently higher bandwidth, notably FDDI and ATM. Although FDDI is today's premier backbone technology because of the 100 Mbps bandwidth that it provides, it's less clear what its role will be in delivering bandwidth to the desktop. Additionally, cost is the concerns. Since FDDI requires new wiring, new network connectors, and new hubs, not to mention new tools and training for managing the technology. Plus, even FDDI offers a finite amount of bandwidth that is reduced when more and more devices attach to the network; thus it still requires segmentation via internetworking devices like bridges and routers [2]. ATM is a question mark because it is still under construction. While it will no doubt offer dedicated bandwidth to each attached device, it will be very expensive at present. Further, how it will integrates with current technologies is also unknown.

As the inherent limitations of these technologies and devices is apparent, network managers must turn to intelligent switching hubs to deliver the performance and flexibility required by their organizations. In this paper, like standard hubs, intelligent switching hubs provide the wiring flexibility of centralized connection for devices, as well as port-level management, and they also provide network segmentation. Moreover, they support multiple Ethernets that can be shared or dedicated, depending on the bandwidth requirements of the user, and multiple media types, including thick, thin, twisted-pair Ethernet. In the next section, we propose that a LAN structure which can achieve real multicasting, broadcasting and concurrent data communications among a group of communicants can be established by using intelligent switching hubs of easy implementation and low delay.

The remainder of this paper is organized as follows. In Section 2 we propose a LAN constructed by low-complexity intelligent switching hubs and describe the mechanism for data communications on it. Section 3 presents some applications for the intelligent switching hubs stated in Section 2. Then, in Section 4 we make analyses and discussions about the mechanism of data communications on the proposed LAN structure and about the advantages and the implementation cost of the structure. Finally, some concluding remarks are included in the last section.

2 A LAN including intelligent switching hubs

In the following we will present a LAN where the data transmission can be switched by using intelligent switching hubs. We first introduce the proposed LAN structure; based on it, we then describe the mechanism for data communications.

2.1 The proposed switching LAN structure

Our proposed switching LAN structure is constructed based on a full tree structure. Let's consider a communication network constructed by a full tree as shown in Fig. 1, where a tree is said to be full if all the nodes connect the children of the same degree and the leaves are on the same level. The leaves of the tree represent user stations, the internal nodes represent intelligent switching hubs and the links between any pair of nodes (or any pair of node and station) represent full-duplex communication connections. Assume that the level of the leaves of the tree is zero. Let l, $0 \leq l \leq L$, represent a level on the tree starting from the leaves to the root node and N_l be the number of nodes at level l that originates from the same parent node at level $l+1$. Then, the number of user stations N constructed by a symmetric tree is given by

$$N = N_0 = m^L,$$

where m is the degree of the symmetric tree.
It is assumed that the communications among user stations are formed under the following four states:

(1) Packet switching: data are exchanged by means of transmission units called packets which also contain all the information needed for the routing that will be stated in Subsection 2.2.

(2) Slotted transmission: the user stations are allowed to transmit packets at fixed time $t_i = iT$, $i = 0, 1, 2, ...$, where T is the time slot length. The packets have a fixed length and their transmission time equals the time slot.

(3) Blocked packets are resent: it may occur that a packet scheduled for a transmission cannot be routed along its path because the port buffer memory of an intelligent switching hub is full. When this is the case, the packet is considered to be resent in the next time slot.

(4) Uniform offered traffic: each user station transmits a packet in each time slot with a constant probability p. The packets are uniformly addressed to any other user station with probability $1/(N-1)$.

Additionally, in order to increase the flexibility of the proposed switching LAN structure, it can also be connected so that each internal node still has the same degree but the leaves must not be on the same level.

Implementation issues regarding the technical feasibility, complexity and cost will be addressed in

Subsection 2.2 and Section 4, respectively.

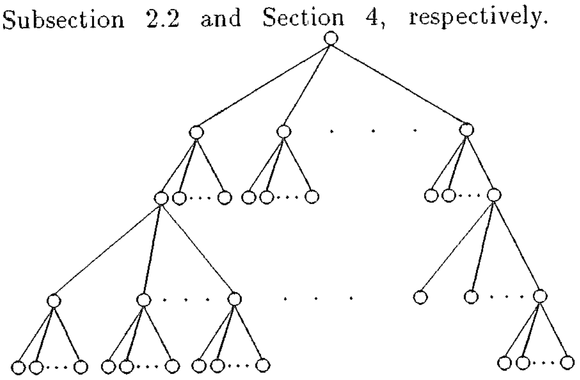

Figure 1: A full tree LAN.

2.2 The mechanism for data communications on the proposed LAN structure

Like the phone number in the telephone system, addressing in either a Token Ring or Ethernet network is the most basic way that two user stations will communicate with each other. Once the connection is established, all data will be transferred between the source and destination user stations. The telephone system does force us to remember phone numbers in order to communicate with another person. But, if we cannot remember the exact phone number, the phone company has phone books that enable us to do a name-number translation. Networks allow the same process of name-number translation although it is accomplished completely transparently to the user. It goes without saying that a network system forcing a user to type in a 6-byte Ethernet address to talk to another user station on the network is not feasible. Most installed networks today do use a naming scheme so that we do not have to remember all the addresses on the network. But we must remember this is only for human intervention. User stations on the network use physical addresses instead of names to communicate each other. The mapping process between names and physical addresses is accomplished in the media access control layer of the data link layer of the ISO model. Then, Our naming scheme will be described in the following.

According to the IEEE 802.3 standard [3] of 10 BaseT that Ethernet follows, we realize that the data transmission between two user stations can only pass 5 levels at most, that is, the maximum value of the level l in Figure 1 is 5. Therefore, we can design a LAN having m ports in each intelligent switching hub so that the LAN can be connected by m^5 user stations at most, as showned in Figure 2. In Figure 2, we utilize the alias scheme to name user stations. An intelligent switching hub will assign aliases to its attached user stations in the registration stage. The alias allocation of the LAN connected by m^3 user stations is illustrated in Figure 3. With network-specific addressing, each user station is assigned an alias that is unique within the LAN but can be the same that of a user station on other LANs. In this case, a unique LAN identifier must be used with the user station alias to provide a unique address when all LANs are interconnected together. Since Ethernet does not define how the 6 bytes of an address must be used, network-specific addressing is possible, but it is the responsibility of higher-level network layers to implement it. Before we go into any details about the proposed algorithm, we first define the incoming and outgoing packets. The former is defined as the packet received by an intelligent switching hub and the latter is defined as the packet transmitted by an intelligent switching hub. Then, we will show the algorithm as follows that can be run by intelligent switching hubs to transmit data securely from the source station to the destination station.

Step 1:

First, depending on the LAN identifier of the destination address in the transmitted packet, if it is not the same as the LAN identifier of the source address in the transmitted packet, then the packet will climb the tree up to the rooted intelligent switching hub and be transmitted to another LAN by a router. Otherwise, it will go to Step2.

Step 2:

The port of the switching hub at level l, connected to the source station at level $l-1$ or the intelligent switching hub at level $l-1$ with the outgoing packet, checks the destination station alias of the incoming packet to see whether it is within the range of the maximum and the minimum aliases associated to its switching hub or not.

(a) If it is within the range, the port of the intelligent switching hub at level l will compute the following formula

$$\lfloor [(\text{The destination station alias of the incoming packet}) - (\text{The minimum alias of the switching hub at level } l)] \,/\, m^{(l-1)} \rfloor \text{ ———————— (A)}$$

to decide the port number of the outgoing packet. So, the packet will be successfully transmitted to the destination station or the intelligent switching hub at level $l-1$ from the computed outgoing port number of the intelligent switching hub at level l. If the packet has been transmitted to the intelligent switching hub at level $l-1$, then recursively apply this process to the intelligent switching hub at level $l-1$ until the packet is reached to its destination station.

(b) If it is not within the range, the packet will continue to climb up one level, and then goes to Step 2.

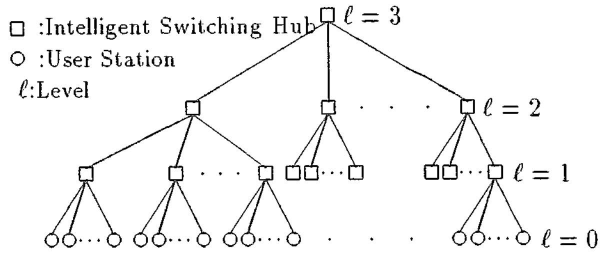

Figure 2: The proposed LAN structure.

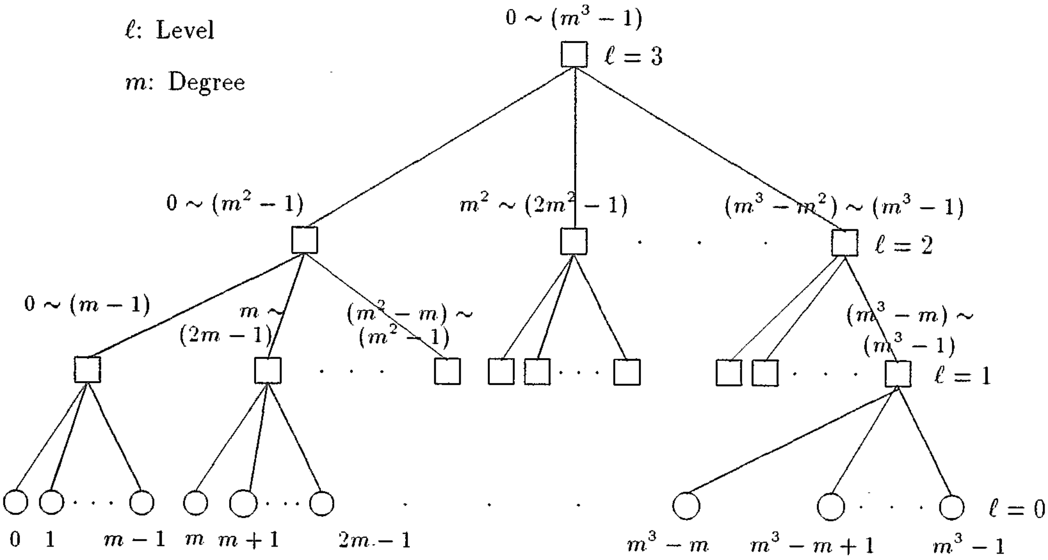

Figure 3: The alias allocation.

For instance, in Figure 3 we may transmit the packet from the source station whose alias is 0 to the destination station whose alias is $m^3 - 1$. All the operations executed by intelligent switching hubs are listed as follows:

(1) First, according to Step 2 of the above algorithm, we find that the alias of the destination station is within the range of the maximum and the minimum aliases associated to the switching hub at level 3, because
$0 \leq m^3 - 1 \leq m^3 - 1$. So, the packet must climb the tree from the source station up to level 3.

(2) Next, the outgoing port number of the intelligent switching hub at level 3 can be computed by formula (A) as follows:
$\lfloor [(m^3 - 1) - 0] \; / \; m^{(3-1)} \rfloor = m - 1$
Therefore, we find that the packet will be transmitted to the intelligent switching hub at level 2 through the port number $m - 1$ of the intelligent switching hub at level 3. Then, the intelligent switching hub at level 2 will compute the formula (A) again
$\lfloor [(m^3 - 1) - (m^3 - m^2)] \; / \; m^{(2-1)} \rfloor = m - 1$
to decide the outgoing port number $m - 1$ to transmit the packet to the intelligent switching hub at level 1. Finally, the intelligent switching hub at level 1 will compute the formula (A) again
$\lfloor [(m^3 - 1) - (m^3 - m)] \; / \; m^{(1-1)} \rfloor = m - 1$
to decide the outgoing port number $m - 1$ to transmit the packet to the destination station $m^3 - 1$.

Therefore, we can realize that the above algorithm will be able to transmit the packet from the source station to the destination station correctly and successfully.

3 Applications

We will present three applications about the tree LAN in the section.

(1) Client/server workgroup accelerator:
The growing acceptance of the client/server computing model, in which networked computers share processing responsibilities, is increasing traffic over the network. In the following, we will show a low-cost cure for client/server overcrowding. That is, we employ intelligent switching hubs to establish point-to-point connections between clients and servers. A single port of each intelligent switching hub can offer 10 Mbps to an LAN server equipped with a single Ethernet adapter card. If the same server is fitted with two, three,or four adapters, then the intelligent switching hub can dedicate 20, 30, or 40 Mbps to it. This means that an intelligent switching hub should be able to deliver 40 Mbps to the server equipped with multiple adapters, as shown in Figure 4.

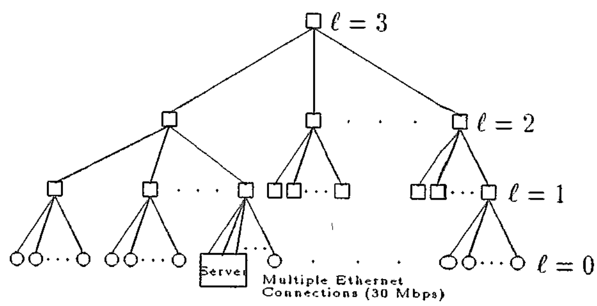

Figure 4: Client/server workgroup accelerator.

(2) Virtual LAN:
The number of network users is rapidly increasing as organizations discover the benefits of networking. In this paper, the intelligent switching hubs can provide the function of the virtual LAN by using the property of the locality multicasting. Since the tree LAN proposed in this paper is to use intelligent switching hubs to switch data, it can form some workgroups due to the location relation and really accomplish the locality multicasting. Hence, in Figure 5, although user stations are distributed in different places, they can be formed some workgroups with considerable bandwidth according to their requirements.

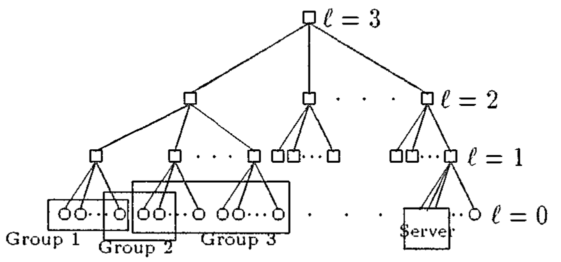

Figure 5: A Virtual LAN.

(3) Multimedia transmission:
There are many LANs in operation today with bandwidths ranging from 4 to 16 Mbps. These LANs handle digital high-speed communications within workgroups and departments. Geographically such LANs are limited to communications within a building or nearby facilities no farther than a few kilometers away. LANs are also designed to handle relatively small data packets, in short bursts, intermittently, rather than continuous data streams required for multimedia video and audio transmissions. However, a tree topology provides multiple branching connections in a hierarchical pattern. A user station can transmit only packets to a higher level network node which passes the message to another user station or to a still higher level network node. A local telephone system operates along those lines. In such a topology the network is only partially loaded when a transmission takes place. This makes it of potential interest for multimedia communications [4]. Hence, since our proposed switching LAN is a tree structure and a switching network, it can provide more bandwidth for transmitting multimedia data by means of the priority scheme. The priority scheme is to divide the transmitted data into multimedia data and general data so that multimedia data can get the higher transmission priority and achieve the transmission continuity and stability. Moreover, we can apply the proposed switching LAN and switching method to the cell-based network such that they can benefit the multimedia data transmission very greatly and control the CDV (cell delay variance) more easily.

4 Analyses and discussions

The analyses and discussions of the proposed LAN structure are listed below.

(1) Borgonovo and Fratta [5] present the throughput analysis of a tree topology, where the network model is similar to our proposed LAN structure. Therefore, this analysis is applicable to our proposed LAN structure.

(2) In our proposed switching LAN structure, it allows simultaneous communications to exist in different parts of the network. So, the number of concurrent transmissions and the aggregate throughput of the network can be increased, and lower average packet delays can be expected. Moreover, the implementation complexity of the secure mechanism for data communications on the proposed LAN structure is low since each port of the intelligent switching hub only needs one comparator, one adder, one multiplier and one divider (no floating-point operation) to compare the LAN identifier and the alias and to compute the formula (A) as stated in Subsection 2.2, and one demultiplexer to switch a packet to the outgoing port. Furthermore, because the address recognition and data forwarding are achieved by the hardware switching circuits instead of software methods that must be executed by a CPU, the proposed LAN can obtain high throughput and low delay. It is designed in such a way that each intelligent switching hub must use one CPU to assign aliases. After aliases have been assigned, then the CPU can be utilized to run management software, including a Simple Network Management Protocol (SNMP) agent. Hence, it only needs one cheap CPU, e.g. Intel 8086 or 8088, to do these affairs.

(3) Routing mechanisms used in internet environments determine the proper path on the networks. In general, the path from the sending host to the receiving host may not be the same as that from the receiving host back to the sending host. It may be a security weakness if they are not the same [6]. In this paper, there is only one path allowed between any pair of user stations. The path is determined by climbing the tree up to the higher level where an intelligent switching hub is the ancestor of both user stations. Then the packet is routed down to the destination switching hub.

(4) Since all traffic on each LAN must pass through the intelligent switching hubs that can restrict data delivery, the data transmission mechanism can prevent eavesdropping by irrelated user stations.

(5) In our proposed tree LAN, different routing possibilities may exist in establishing a connection between two user stations. With simple hubs [7, 8, 9], packets from leaf stations may be forwarded on uplinks to the root, then broadcasted

on downlinks to all the leaf stations. But, with our proposed intelligent switching hubs, it can have a packet travel up until the proper ancestor of its source and destination station is reached, where the proper ancestor of two leaf stations A and B is the root of the smallest subtree that has both A and B as its leaves. Then the packet is routed through the appropriate links to its destination station. Therefore, the intelligent switching hubs can isolate certain user stations or networks so that one-to-one, one-to-many, many-to-one or many-to-many communications can be securely achieved.

(6) Since Ethernet does not define how the 6 bytes of an address must be used, in order to satisfy our proposed LAN structure we define them in the following. First byte represents the multicast of Ethernet, second byte represents the LAN identifier, third and fourth bytes represent the alias address, fifth byte represents the locality multicast, and sixth byte represents the priority and aging counter value.

5 Conclusions

We have presented the design of the mechanism for data communications on our proposed LAN structure. We can find that its implementation complexity is low, because each port of the intelligent switch hubs only needs one comparator, one adder, one multiplier, one divider, one demultiplexer and one buffer memory. Besides, the network performance can be improved because of the increased percentage of concurrent transmissions. In short, some advantages of the proposed LAN structure can be listed as follows:

(1) Its operation is completely transparent to both network users and machines.

(2) It allows for an easy and economical implementation in local area networks.

(3) Because of increased concurrency of transmissions, it can reduce the network traffic efficiently.

(4) Since the intelligent switching hubs can be implemented by the hardware switching circuits of low complexity to recognize addresses and forward data, it can accomplish high throughput and low delay.

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