Copyright © 1983 American Telephone and Telegraph Company
THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 62, No. 3, March 1983
*Printed in U.S.A.*

# Star Network With Collision-Avoidance Circuits

By A. ALBANESE

(Manuscript received July 15, 1982)

*This paper describes the implementation of a multiple-access star network that uses a new collision-avoidance circuit to avoid collision of packets and to take full advantage of wideband transmission systems. The analysis shows that the resulting network has a channel capacity equal to 1, has good stability under heavy traffic conditions, allows transmission of packets shorter than the network round trip time, and provides distributed switching. Collision-avoidance circuits have been built and operated up to 50 Mb/s.*

## I. INTRODUCTION

Carrier-Sense Multiple-Access local-area networks with collision detection (CSMA-CD)[1] have been implemented using lightwave technology,[2] but the use of lightguides is questioned because the networks do not benefit from the full bandwidth of the lightguides. In these networks, the lightguides are used to reduce ground-loop voltage, electromagnetic interference (EMI), size, and weight of the cable.

CSMA-CD networks have the disadvantage of requiring a large packet size when they operate at high bit rates. For example, a 1-km-long (2-km round trip) passive star network,[2] operating at 150 Mb/s, has an efficiency of 5 percent for 256 bits/packet, 44 percent for 4096 bits/packet, and 93 percent for 65,536 bits/packet. In addition to the low efficiency there is an associated instability problem that appears when the network reaches the channel capacity.[3] Without traffic restrictions or under heavy traffic conditions the network becomes unstable and crashes.

This paper describes a new method to eliminate the collisions caused by simultaneous transmission of packets in a star network. The method consists of placing collision-avoidance circuits in the node at the center of the star. This collision-avoidance circuit does the work of a "traffic cop," in that it lets pass the packets that arrive while the node is idle and blocks those that arrive while the node is busy. The packets that make it through the "traffic cop" are broadcast to all users including the sender, and the blocked ones are retransmitted (by the originating users) until they succeed in getting through the node.

The insertion of collision-avoidance circuits in a star network results in a network that has the combined advantages of a zero-length CSMA-CD (high throughput and good stability) with those of ALOHA (transmission of packets shorter than the network round trip time). The resulting network is more efficient and stable than CSMA-CD networks and takes full advantage of high-bit-rate transmission. These characteristics make the network attractive for transmission at high bit rates and make lightwave networks suitable for local area networks.

The "traffic cop" requires active components at the center of a passive star, which poses a disadvantage in terms of reliability. This problem is minimized by using a small number of components in the circuit, conserving the distributed-switching feature of multiple-access networks, and providing centralized maintenance.

The sections that follow describe the architecture, protocol, implementation, and analysis of the network.

## II. NETWORK ARCHITECTURE

Figure 1 shows the case of a local-area network where all users are connected in a star configuration to a central node (N) by a user-interface circuit (UIC). This interface consists of a transmitter (T), a receiver (R), and a logic circuit (C) that enable the receiver that first receives a packet after the node is idle. The node consists of a short bus with a maximum length equal to the length that makes the time of a bus round trip equal to the period of one bit. Each user is connected to the UIC by a user's link.

## III. PROTOCOL

The protocol between the user and the network can be summarized as follows: the user-interface circuit blocks those packets arriving at the central node before they could cause a collision, and the users keep retransmitting unsuccessful packets until they succeed in getting through the node.

The description of the protocol is divided into the user and node protocols.

### 3.1 User protocol

The user has input and output buffers to store the received and transmitted packets. When a user end has a packet in the output buffer to be transmitted:

(*i*) It transmits the packet at once.

(*ii*) It waits the user's round trip time, $T_{\mathrm{RT}}$.

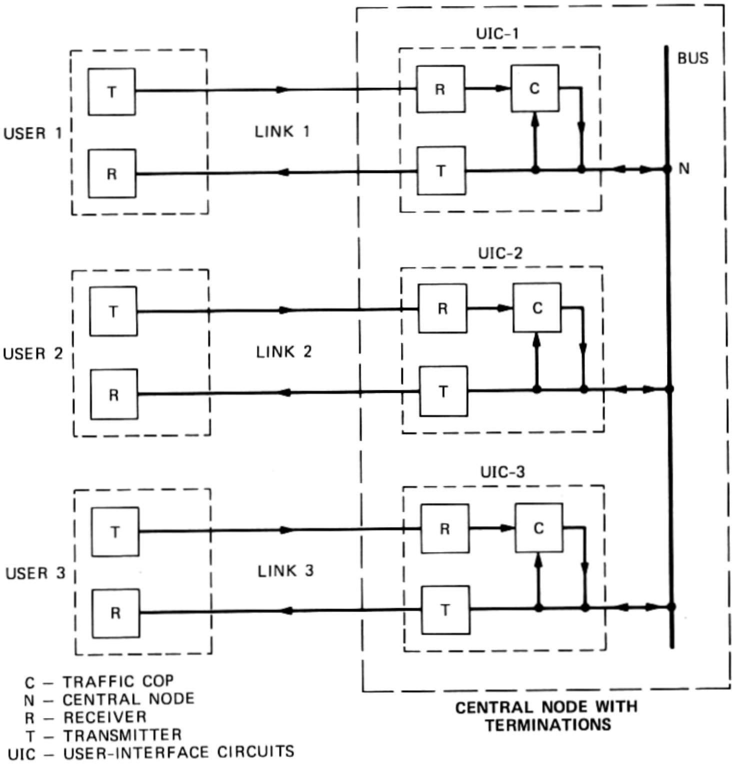

Fig. 1—A local-area network showing how all users are connected in a star configuration to a central node by independent user-interface circuits.

(*iii*) It checks the input buffer, and if a packet was received, it analyzes the origination and destination.

(*iv*) If a packet was not received, or if the received packet is not the same as the transmitted one, the packet was blocked at the node, and the whole process is repeated until the packet succeeds in getting through the node.

### 3.2 Node protocol

The transmitters and receivers at the central node are controlled in the following way:

(*i*) All the transmitters are connected to the node N at all times. Therefore, all the users are continuously receiving the packets broadcast by the node.

(*ii*) All the receivers are disconnected from the node.

(*iii*) The receivers and the node are continuously monitored for "idle" or "busy" status.

(*iv*) When a packet arrives at the receiver, the receiver becomes "busy." A transition of the receiver from "idle" to "busy" while the node is "idle" connects the receiver to the node, and changes the node status to "busy." A transition of the receiver from "idle" to "busy" while the node is "busy" is ignored and the receiver remains disconnected. In this way, only the receiver with the first arriving packet is connected to the node, and all the others are ignored or disconnected.

(*v*) The node status returns to "idle" when the broadcast packet ends and the receiver is disconnected.

This protocol is performed by a logic circuit (C) whose functions are shown in Fig. 2. The receiver (R) and the transmitter (T) are part of the user's link and they vary according to the type of link. The logic circuit consists of an AND gate and four flip-flops. The four flip-flops are wired to perform the receiver-monitor, node-monitor, arbiter, and hold-on functions. The AND gate connects and disconnects the receiver to the node (N) following the status of the hold-on flip-flop. Figure 3 shows the timing diagram for the different parts of the circuit.

The receiver monitor and the node monitor are retriggerable single-shot circuits that detect the presence of a packet by sensing the carrier. They go "high" at the arrival of a packet and return "low" at the end of the packet.

The arbiter is a D-type flip-flop that produces an "I was first" pulse when the receiver monitor goes "busy" while the node monitor is "idle." The "I was first" pulse indicates that the receiver has the first arriving packet and sets the hold-on flip-flop "high." All "idle" to "busy" transitions of the receiver monitor that occur while the node monitor is "busy" are ignored and they do not set the hold-on flip-flop.

The hold-on flip-flop goes "high" following the "I was first" pulse

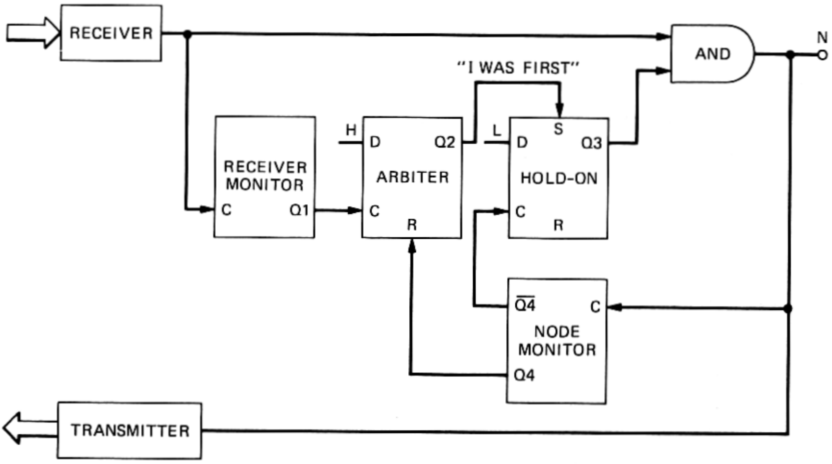

Fig. 2—User-interface circuit showing four flip-flops wired to perform the receiver-monitor, node-monitor, arbiter, and hold-on functions.

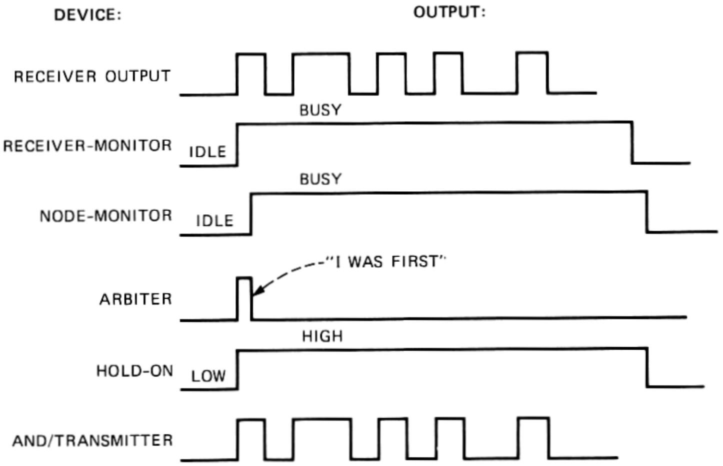

Fig. 3—A timing diagram of the user-interface circuit. The hold-on goes high only when the receiver monitor goes high before the node monitor does.

and returns "low" when the node monitor goes "idle." The output of the hold-on flip-flop activates the AND gate that connects and disconnects the receiver to the node (N).

The reader may wonder what happens when two or more packets arrive simultaneously. This is a rare event because it takes less than 20 ns to determine which was the first packet arriving. But suppose anyway that two packets arrive within a period of 20 ns; then a collision is possible because two receivers will be simultaneously connected to the node. An exclusive-OR circuit can be installed in the way shown by Fig. 4 to handle this rare event. This additional circuit resets the hold-on flip-flop ("low") any time that the receiver signal is different from that of the transmitter and while the node is "busy." The two receivers remain connected until the signal for one of the receivers differs from its transmitter signal. The receiver with the first low bit stays connected and the others are disconnected. Figure 5 shows the timing diagram of the different components when two users are randomly transmitting words.

## IV. ANALYSIS

To study the system let us consider a network of $K$ users each successfully transmitting $\lambda$ packets/second, each $\tau$ seconds long through the node. Then one defines $S = K\lambda\tau$, which is the average channel utilization, also known as the traffic intensity or traffic throughput.

$S$ is also the probability of a user encountering a busy node in any attempt at transmitting a packet. The probability of successfully

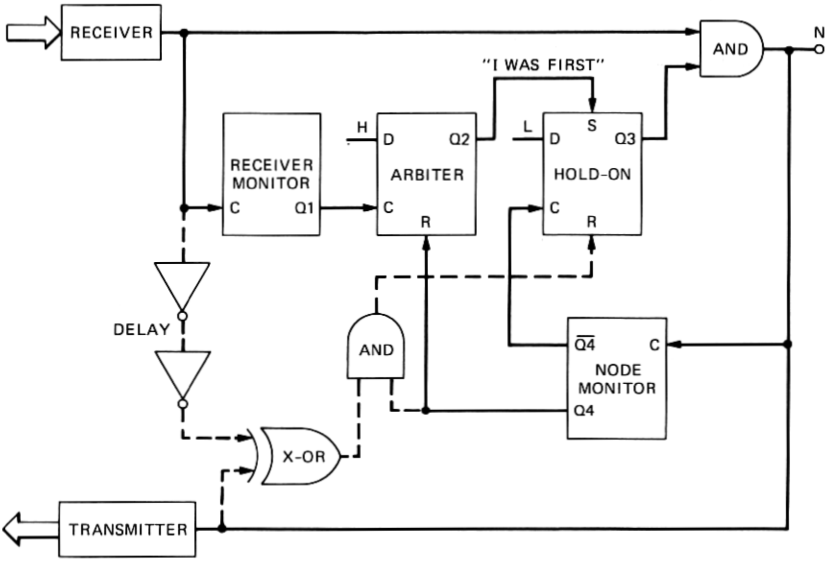

Fig. 4—Addition to the circuit to handle simultaneous events. The dashed lines indicate the circuit added to Fig. 3 to determine the priority of packets that arrive within the circuit response time.

transmitting a packet is $1 - S$. Therefore, the average number of transmissions required to get a packet through the node is

$$N = \frac{1}{1 - S} \tag{1}$$

and the average traffic offered by the users to the network is

$$G = SN = \frac{S}{1 - S}; \tag{2}$$

consequently, $S$ can be expressed in terms of $G$ as

$$S = \frac{G}{G + 1}. \tag{3}$$

Another parameter of importance in the network is the average user's transmission delay. This delay is computed adding all the possible delays weighted by their probabilities:

$$\begin{aligned} D &= T_1(1 - S) + (2T_1 + T_2)S(1 - S) \\ &\quad + (3T_1 + 2T_2)S^2(1 - S) + \cdots \\ &= T_1 N + T_2 S N, \end{aligned} \tag{4}$$

where $T_1 = T_{\mathrm{RT}} + \tau$, $T_2$ is the retransmission delay in addition to $T_1$,

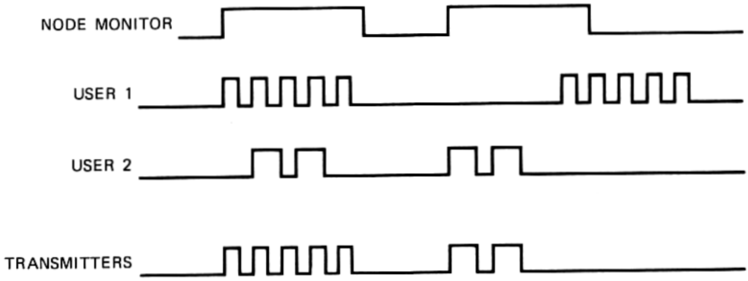

Fig. 5—Timing diagram showing two users randomly transmitting. The circuit broadcasts the packets of user 1 and user 2 that arrive only while the bus is idle.

and $T_{RT}$ is the user's round trip time. The delay is reduced by making $T_2$ small comparable to $T_1$, which leaves only the first term in eq. 4.

The above equations are analogous to those of a zero-length CSMA-CD network where the ratio $T_{RT}/\tau = 0$ makes the maximum value of $S$ equal to 1.

More efficient modes of operation are possible but they will increase the complexity of the stations. For example, a clock may be installed at the node N to broadcast a burst to indicate the beginning of a frame, and have reserved channel assignment. This arrangement decreases the average delay but it requires a reservation protocol.

## V. CONCLUSION

A new arrangement for a star network was proposed and a central-node configuration, as shown in Fig. 1 with UIC, was built and operated with packets up to 50 Mb/s. The node eliminates collisions by resolving the right-of-way when several packets arrive at the node. The node lets pass the packet that arrives first and blocks all other packets that would collide with the first one. Meanwhile, the users keep retransmitting packets until they get through the node.

The analysis shows that the average number of retransmissions depends on the traffic intensity at the node, and the retransmission of unsuccessful packets does not degrade the traffic throughput of the node. Also, the channel capacity has the maximum value 1, and it is not a function of the ratio between the packet size and the network-round-trip time.

The analysis shows that at moderate traffic intensities (50 percent) the average number of retransmissions is two. Traffic intensities approaching 100 percent may cause a large number of retransmissions. A 75-percent traffic intensity requires an average of four retransmissions, 80 percent requires five, and 90 percent requires ten.

High-bit-rate services can be provided simultaneously with low-bit-rate services without changing the traffic intensity simply by increasing the transmission bit rate and holding the packet duration and the packet frequency constant.

## REFERENCES

1. R. M. Metcalfe and D. R. Boggs, "Ethernet: Distributed Packet Switching for Local Computer Networks," Commun. ACM, *19,* No. 7 (July 1976), pp. 395–404.
2. E. G. Rawson, R. M. Metcalfe, R. Norton, A. B. Nafarrete, and D. Cronshaw, "Fibernet: A Fiber Optic Computer Network Experiment," IEEE Trans. Commun., *COM-26,* No. 7 (July 1978), pp. 983–90.
3. L. Kleinrock and F. A. Tobagi, "Packet Switching in Radio Channels: Part I—Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics," IEEE Trans. Commun., *COM-23,* No. 12 (December 1975), pp. 1400–16.