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STARNET A FIBER OPTIC METROPOLITAN AREA NETWORK WITH CENTRALIZED CONTROL

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STARNET, A FIBER OPTIC METROPOLITAN AREA NETWORK WITH CENTRALIZED CONTROL

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We present here a project involving a new long distance, high speed, fiber optic network with a passive star topology. The medium access mechanism is based on a centralized controller allowing channel reservation. This controller is connected to each station through an independent pair of optical fibers. It grants access using a deterministic scheme (DAMA/ICCC, demand assignment multiple access by independent centrally controlled channel) by means of a Round Robin algorithm allowing a simple implementation of priority levels and very high data channel efficiency. An overview of the first implementation design is given and some experimental results are presented.

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We present here a project involving a new long distance, high speed, fiber optic network with a passive star topology. The medium access mechanism is based on a centralized controller allowing channel reservation. This controller is connected to each station through an independent pair of optical fibers. It grants access using a deterministic scheme (DAMA/ICCC, demand assignment multiple access by independent centrally controlled channel) by means of a Round Robin algorithm allowing a simple implementation of priority levels and very high data channel efficiency. An overview of the first implementation design is given and some experimental results are presented.

1. Introduction

A new class of networks (MANs, metropolitan area networks) using fiber optics as physical medium and allowing integration of file transfer, real-time data control, voice and video at speeds higher than 100 Mbps, over distances of the order of 50 km, are presently under study. Examples include the Queued Packet and Synchronous Switch (QPSX) [1], the hybrid Fiber Distributed Data Interface (FDDI-II) [2], and the Multiple Slot and Token Protocol (MST) [3]. These networks protocols are at different stages of development. All these networks have as a common characteristic a medium access scheme, which maintains packet switched (PS) as well as circuit switched (CS) connections, allowing the integration of the different services.

In this paper we present the characteristics of a new MAN, STARNET [4,5], using star topology implemented with passive star couplers and a central controller (TRANTOR, transmission analyzer and network traffic organizer of resources) for handling the channel requests from each station and for allocating the data channel to them according to topological parameters and the length of the packets to be transmitted. This protocol retains the topological knowledge requested by the traditional DAMA schemes [6–8], but the control is implemented by a centralized controller linked to the stations through separate point-to-point communication channels instead of a linear channel and a distributed algorithm. This results in a better performance measured in terms of the maximum cycle time and throughput.

STARNET, as the other MANs mentioned above, defines a medium access protocol (MAC) compatible with the LLC software level, specified by the ISO/OSI 8802/2 document [9], thus assuring a valid interface to the highest ISO/OSI levels.

The STARNET design was conceived two years ago and during this period the work developed in the following areas: topology design, optical fiber study and laboratory tests, transmitter and re-

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ceiver implementation, station interface project, star controller implementation, and protocol simulation. The aim of this paper is to give an updated outline of the project at the present stage.

2. Topology and protocol

STARNET is based on the use of single mode optical fibers and passive start couplers (fig. 1a) for distances greater than 50 km and speeds starting at 120 Mbps. Passive star couplers are inherently reliable and contain no electronic components. This makes STARNET more reliable than networks using active processing components in each station, such as in token mechanism models on ring or bus topologies. The maximum multiplicity of a STARNET star can be calculated as a function of the optical power margin defined as the difference between the laser output power and the minimum power detectable at the receiver. If the power margin is about 40 dB, up to 32 stations over a maximum distance of 50 km can be connected [5]. The number of interconnected stations can be increased to 256 with the same power margin, if the $N \times N$ star is realized by connecting two $N \times 1$ stars through an active repeater (fig. 1b). For reliability reasons, two $N \times 2$ stars with two repeaters could be used.

The data channels from all the stations converge into a passive optical star coupler in a flooding configuration. The central controller (TRANTOR), allocating the data channel, communicates with each station through physically separated fiber optical links. Although this configuration increases the number of fibers, it enables extremely efficient channel utilization. Note that the price of a multifiber cable is much higher than that of the fibers it contains, due to the high cost of shieldings, protective coatings and installation.

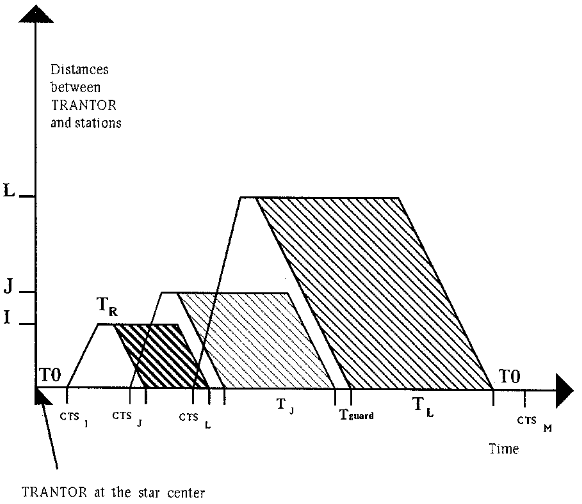

Fig. 2. Packets lined head to tail in the center of the optical star.

A STARNET station is made up (fig. 1c) of a host and network interface (DIASPAR, data interface adapter and standard port access to resources) connected to the data channel through the optical interface (TRIFFID, transmission and

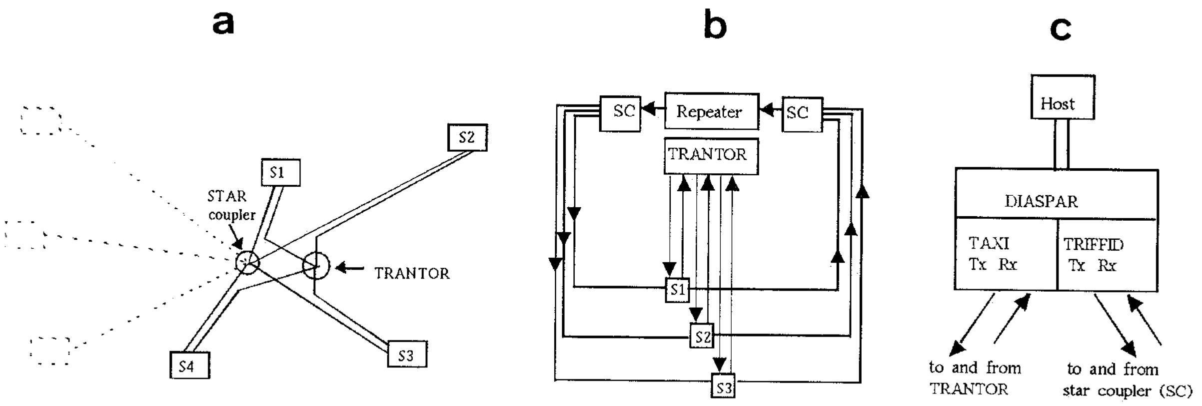

Fig. 1. STARNET (a), basic STARNET topology with repeater (b) and station scheme (c).

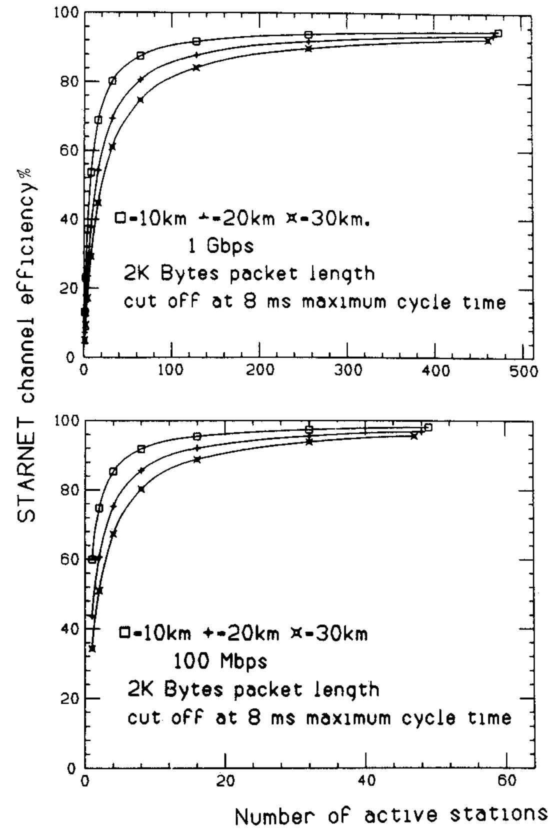

Fig. 3. STARNET channel efficiency vs. number of active stations for different star radii.

reception implementor and fast fiber interface driver) and to the control channel using AMD TAXI chips and electro-optical converters.

A station wanting to send a message must request permission from TRANTOR on its private control channel (request to send, RTS). The station enters a waiting state until a "clear to send" (CTS) message is received from TRANTOR. TRANTOR knows some of the configuration parameters: distances, station reaction times and guard times. Using this data, it is able to determine when the CTS message has to be sent to each station (see fig. 2).

Results of the channel efficiency calculations as a function of the number of "active" stations in the star are given in fig. 3 for different star radii and different channel speeds. The maximum number of stations is bounded in any case by a maximum cycle time of 8 ms in order to assure the maximum delay requested for voice applications. A larger number of stations can be obtained by implementing priority levels in the authorization algorithm.

The efficiency, eff(N), where N is the number of active stations, is calculated using the following expression,

$$\mathrm{eff}(N) = \frac{\sum_{i=1}^{N} T_i}{T_{\mathrm{cycle}}}, \tag{1}$$

where T_i gives the packet time of the station i and the cycle time, T_{cycle}, is given by

$$T_{\mathrm{cycle}} = T_0 + T_{\mathrm{R}} + 2\tau d_1 + \sum_{i=1}^{N} \left(T_i + T_{\mathrm{guard}}\right) + \sum_{j=2}^{N} \eta^j. \tag{2}$$

Here T_0, T_{R}, and T_{guard} are, respectively, the initial TRANTOR time for each cycle, the station reaction time and the interpacket time (i.e. the minimum time between two consecutive packets). The $\tau = 5$ μs/km is the delay per unit length of the fiber, and d_1 is the distance between the first station transmitting in each cycle and the TRANTOR, which is supposed to be located at the center of the star. The last term takes into account the cases where due to the very different distances between station and TRANTOR, it will be impossible to align packets in the center of the star with the minimum intergap between them. The interpacket value depends on the indeterminacy on the distances (less than 10 meters using standard optical instruments), and laser power on and off times. Due to the introduction of the controller the STARNET efficiency, both at heavy and light loads, depends only on the number of stations transmitting in each cycle and not on the total number of stations in the network. Moreover, the efficiency is determined by the minimum distance from the star hub of all the stations transmitting in each cycle, and does not depend on the total round trip propagation delay as in the case of network protocols using implicit or explicit token mechanisms. This makes possible a high efficiency even if the star is extended beyond the traditional 1 km limit [10].

3. The TRANTOR module

TRANTOR is the central intelligent controller for a star. Its purpose is to collect and record the reservations (RTS) from each station of a star and to grant permission to transmit (CTS) in an organized sequence (see fig. 4). For optimization purposes the controller is located near the center of the star, close to the optical star coupler. Since the authorization CTS messages are sent over separate channels, it is possible to time their transmission to take into account the propagation delay from TRANTOR to the station and vice versa. In order to optimize the traffic in the center of the star, TRANTOR assigns transmission authorizations to the active stations in order of distance, starting with the one closest to the center of the star. This method minimizes the channel inactivity time at the beginning of each cycle. To allow this complicated system of decisions and permit flexibility and adaptability to future STARNET versions, the prototype TRANTOR contains a very fast CPU (the Texas Instruments DSP TMS 320C25, with an instruction time of 100 ns and a fairly large instruction set). The prototype TRANTOR has been projected on VME boards and is capable of handling 8 stations. The AMD TAXI chips have been used to implement the control channels, due to their ease of connection and high integration. The communication protocol between TRANTOR and DIASPAR's has been designed to be extremely simple in order to minimize time losses. The RTS message contains the length of the packet to be sent as a parameter, which is necessary to calculate the correct CTS time to get contiguous packets on the line.

4. The DIASPAR module

DIASPAR is the data communication controller of the STARNET station. It provides the interface between the host and the network. Two different modules implement the DIASPAR transmitter and receiver (see the block diagram in fig. 5). Each of them uses a DSP in order to realize the functions described in the following and uses gate arrays in order to implement the most time critical parts: CRC calculation and address manipulation.

In transmission, when the HOST INTERFACE (see fig. 5) receives the transmission request from the host, it starts to fill a free buffer activating the packet construction logic that inserts the following in sequence: the destination address obtained from the host, the DIASPAR source address, the data length in bytes, the user data (eventually extended with null bytes if their length is smaller than the

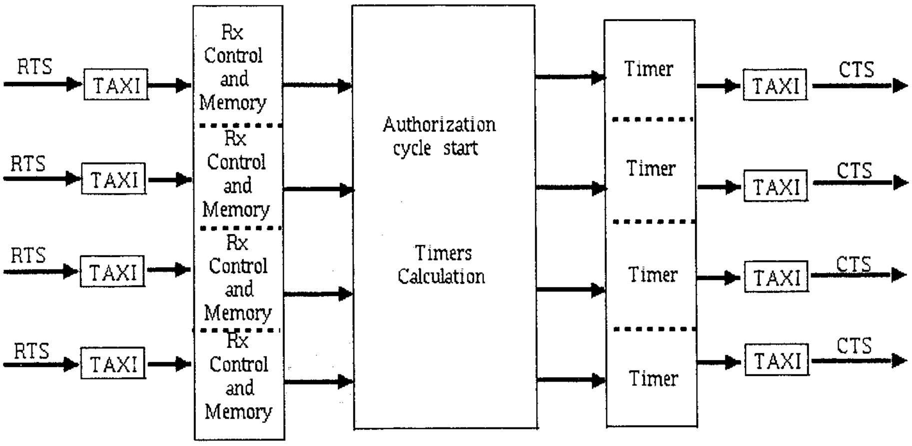

Fig. 4. TRANTOR block diagram.

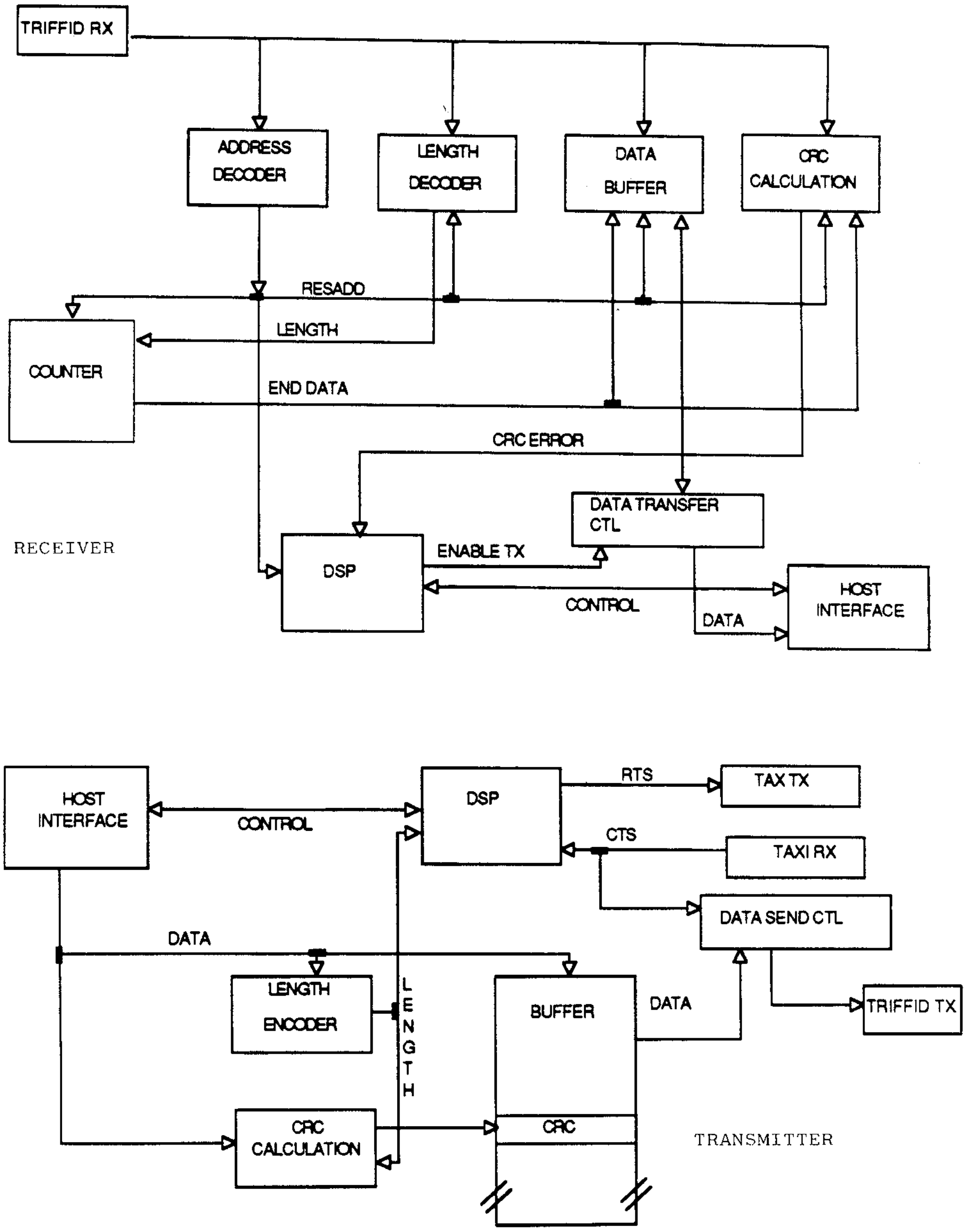

Fig. 5. DIASPAR block diagram.

minimum packet length required), and the CRC (that is calculated using the fields defined in the previous points).

The packet length is also used by the DSP in order to construct the RTS message to be sent to the TRANTOR. When the packet is completed, the HOST INTERFACE tells the DSP that the RTS message can be sent. After sending the RTS message, the DSP activates a timer marking a time interval longer than the STARNET maximum round trip, to be used to inform the host that the TRANTOR is down. This timer is reset when the

CTS message is received from the TRANTOR. The CTS message is also received by the DATA SEND CTL logic (see fig. 5), which activates the TRIFFID in order to start the packet transmission. This logic presents 32 bits to the TRIFFID each time until the end of the packet is reached. At this moment, the DSP is informed so that it can communicate the end of transmission to the host. While the DSP must serve different interrupt requests, the DATA SEND CTL logic repeats serially the same operations from the CTS reception up to the start of the packet transmission, thus giving a constant execution time. This time is critical for the protocol and must be exactly known in order to assure the efficiency of the authorization algorithm.

In reception, the ADDRESS DECODER logic (see fig. 5) examines the packet destination address to determine if the packet is addressed to it. DIASPAR can work in promiscous mode accepting all addresses or can accept only packets with destination address matching one of the following types: physical address of the station, broadcast address for all the stations, one of the multicast addresses the user may assign. The time required in order to analyze the destination address defines a minimum packet length, because the address must be recognized before the end of the packet.

If the packet is accepted, DIASPAR must decode the data length and must calculate the CRC frame during the packet reception time. This packet is moved to a buffer memory organized as

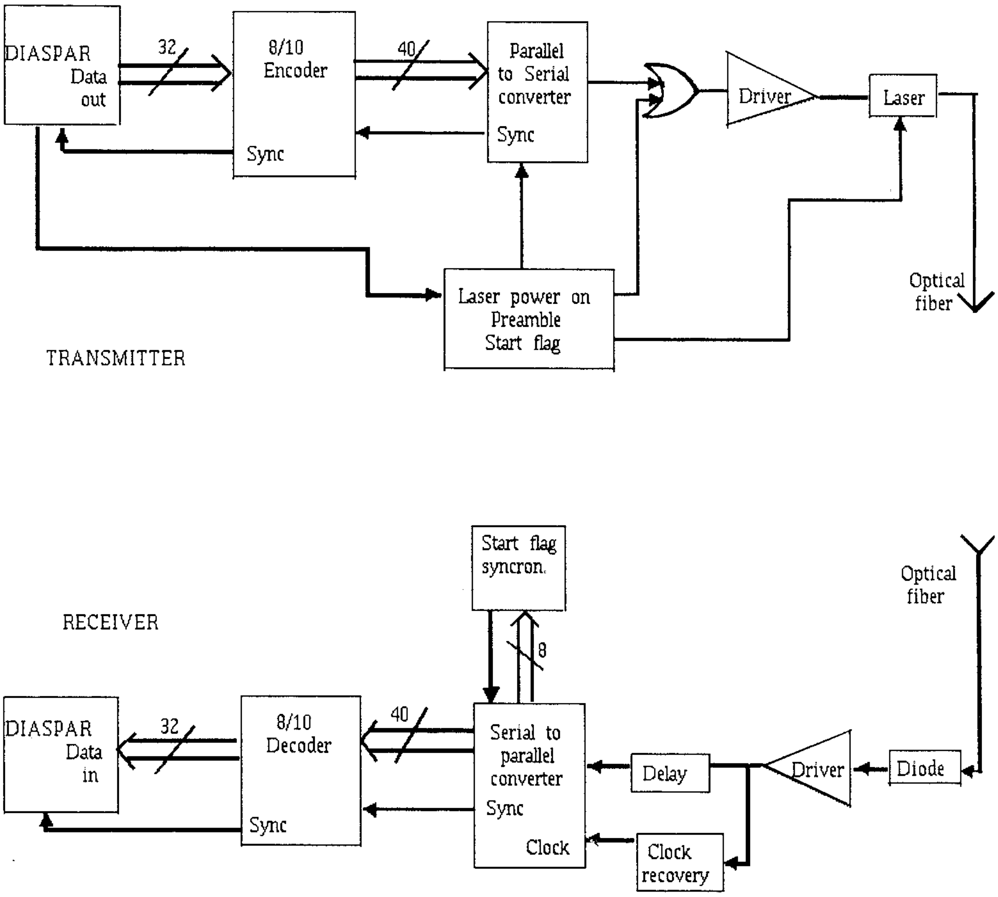

Fig. 6. TRIFFID block diagram.

a FIFO, and simultaneously another packet can be examined. The buffer memory is sized according to the difference in speed between the network and the host channel.

5. The TRIFFID module

TRIFFID is the part of a station which handles the optical interface through parallel to serial and serial to parallel converters, the data encoder–decoder using a 8B/10B scheme (in order to balance the number of "1" and "0" transmitted), and the clock recovery circuit. In fig. 6 the TRIFFID block diagram is presented. The STARNET data channel requires asynchronous transmissions. For this reason, three parameters strongly influence the TRIFFID transmission efficiency, defining the delay between the time when a packet is ready to be transmitted and the time when it is really started: the time required in order to recover the clock from the packet preamble, the time to recognize the start message flag, and the laser powering-up time (because the star configuration requires that in order to reduce the noise, each station must turn off the laser standby output power at the end of the packet transmission).

The problem related to a fast clock recovery circuit (about ten cycles), and the start message synchronization have been solved at prototype level. Optical stars to be used in the first STARNET implementation have been tested against the declared attenuation and reflection characteristics and found satisfactory. Experiments measuring the power-on and power-off times of commercial lasers are now in progress. TRIFFID receiver and transmitter prototypes using different technologies have been realized and tested with satisfactory results. The maximum transmission frequency has turned out to be about 200 Mbps for the ECL and over 1 Gbps for the GaAs technology.

6. Conclusions

We presented a new metropolitan area network using optical fibers, passive topology and a protocol allowing a high bandwidth utilization even at light network load and assuring a bounded service time. This is obtained using a central controller to implement a channel allocation mechanism. A first implementation design using a controller capable of connecting up to 8 stations was described. This implementation will allow the testing of the protocol robustness and the feasibility of such a realization for a range of speeds beginning at 120 Mbps and exceeding 1 Gbps. A new modular controller, capable of extending the total number of stations is under study.

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