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RESEARCH IN HIGH SPEED FIBER OPTICS LOCAL AREA NETWORKS

A report on accomplishments during the period January 1, 1985 to February 28, 1986, under National Aeronautics and Space Administration Grants No. NAG 2-292 and NAGW 419.

Fouad A. Tobagi
Principal Investigator

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1. Introduction

The design of high speed local area networks (HSLAN) for communication among distributed devices requires solving problems in three areas: 1) the network medium and its topology, 2) the medium access control, and 3) the network interface. Considerable progress has already been made in the first two areas. Accomplishments are divided into two groups according to their theoretical or experimental nature. A brief summary is given in Section II, followed by Appendices containing reprints of papers which appeared in the literature.

II. Summary of Accomplishments

2.1 Theoretical Studies

2.1.1 Background

There is a close relationship between the network topology and the access protocol. Some protocols, such as CSMA or PODA, require simply a broadcast feature; others, such as Expressnet*, require a linear ordering among the stations which can only be accomplished by a unidirectional medium. Among the many potential media available, optical fibers are particularly attractive for HSLANs due to their light weight, high bandwidth-distance product, and their immunity to EMI; thus we have considered them as the primary medium in our studies. In the selection of adequate topologies and user interconnection schemes, one has to take into account a number of constraints intrinsic to fiber optics components, such as transmitter power, coupler insertion loss, and receiver performance. These constraints have an impact on the size of the network (mainly in terms of the number of stations that can be accommodated). Two theoretical studies have been performed on that topic as described in this section. A third study related to the design of a fast interface, and addressed the performance measurement of a link level protocol. In the following we provide a brief description of these studies and the main results obtained.

2.1.2 Topological Design of Fiber Optics Local Area Networks with Application to Expressnet

For networks which require a physical linear ordering among the stations, such as Expressnet, the *data transmission* and *linear-ordering* functions may be distinguished and provided by separate *data* and *control* subnetworks. While the data subnetwork may have various configurations, the control subnetwork must always have a linear unidirectional

*F. A. Tobagi, F. Borgonovo, and L. Fratta, "EXPRESS-NET: A High-Performance Integrated-Services Local Area Network," *IEEE Journal on Selected Areas in Communications, Special Issue on Local Area Networks, Vol. SAC-1, No. 5,* pp. 898–913, November 1983.

bus structure. Due to the reciprocity and excess loss of optical couplers, the number of stations N that can be accommodated on a linear fiber optic bus is severely limited; consequently, two techniques have been proposed to overcome this limitation; these are the *stretch* and the *bypass* techniques. The stretch technique reduces the number of transmit and receive couplers between the end stations from $2N$ to N. The bypass technique further reduces this number, for sufficiently large N, from N to $2\sqrt{2N}$. With regards to the data subnetwork, a number of configurations based on the linear, star, and tree topologies have been considered, (which can also be employed independently for access schemes which do not require any linear ordering among stations). For each of these data and control subnetwork configurations, the maximum number of stations as a function of the power margin have been computed for both reciprocal and non-reciprocal couplers. These results are important in that they suggest specific topologies which are good candidates for the implementation of Expressnet.

This work has been reported upon in three publications:

1. M. Mehdi Nassehi, Fouad A. Tobagi and Michel E. Marhic, "Topological Design of Fiber Optics Local Area Networks with Application to Expressnet," Stanford Electronics Laboratories, *Technical Report No. 85–271*, March 1985; also CASIS *Technical Report No. 85–2*, March 1985.

2. F. A. Tobagi, M. M. Nassehi and M. E. Marhic, "Fiber Optic Configurations for Local Area Networks," International Seminar on Computer Networking and Performance Evaluation, Tokyo, Japan, September 18-20, 1985.

3. M. M. Nassehi, F. A. Tobagi and M. E. Marhic, "Fiber Optic Configurations for Local Area Networks," *IEEE Journal on Selected Areas in Communications, Special Issue on Fiber Optics Systems for Local Communications*, November 1985.

In Appendix A, we provide a reprint of the article which appeared in *JSAC*, November 1985.

2.1.3 Selective Broadcast Interconnection (SBI) for Wideband Fiber-Optic Local Area Networks

The selective broadcast interconnection (SBI) is a scheme for directly interconnecting transmitting stations, each equipped with C_T transmitters, and receiving stations, each equipped with C_R receivers, such that each transmitting station is always connected to all receiving stations through passive communication channels with no intermediate switches. SBI consists of $C_T \cdot C_R$ separate broadcast subnetworks, each of which interconnects a subset of transmitting stations and a subset of receiving stations, such that each transmitting station and each receiving station are interconnected through a single subnetwork. Each subnetwork is shared by its transmitting members via some multiple-access scheme.

Comparing SBI with $C_T = C_R = C$ with the use of C broadcast buses, each connecting all transmitting stations to all receiving stations, one finds that in some cases, including that of equal single-destination traffic requirements for all source-destination pairs, the aggregate throughput with SBI can be higher by a factor of C, while the stations' hardware is the same. For nonuniform traffic requirements, however, the maximum aggregate throughput with SBI can be C times lower (in extreme situations). For fiber-optic implementations employing a central wiring closet, the two schemes require the same amount of fibers and, if the same elementary couplers are used to construct the required star coupler, SBI requires fewer couplers. Clearly, the same number of couplers and up to C times more fibers may be required for SBI in a linear-bus implementation. In all cases, transmitter power need only reach N/C receivers with SBI (instead of N with C parallel buses); this allows to accommodate a larger number of stations when implementing the interconnection with passive components.

This work has been reported upon in the following papers:

1. M. E. Marhic, Y. Birk and F. A. Tobagi, "Selective Broadcast Interconnection: a novel scheme for fiber-optic local area networks," *Optics Letters,* December 1985.

2. Y. Birk, M. E. Marhic and F. A. Tobagi, "Selective Broadcast Interconnection for Wideband Fiber Optic Local Area Networks," 2nd International Technical Symposium on Optical and Electro-Optical Applied Science and Engineering, Cannes, France, November 25-29, 1985.

In Appendix B, we provide reprints of both articles listed above.

2.1.4 Performance Measurements of a Data Link Protocol

In an attempt to improve our understanding of packet processing requirement within a network interface, we measured the performance of a program implementing IEEE Std 802.2 Logical Link Control (LLC) protocol. Measurements were conducted in a controlled environment consisting of the LLC program running on a VAX under UNIX. The network is modeled as an infinite bandwidth channel; higher layers are modeled such that messages are always waiting to be transmitted, and receive buffers are always available. Thus, the LLC program is always either sending or receiving a message. The environment so chosen appropriately focuses the attention on the internal processing done within the LLC protocol. We measured the relative execution times of the various functions required in transferring data, over virtual circuits or as datagrams. The results show that most of the program execution time is spent in a few relatively low-level functions; most importantly, the block movement of data in memory, and packet queue management. The importance of these findings is paramount as they suggest the main problem areas to be addressed in the design of high speed network interfaces. We take advantage of these findings in the new proposed effort outlined below.

This work has been reported upon in the following paper:

1. H. Kanakia and F. A. Tobagi, "Performance Measurements of a Data Link Protocol," accepted for presentation at the *International Conference on Communications*, Toronto, June 1985.

In Appendix C, we provide a preprint of this paper.

2.2 Experimental Studies

In addition to the theoretical studies reported upon above, we have, in the past year, undertaken the implementation of a 10 Mbps fiber optic Expressnet prototype. The main purpose of this task was two-fold: (i) to demonstrate the feasibility of the Expressnet concept which has never been implemented prior to this prototype, and (ii) to address issues that are specific to the fiber optics medium and to experiment with fiber optic components for broadcast *bus* networks in general, and Expressnet in particular. At the present time a two-station 10 Mbps fiber optics Expressnet prototype is complete and has been be successfully demonstrated in the laboratory. It is the result of an *iterative* process involving several subtasks outlined in the following.

2.2.1 Experimentation with Fiber Optic Media and Components

This subtask consisted of an evaluation of connectors, couplers, transmitters and receivers. Signal loss measurements have been conducted on connectors and couplers, particularly for their performance in the presence of concatenation. Many commercial transmitters and receivers have also been evaluated for operation in the prototype environment. The sample included: (a) API model TR1000C transmitter and receiver, (b) Codenoll model Codelink-50-T012 transmitter, (c) AFC model 2000D receiver, (d) modified AFC model 2000D receiver, (e) HP transmitters models HFBR-1402 and 1404, (f) HP receiver model HFBR-2404 with home-made amplifier and TTL conversion, (g) HP receiver board based on HFBR-2404 with HP-designed TTL compatible circuitry, and (h) Lytel Lytelink TR-050-101 receiver with TTL compatible circuitry. System studies, including bit-error rate measurements as a function of received pulse length have been performed with some of these components. The applicability of the various units for use in the *data subnetwork* or the *control subnetwork* has also been evaluated, thus identifying the most appropriate combination of topologies and components. Both performance and cost factors have been taken into account in determining the appropriateness of topologies/components combinations.

This work has been reported upon in the following internal note:

1. M. Marhic, "Optical Transmitters and Receivers and Ancillary Electronics," *Expressnet Technical Temporary Note*, Drafts 6/19/85 and 9/23/85.

2.2.2 TTL Implementation of Expressnet Media Access Control (MAC) Protocol, and Station Board Assembly

One of the primary reasons for selecting 10 Mbps for the *first* Expressnet prototype is to remain compatible with existing LAN interface microprocessor boards and LAN chips, and thus to simplify the overall task considerably. The station consists of a 68000 microprocessor board and a network board. (See Figure 1.) The former represents in essence the host where packets originate or to which packets are destined, and thus drives the network board. The latter performs serial-parallel conversions, encoding-decoding, address generation and recognition, CRC generation and checking, and media access control. All but the last functions are performed by Advanced Micro Devices LANCE and SIA chips. Expressnet media access is implemented in TTL.

2.2.3 Station Software

The 68000 microprocessor has been programmed to generate and transmit packets for the purpose of demonstration and experimentation. Several modes of operation exist which provide the necessary flexibility. The ability to transmit continually specially designed packets and to collect statistics of importance has allowed experimentation with fiber optics transmitters and receivers, and the assessment of their performance under specific signal waveforms.

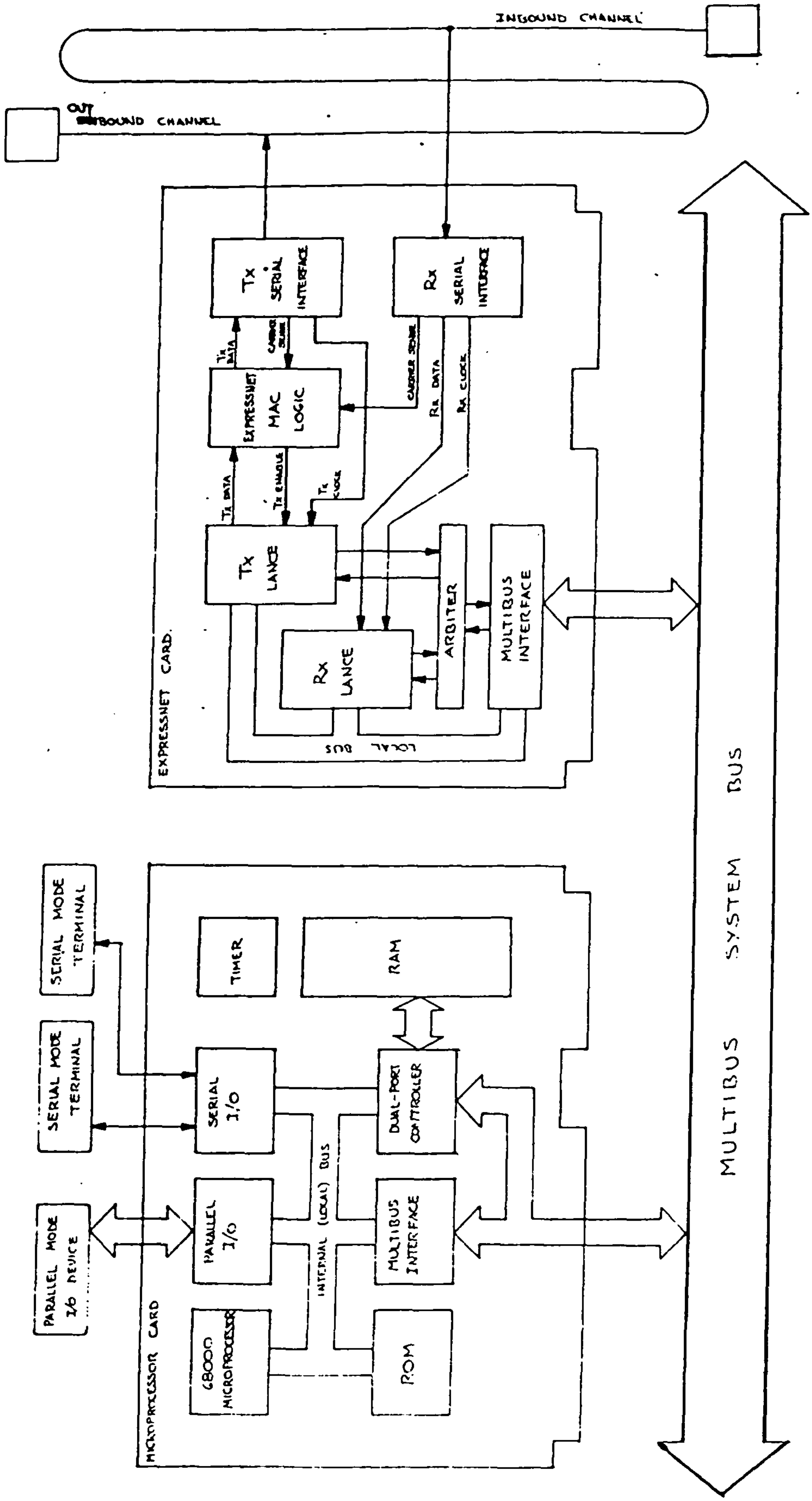
INBOUND CHANNEL
OUTBOUND CHANNEL
Tx SERIAL INTERFACE
Rx SERIAL INTERFACE
Tx DATA
CARRIER SENSE
EXPRESSNET MAC LOGIC
CARRIER SENSE
Rx DATA
Rx CLOCK
Tx DATA
Tx ENABLE
Tx CLOCK
Tx LANCE
Rx LANCE
ARBITER
MULTIBUS INTERFACE
LOCAL BUS
EXPRESSNET CARD
SERIAL MODE TERMINAL
SERIAL MODE TERMINAL
PARALLEL MODE I/O DEVICE
TIMER
RAM
SERIAL I/O
DUAL-PORT CONTROLLER
PARALLEL I/O
INTERNAL (LOCAL) BUS
MULTIBUS INTERFACE
68000 MICROPROCESSOR
ROM
MICROPROCESSOR CARD
MULTIBUS SYSTEM BUS

Figure 1.