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Optical Fibers in Local Area Networks

(Fibres optiques dans les réseaux locaux informatiques)

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Rapport de recherche
DIUL-RR-8311

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Résumé

1 - Les Réseaux Locaux

Par réseau local ou LAN (de l'anglais Local Area Network) THUR'82), nous entendons un système de communication numérique qui permet à un nombre d'appareils informatiques indépendants de se communiquer entre eux. Les réseaux locaux se distinguent des autres types de réseaux de communication pour les raisons suivantes:

(a) les réseaux locaux ont une portée géographique assez restreinte et se limitent à un édifice ou à un complexe d'édifices avoisinants. De façon générale, la distance entre les noeuds (blocs-interfaces-réseaux) est d'un kilomètre environ. En plus, le réseau local appartient exclusivement à une seul entreprise dont il dessert les besoins;

(b) le taux de transmission du support de transmission est relativement modeste, allant de 1 à 100 Mbps, quoique l'un des réseaux que l'on a proposé dernièrement (TSEN'83) fonctionne à 1 Gbps;

(c) le taux d'erreur est uniformément faible, mettons moins de 1*10**-9 bps;

(d) le réseau local est complètement connexe, c'est-à-dire, chaque station peut, en principe, accéder à toute autre station;

(e) l'architecture du réseau local est suffisamment simple que l'on n'ait pas besoin d'algorithmes complexes de routage. On peut donc simplifier le modèle en couches des systèmes ouverts (OSI/RM) de la

Société Internationale des Normes (OSI), tout comme le propose le Projet 802 de la Computer Society de l'IEEE (IEEE'81).

Comme principale application des réseaux locaux, on vise l'infrastructure de communication des systèmes bureautiques et les systèmes de communication tels que ceux qui se trouvent dans les hôtels, les hôpitaux, les usines et dans d'autres institutions. Les réseaux locaux devraient donc offrir des services tels que:

- le transfert de fichiers;
- les applications graphiques;
- le traitement de mots;
- le courrier électronique;
- les bases de données réparties;
- (à la longue) la téléphonie et le vidéo.

De plus, un réseau local devrait supporter toute une gamme d'équipements informatiques assez variés du point de vue de vitesse, intelligence, niveau d'interactivité requis et codes employés, parmi autres.

La Société Internationale des Normes ou l'ISO (International Standards Organization) a proposé un modèle en couches comme moyen de spécification de l'architecture des réseaux de communication de données (TANN'81). A même ce modèle, on peut préciser les protocoles d'échange de l'information entre les sites (blocs-interfaces-réseaux) du réseau aussi bien que les interfaces. On appelle ce modèle le modèle des systèmes ouverts ou OSI/RM (Open Systems Interconnexion Reference Model). La Computer Society de l'IEEE, Projet 802, a simplifié ce modèle pour le cas des réseaux locaux, donnant ainsi le LAN/RM (Local Area Network Reference Model) (IEEE'81).

La couche la plus critique du modèle LAN/RM, en ce qui concerne la présente étude, tout au moins, est celle qui est chargée de contrôler l'accès aux voies de transmission, c'est-à-dire, de «saisir» le canal de communication lorsque l'on en a besoin. Les algorithmes d'accès, appelés conventionnellement algorithmes de multi-accès (TANN'81, TOBA'80), jouent un rôle primordial dans les réseaux locaux parce que c'est au moyen de tels algorithmes que l'on puisse déterminer le débit et le délai globaux du réseau. Il faut signaler que dans les réseaux locaux, le délai provenant de la durée de transmission des signaux au travers du réseau est dominé par le délai dû au logiciel (ROSE'82).

2 - Les Fibres Optiques dans les Réseaux Locaux

Les fibres optiques offrent plusieurs avantages en tant que candidates pour le support physique de transmission (CHOU'83):

(a) largeur de bande potentiellement énorme, allant jusqu'à plusieurs gigabits/sec.;

(b) encombrement physique très faible surtout en comparaison avec les supports métalliques conventionnels;

(c) atténuation des signaux optiques moins élevée que celle des fils métalliques, permettant donc la possibilité de traverser des distances jusqu'à 50 km sans besoin de faire de la regénération;

(d) immunité contre l'interférence électro-magnétique.

Parmi les désavantages on trouve:

(e) pertes de l'énergie optique occasionnées par les coupleurs optiques, rendant ainsi problématique la construction de configurations linéaires dans lesquelles il y a plus d'une dizaine de coupleurs enchaînées en cascade (ALBA'82);

(f) pertes et distorsions dues aux connecteurs et aux épissures;

(g) sensibilité des détecteurs optiques à la représentation des données (CRES'82) (par exemple: NRZ, RZ, Manchester, etc.);

(h) l'absence, dans le domaine optique, du genre de prise de connexion à très haute impédance que l'on connaît dans la technologie des câbles coaxiaux («high impedance tap»); cette dernière limitation est très grave: chaque fois que l'on veut établir une nouvelle connexion avec un câble optique, il faudra avoir recours aux coupleurs optiques, et les problèmes mentionnés en (e) ci-haut se feront sentir.

De tous ces points, il s'ensuit que, pour les réseaux locaux, le choix d'une topologie viable de fibres optiques s'avère problématique, dont l'une des principales motivations du travail présenté dans le présent rapport. Les principales topologies à considérer sont:

- les anneaux;
- les étoiles;
- les «bus»;
- des hybrides.

Les topologies peuvent être passives ou actives, dépendant de l'absence ou la présence d'éléments actifs dans les liaisons. En plus, ces topologies peuvent être uni ou bidirectionnelles.

Il faut remarquer qu'une architecture comprend non seulement la spécification d'une topologie, mais aussi la spécification des protocoles, surtout des protocoles de multi-accès. Les principaux protocoles de cette catégorie qu'utilisent les réseaux locaux sont:

- les protocoles qui «tâtonnent» l'onde porteuse (CSMA/CD);
- la technique du passage de jetons («token passing»);
- les techniques de multiplexage dans le temps (TDMA);
- divers hybrides.

Les protocoles du genre CSMA/CD s'avèrent efficaces lorsque le taux de transmission est inférieur à 32 Mbps environ, tandis que pour des taux plus élevées, la technique des jetons ou la technique TDMA seraient plus efficaces (CHOU'83, FINL'82).

3 - Procédure de Conception d'un Réseau Local de Fibres Optiques

Tout comme pour n'importe quel réseau local, peu importe le support de transmission à employer, il faut spécifier d'abord:

(a) les services à offrir;
(b) la portée géographique du réseau;
(c) la largeur de bande requise en fonction du trafic prévu;
(d) le nombre de noeuds et le nombre de terminaux par noeud;
(e) la fiabilité exigée;
(f) l'expansion future éventuelle du réseau;
(g) la comptabilité du réseau avec des systèmes déjà en place.

La procédure qui a été développée dans ce travail peut se résumer comme suit:

A partir des spécifications (a) à (g) ci-haut, on peut proposer:

(h) (un candidat pour) une topologie;

(i) une méthode d'accès et son organisation;

(j) une méthode de représentation de l'information numérique (NRZ, Manchester, etc.).

Muni de ces candidats, on peut proposer des candidats pour les composants optiques, tout en consultant des «matrices» de composants qui sont publiées par différentes revues ou par les manufacturiers eux-mêmes. Ensuite, il faudra passer à une version généralisée du calcul du budget de puissance optique et, pour les systèmes plus rapides (taux plus grand que 45 Mbps), du temps de montée du système. Suite à des contraintes (k) que l'on aura spécifiées sur le coût total, sur la fiabilité, etc., la procédure essayera de trouver le «meilleur» choix de composants, Si la procédure ne peut pas faire respecter les contraintes (k), elle le signalera et le concepteur humain sera obligé de scruter de nouveau les spécifications (h) à (k) et si, après avoir essayé de trouver une configuration faisable sans réussite, la procédure provoquera une examination des spécifications (a) à (g) ci-haut. À même cette procédure, on a pu identifier une vingtaine de paramètres des plus importants. Dans la pleine version de ce rapport (ci-jointe), on trouvera la liste de ces paramètres à la Table 2.1. À la Table 3.1, on compare plusieurs réseaux locaux contemporains de fibres optiques.

On a partiellement informatisé la procédure décrite ci-haut. Ceci donne une procédure de conception assistée par ordinateur (CAO), au moins dans une forme embryonaire. Pour le futur, on propose de coder davantage les «règles heuristiques» de conception, ensuite, en faire un système de productions comme dans le système MYCIN qu'ont développé des chercheurs en intelligence artificielle à la Stanford University. MYCIN (BARR'82) est un système de diagnose médicale des infections bactériennes de l'homme. Ce système est l'un des premiers systèmes experts que l'on connaît de nos jours (GEVA'83). Il sert à guider l'usager humain dans la diagnose du profile clinique que présente le malade. MYCIN a connu une grande réussite et les techniques employées peuvent s'appliquer au problème de conception auquel on s'intéresse ici.

On a aussi développé un modèle pour les réseaux locaux qui utilisent des coupleurs optiques passifs. Ce modèle, que l'on peut appeler modèle de coupleurs-liens, permet l'étude des propriétés des chemins de longueur k(k=1,2,...) d'un réseau donné, soit numériquement, soit symboliquement. Par exemple, on peut calculer les pertes optiques pour chacun de ces chemins ou on peut trouver les expressions algébraiques pour ces chemins. Il ressort de ce modèle qu'un réseau local est, en quelque sorte, un coupleur généralisé.

4 - Quelques Réseaux Locaux Contemporains de Fibres Optiques

Les réseau locaux contemporains de fibres optiques tombent dans les catégories suivantes:

(a) ceux qui utilisent le protocole CSMA/CD et une topologie en étoile (active ou passive), par exemple, le réseau CODENET (JONE'82) qui utilise une étoile passive, et FIBERNET II (RAWS'82) qui utilise un coupleur-étoile active. Ces deux réseaux visent la compatibilité avec ETHERNET, le grand-père des réseaux locaux. Paraît-il, la société japonaise Toshiba vient d'en créer un de ce genre, encore avec coupleur-étoile passif. De plus, la Nippon Telegraph and Telephone Corporation, le PTT japonais, vient de sortir un appel aux soumissions pour un réseau local CSMA/CD utilisant un coupleur-étoile passif à 32 Mbps;

(b) les réseaux en anneaux actifs, utilisant la technique du passage de jetons. Ce genre de réseau semble être devenu le standard au Japon pour les réseaux locaux de plus grande envergure, quoique, pour les taux de transmission plus élevées, on emploie une technique hybride ou le TDMA. Remarquer que le géant IBM semble favoriser la technique des jetons, sans pourtant que le support soit de fibres optiques. D'ailleurs, IBM favoriserait les pairs de fils torsadés (DIXO'83).Le taux de transmission varie de 32 à 100 Mbps et on a introduit plusieurs techniques de protection en cas de panne, p.ex., le «retour du canal» («loop-back»), la commutation automatique d'une fibre à l'autre, etc.;

(c) les réseaux en configuration de bus ou de bus-étoile comme les réseaux développés à la NASA aux États-Unis (BOOS'82, PORT'82) qui utilisent le TDMA à un taux de 100 Mbps;

(d) les réseaux utilisant soit une architecture, soit une méthode d'accès innovatrices tels que le HUBNET (BOUL'82) en cours à l'Université de Toronto et le D-Net, en cours à TRW aux États-Unis (TSEN'83). On aurait fait une démonstration de D-Net avec taux de gigabit/second et six sous-bandes de télévision digitalisée et paquetisée de 84 Mbps chaque. La méthode d'accès serait une version de la technique des jetons;

(e) les réseaux basés sur l'approche PBX, à savoir, utilisant un commutateur centralisé à bande large. Au Canada, on est en train de construire le prototype d'un commutateur opto-électronique à cette fin (HARA'82).

5 - Conclusion

Les fibres optiques ont fait leur preuve pour ce qui est de leurs applications aux réseaux locaux et l'on remarque deux grandes ruées différentes, soit les réseaux de taille et de taux de transmission modestes, basées sur la technique d'accès CSMA/CD et sur une topologie en étoile, soit les réseaux de grande taille, basés, eux, sur la technique du passage de jetons ou de TDMA ou une hybride et utilisant une topologie en anneau. Il existe d'autres efforts, p.ex., D-Net, HUBNET et l'approche PBX, et on attend des développements futurs intéressants dans ces cas.

La procédure de conception que l'on a élaborée, quoique toujours en forme embryonaire, devrait servir d'outil de conception et d'évaluation des réseaux locaux de fibres optiques.

Comme dernier point, il faut signaler que le talent et la capacité de fabriquer des réseaux locaux de fibres optiques ayant une excellente performance, existe au Canada. Il s'agit tout simplement de «pousser» l'industrie et les autres organismes intéressés.

Références: Veuillez voir la bibliographie du rapport principal.

1 - Introduction

The purpose motivating the work reported in the following pages was threefold:

1- to provide the designer of local area computer networks (LAN's) a tool by means of which the task of specifying the physical layer using optical fiber components would be simplified and systematized. Such a design tool, eventually to be coupled with a component data base, would permet derivation of the optical components meeting the basic network requirements. Modifying these requirements would, of course, usually cause the components specification to change. In this way, the designer could readily compare different configurations (viewed from the physical layer only) satisfying various sets of requirements and therefore make a choice of the best fit for his application.

2- to give an overview of current trends in the application of optical fibers to local area networks and to indicate the most promising efforts.

3- to create a computerized database on optical fibers and on fiber optic LAN's.

Concerning the first goal mentioned above, a simplified design procedure was developped and computerized. For this procedure, a list of about twenty key network parameters was identified, which summarizes the most important network characteristics and permits comparison of different configurations.

For a more detailed procedure, one would have to encode the heuristic design rules used by network designers, somewhat as is done in expert systems (GEVA'83) created by workers in artificial intelligence. An example of such a system is MYCIN used in machine-aided medical diagnosis. The program developped in the present project is a first step towards such a more powerful computer-assisted design program. It is coupled with a sample component database and, being coded in modular and portable form in PASCAL, is easily expandible. A simple systems model is also proposed which is convenient for the study of passively coupled networks. This model allows the expression in matricial form of the optical behavior of source-to-receiver paths of the network. The matricial elements are, in the most general case, pointers to lists that convey detailed information about the optical components and links of such paths, permitting the study of these paths for optical power budget, rise time or other purposes. This approach is being pursued and will be reported at a later time.

As for the second goal, a review is included on a number of recent fiber optic LAN activities both here and abroad. The impressive successes of the Japanese must be noted.

While it is perhaps premature to make definitive claims, the trends seem to favor CSMA/CD , passive star coupled configurations for modest bit rate networks (say 10 to 32 Mbps), and hybrid token- TDMA active ring configurations for higher bit rate networks (say 32 to 100 Mbps). There are several "dark horses" in the running, however, that offer great promise, such as the University of Toronto's HUBNET, using an ingenious active star arrangement for multi-access, at 50 Mbps, and D-Net of TRW, using a passive bus-star configuration with a variant of the token protocole method at 1 gigabit/sec. It remains to be seen whether these, or other, approaches will become popular.

In this connection, it is worth noticing the impact of the stand taken by the International Business Machines Corporation on local area networks. Given the importance and the influence of this corporation, the approach that IBM will eventually recommend will be a driving force in the industry. No proof of this statement is needed, but perhaps recalling the impact of IBM's decision concerning personal computers may be helpful here. To judge the extent and weight of this impact, the reader is left to consult for himself the open literature on micro-computers: there is no small concern that some of the companies responsible for launching the era of personal computers may not survive the entry of IBM into this field. Moreover, again by virtue of its importance, the corporation tends to set de facto standards for the rest of the industry. To come back to LAN's, IBM has, through publications in its own and in the general sientific literature seemingly adopted a ring-star, token passing type of network in which twisted wire pairs would be used for local segments of the network at a bit rate of 1 to 10 megabits. These local segments would be arranged in a star configuration. The stars then would be interconnected by optical fibers or other technologies. This approach has not yet been announced as the official approach of the company nor has any product announcement been made yet, at least as far as the author is aware at the time of this writing. Apparently, there is an operational prototype at the IBM laboratories in Switzerland. The point of these remarks is that we have a driving force that will seriously influence further commercial endeavors in this field: everyone will aim for IBM-compatibility: again, a de facto standard is in force. For further information about this subject, see, for example, the article by Dixon et all cited in the References (DIXO'83).

Finally, concerning the last-stated goal, an interactive database system was developped for the optical fiber literature in general and another for fiber optic LAN's. Both these databases are continually being updated and are, of course, available to interested users.

Optical fibers had their first great success in telephone and CATV trunking applications. The results of this study show that they have now been successfully applied to local area networks, at least for the first generation. Hopefully, the concepts presented in this paper will aid the designer to attack the next generation and profit maximally from the enormous bandwidth potential offered by optical media.

2 - Design Considerations for Fiber Optic Local Area Networks

2.1 - General Observations

Local Area Networks form a special class of computer communication networks in that

-distances between nodes are usually of the order of 1 kilometer, where by "node" is meant a concentrator/deconcentrator interface which usually includes packetization/depacketization procedures as well. to which the usual network devices may be connected;

-aggregate bandwidth (bit rate) is modest, varying from 1 to 20 Mbps, although newer systems are now emerging in the 32 to 150 Mbps range, with one recent experimental prototype achieving 1 giga bits per second;

-uniformly low bit error rates are assumed, usually less than 10**-9 bps;

-network architecture is such that total connectivity is achieved and is sufficiently simple that complex routing algorithms are not necessary;

-the ISO Open Systems Interconnexion Reference Model, OSI/RM is greatly simplified thanks to the lack of routing algorithms and to the basic simplicity of this class of networks. The IEEE Computer Society Project 802 (IEEE'81) has developped standards for three classes of local area networks, namely:

-contention networks using CSMA/CD;
-token buses;

-token rings.

It remains to be seen whether these standards will become an industry standard or not, but they have at least forced manufacturers to consider the issue;

-a high degree of connectability/reconnectability is usually desired.

These features have direct repercussions on the use of optical fibers for the physical layer of such networks, namely

-with internodal links limited to 1 kilometer, standard optical fiber cable segments may be used, thereby avoiding unnecessary splicing and connectorizing operations. Moreover, with relatively short link distances, cables with modest bandwidth * distance products may be used;

-modest aggregate bandwidth requirements mean that the optical bandwidths of the cables and of the transmitter/receiver pairs needed are well within the reach of the current technology. However, the bursty nature of the traffic and the data patterns carried may affect source/detector performances (BOOS'82, CRES'82);

-the low bit error rates are virtually an industry standard;

-the connectability/reconnectability condition implies the need for efficient optical connectors and couplers. In particular, there is need for the optical equivalent of the high impedance tap familiar in coaxial cable technology. This has motivated much work on passive tee and star couplers and on innovative architectural schemes designed to minimize, if not entirely eliminate, optical losses suffered because of couplers;

-the standardization work of Project 802 has produced a proposed standard for the fiber optic subsystem of LAN's;

In the attempt to profit maximally from the advantages offered by optical fibers, while minimizing the inconveniences, the search for viable fiber optic local area network configurations reduces essentially to the search for:

low-loss couplers,

novel topologies, and

innovative multi-access protocols.

To give an idea of the tradeoffs possible, consider the example of an active ring configuration. In the optical domain, this is perhaps the simplest possible configuration, involving as it does only point-to-point links, coupler losses are non-existent since couplers are not present in such configurations. However, one must deal with ring multiple access protocols and with fault-tolerance mechanisms such as loop- back and by-pass switching. At higher bit rates, the electronic side of the interface units becomes critical because of the need for high-speed buffers. Thus, the ring offers simplicity in the optical domain, but complexity elsewhere, and construction of the ring controller interface unit becomes a critical problem. Now consider a passive star configuration. With this kind of configuration, one might use, at bit rates ranging from 1 to 32 Mbps, say, the carrier- sensing multiple access protocols, which are well-undestood and exist in many implementations, but one must also contend with the distortion of the light beam as it traverses the coupler. This latter might make the detection of collisions difficult, for example. Hence, construction of high-performing couplers is a must for such configurations. Similarly, in the case of passive linear bus configurations , the presence of tee couplers introduce optical loss to the extent that , at the current state-of-the-art, one can concatenate only about thirteen on the same leg of a bus (ALBA'82) before the losses become unacceptable, and this even though using the best performing sources and detectors. Moreover, there might be unexpected effects due to the nature of the coupling process itself. For example, at high bit rates (137.088 Mbps), it has been found that the presence of one or more biconically fused tapered couplers improved the performance of an optical link (in this case, a "leg" of a star-bus configuration) by 3 dB (CRES'82). Prototyping must be done to verify actual performance.

A number of these issues have been treated in recent, published literature. For example, extensive testing has been conducted on high-speed fiber optic buses, in particular of tee and star coupler performance when concatenated and on receiver sensitivity to data patterns (BOOS'82). For example, the work was done for the NASA Goddard Space Flight Center fiber optic network (see Table 3.1, Chapter 3). The network studied uses a rooted-tree topology, TDMA, and for taps, passive tee couplers in one version, passive star couplers in another. This work shows the importance of experimental verification of the behaviour of the optical subsystem before committing oneself to specific components.

In the following sections, a design procedure for fiber optic LAN's is outlined and a list of key network parameters suggested. These should provide the basis for meaningful evaluation of proposed fiber optic LAN's and help focus on specific problem areas. In this study, it was not possible to refine this procedure as far as had been hoped. Nonetheless, the approach seems quite valid and the basis for further work has been laid. This work will form the object of future publications.

2.2 - Design Process for Fiber Optic LAN's

The overall design process for fiber optic LAN's may be summarized by the following steps:

S1 - determine network requirements;

S2 - as a function of these requirements, propose a plausible topology/multiple access protocol combination;

S3 - for this proposed topology/multi-access combination, select feasible fiber optic components that respect all constraints flowing from step S1;

S4 - specify network interface hardware, i.e., the network interface controller;

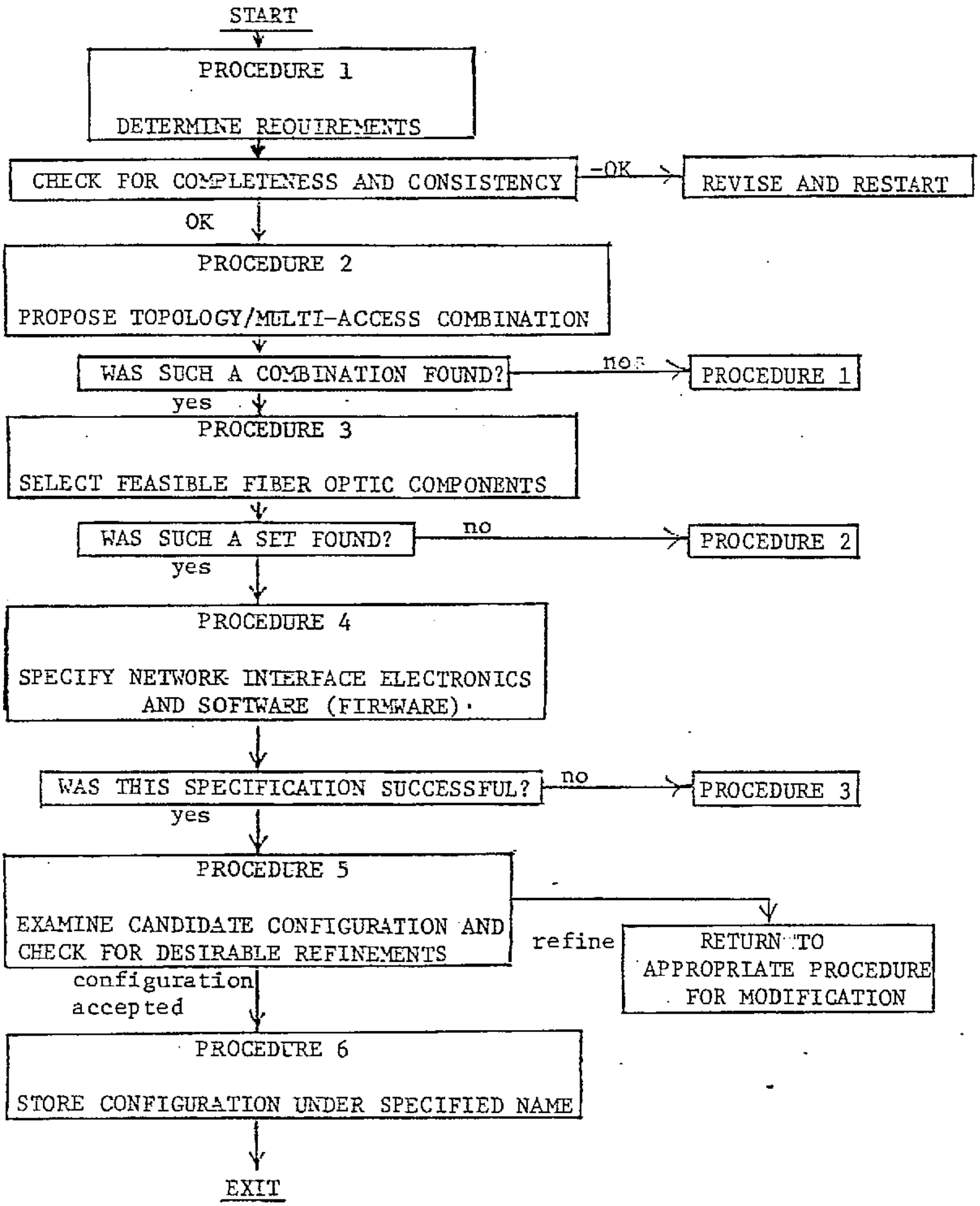
S5 - verify that all requirements are adequately satisfied. If not, loop back to appropriate step;

S6 - display and save proposed configuration.

Each of the above steps includes tests for success in realizing the function of the step, requiring looping back to previous steps if needed or abandoning the procedure if the basic network requirements are found to be unsatisfiable. In Figure 2.1, this overall procedure , including tests, is summarized. Since the emphasis in this report is on the fiber optic subsystem, the fourth step is not treated in any great detail, although clearly, for complete specification of a fiber optic LAN, it must be.

In the following sections, these steps are examined in some detail.

Figure 2.1 - Overall Design Process for Fiber Optic Local Area Networks



S1 - Determining network requirements

In the most general case, as for any local area network, one must determine the following:

R1 - the network services to be offered and any constraints relevant to these services (priorities, delays, etc.);

R2 - the approximate geometrical distribution of network devices and the distribution of the interface nodes to which they are to be connected;

R3 - the maximum and the average traffic generated per node and the mix of data patterns if possible;

R4 - the maximum number of nodes foreseen;

R5 - the expected bit error rate;

R6 - the level of reliability desired ("fail- safe" or fault-tolerance requirements);

R7 - the level of reconnectability desired;

R8 - overall cost budget;

R9 - possible expansion for future services;

R10 - any compatibility constraints that might be imposed, e.g., use of fiber cable already in place, performance constraints for already existing services being handled currently by other networks, etc..

Environmental and installation-related constraints may also be specified under R10.

This list of requirements must be analysed for completeness (to check whether all necessary requirements have been specified) and for consistency (to verify the absence of contradictory requirements or constraints). This list represents the general case, in practice some of the information required may be available only in very approximate form. For LAN's, one usually does not need to do a detailed traffic analysis as is the case for large-scale networks since bandwidth is assumed to be relatively inexpensive and abundant and since internodal distances are limited to a few kilometers.

Requirements R1 and R3 yield such parameters as the end-to-end delay constraints, the maximum traffic generated per node, and the aggregate (network) bit rate. R2 gives the total number of interface nodes, N, , the maximum number of devices per node, and D, the network diamter. R4 is given to foresee future expansion and gives the parameter Nmax, the maximum value for N.

The requirement R6 might be characterized as the "RAS" or reliability, accessibility and serviceability condition. One might specify three basic levels for this requirement: high, medium, and low. A high level requirement obliges the designer to introduce the maximum fault-tolerance, both in hardware as well as in software. Depending upon the configuration proposed, this means duplication of critical elements, switch-over mechanisms, etc. Medium level requirements would relax the preceding somewhat, and low level would imply a minimally protected configuration.

Similarly, the requirement R7 might have several levels, where the highest would impose stringent conditions on the connectors and couplers to be used, whereas the lowest level would correspond to a virtually unchanging network (as on aircraft, perhaps).

R9 serves to foresee future expansion of the aggregate bit rate due to the addition of new services.

Finally, R10 serves to force compatibility with any network plant already in place which is to form part of the new network. This might happen, say, if existing fiber cable is to be relieved of its current function and to be used by the new network.

S2 - Proposing a Plausible Topology/Medium Access Combination

From the list of basic requirements R1-R10 given above, one can infer prospects for both network topology and medium access protocol. As stressed elsewhere (FINL'82), specifying network architecture means, in fact, specifying details of the LAN layered reference model (LAN/RM) protocols and interfaces (in the general case, one would use the ISO's Open Systems Interconnexion Reference Model, OSI/RM). The most important protocols as far as basic network performance is concerned, are the multiple access protocols, as they determine overall throughput, delay and channel utilization.

For LAN's, topologies are usually limited to one of the following:

T1- linear buses;

T2- rings;

T3- stars;

T4- hybrid combinations of the above.
(these topologies may be used in either passive or active configurations.)

While the more general mesh topologies are certainly feasible, the emphasis in LAN architectures has been on architectural simplicity: mesh topologies would introduce, among others, complications of routing (level 3, network level in the OSI/RM) that are usually absent in LAN's.

To complete the architectural specification needed, we must also specify the multiple access protocol. For LAN's, these are usually one of the following:

P1- carrier-sensing protocols, with or without collision detection (CSMA, CSMA/CD, and variants);

P2- token passing protocols;

P3- ring contention protocols;

P4- slotted ring protocols;

P5- register insertion ring protocols;

P6- TDMA;

P7- various hybrids, such as protocols of type P1 in ordinary slotted ALOHA systems where the worst case propagation time between nodes is short with respect to the bit time.

In addition, one must decide to what extent the protocols should be centralized or decentralized (distributed). For example, in CSMA/CD, the collision detection may be carried out at a central point of the network, as in Fibernet II, or at the nodes themselves, as in Codenet (see the discussion of these networks in Chapter 3).

The performance of these multi-access protocols is the object of much study, both theoretical and experimental. As there is a lack of detailed hard information (in the public domain at least) on the real performance of these protocols in operational environments (STUC'83), it is difficult to give definitive selection criteria. This said, however, one can make some general assertions:

1- CSMA/CD, which involve relatively simple controller chips (BURS'82, JOSH'82), seem to give best theoretical performance with transmission rates up to 32 Mbps;

2- the token ring protocols, involving complex controller chips (STIE'82), give better performance at bit rates, say higher than 32 Mbps;

3- for very high bit rates, going eventually up to 1 Gbps, some kind of reservation scheme , perhaps in conjunction with a token scheme, gives the best results (see Chapter 3, section on D-Net).

There seems to be no universally applicable multiple access protocol.

The relationship between topolgy and multiple access protocols is another knotty isue: almost all of the protocols mentioned above could be implemented on. any of the physical topologies mentioned, although protocols P2-P4 are perhaps intrinsically better suited to ring and loop-bus topologies.

One might state the following rules of thumb:

-if the bandwidth is less than 32 Mbps (approx), then use either a star-CSMA/CD combination or a ring-token passing combination;

-if the bit rate is higher than 32 Mbps, say in the 32 to 200 Mbps range, then use a bus or star-TDMA or a ring-token passing plus TDMA combination;

-for very high bit rates, use a variant of the token reservation plus TDMA on a bus topology as in D-Net (see Chapter 3).

S3 - Optical Fiber Component Selection

Up to this point, the basic network requirements have been detailed and a candidate topology-multiple access protocol combination, (T,P), proposed. Now, candidates for the optical subsystem components must be found. Failure to find a viable set of optical components means that one must propose another combination (T,P) if such exists for the given requirements. If all feasible combinations (T,P) have been exhausted without having found a viable set of optical components, one must re-examine the requirements R1-R10.

The optical components are selected from published manufacturers' descriptions or from component matrices published by the various trade magazines such as LASER FOCUS or the International Fiber Optics and Communications Handbook & Buyers Guide (both of these publish these matrices yearly). Unfortunately, there is no universally agreed-upon standard way of describing optical components and the designer may often have to contact the manufacturers directly for details. This said, the component matrices serve as a starting point and we shall assume that they have been entered into a computer database.

The optical components needed are:

OT: optical sources (LED's, lasers), or optical transmitter packages;

OR: optical detectors (PIN's or APD's) , or optical receiver packages;

OF: optical fibers or optical fiber cables;

OC: optical couplers, including

OTC: optical tee couplers;

ORSC: optical reflective star couplers;

OTSC: optical transmissive star couplers:

Note that the tee couplers exist in active and passive forms;

OCON: optical connectors;

OS: optical splices (not really components as such, but must be considered as such for power budget calculations and do imply costs);

OX: optical switches;

OMUX/ODEMUX: wave-length division multiplexers/demultiplexers.

One can, if desired, build one's own transmitter and receiver packages, using sources and detectors selected from the corresponding matrices. However, transmitter and receiver packages already have been designed for a wide range of applications and are described in matrix form. Moreover, there are matrices describing both digital and analog links, that is transmitter/receiver pairs, thus simplifying the designer's task. As always, however, one must be aware that the published information on these links may be incomplete or inaccurate. Even if complete, experimental verification of actual performance may be required.

In Table 2.1, fragments of some typical component matrices are shown. Notice the frequent absence of prices, along with other specifications.

Table 2.1- Samples of Component Matrices
(from IFOC Handbook & Buyers Guide 1983-84, pp 56-110, with permission of Information Gatekeepers, Inc.)

Below a fragment of a data link matrix is given. In this and the following examples, the manufacturers' names have been omitted. Components from various well-known manufacturers are given.

In the data link matrix, notice that the link is specified by about twenty parameters including OT and OR types, wavelength, BER, bandwidth, data formats, fiber types and so forth. A key parameter of interest also is the maximum cable length usable with each OT/OR pair.

Transmitter Model Number	Receiver Model Number	Emitter Type	Detector Type	Total CW Power (mW)	Optical Sensitivity (µW)	Wavelength (nm) - TX/RX	Data Rate	BER	DC Coupled (Yes or No)	Pigtails (Yes or No)	Electrical Connector Type	Optical Connector Type	Operating Temperature (°C)	Power Requirement (W) - TX/RX	Data Format Compatibility	Optical Loss Budget (dB)	Maximum Cable Length (m)	Fiber Type	Maximum Duty Cycle (%)	Termination Cable (Yes or No)	Size - TX/RX	Dynamic Range (dB) - TX/RX	Price per pair (US $)
ODN 1D(5) JT	ODN 1D(5) JR	LED	PIN	-25 dBm •••	-25- -37 D	830 ±30	DC to 1 Mbps	10^{-9}	Y	N	6-pin	NEC D-type	0-50	•	NRZ	12	1.5k	SI 80	50	N	1.6x 1.6x 6.0	12	560
ODN 10D(4) CT	ODN 10D(4) CR	LED	PIN	-14 dBm •••	-14- -26 dBm	830 ±30	DC to 1 Mbps	10^{-9}	Y	N	Indiv. leads	NEC D-type	0-50		NRZ	12	500	SI 100	50	N	1.4x 1.3x 4.5†††	12	940
ODN 10D(4) JT	ODN 10D(4) JR	LED	PIN	-14 dBm •••	-14- 26 dBm	830 ±30	DC to 1 Mbps	10^{-9}	Y	N	Indiv. leads	NED D-type	0-50		NRZ	12	1.5k	SI 80	50	N	1.4x 1.3x 4.5†††	12	950
ODN 10DL CT	ODN 10DL CR	LED	PIN	-12 dBm •••	-22- -35 dBm	830 ±30	DC to 10 Mbps	10^{-9}	Y	N	Indiv. leads	NEC D-type	0-50	••	NRZ	10 to 23	1.5k	SI 100	50	N	1.4x 1.3x 4.5†††	13	975
ODN 10DL JT	ODN 10DL JR	LED	PIN	-12 dBm •••	-22- -35 dBm	830 ±30	DC to 10 Mbps	10^{-9}	Y	N	Indiv. leads	NEC D-type	0-50	••	NRZ	10 to 23	2k	SI 80	50	N	1.4x 1.3x 4.5†††	13	995
ODN 35D CT	ODN 35D CR	LED	PIN	-15 dBm •••	-15- -26 dBm	830 ±30	DC to 35 Mbps	10^{-9}	Y	N	Indiv. leads	NEC D-type	0-50	††	NRZ	11	500	SI 100	50	N	5.5x2 x6	11	1450
ODN 35D JT	ODN 35D JR	LED	PIN	-15 dBm •••	-15- -26 dBm	830 ±30	DC to 35 Mbps	10^{-9}	Y	N	Indiv. leads	NEC D-type	0-50	††	NRZ	11	1k	SI 80	50	N	5.5x2 x6	11	1470
ODN 35D DT	ODN 35D DR	LED	PIN	-15 dBm •••	-15- -26 dBm	830 ±30	DC to 35 Mbps	10^{-9}	Y	N	Indiv. leads	NEC D-type	0-50	††	NRZ	11	2k	GI 50	50	N	5.5x 2x 6	11	1490
ODN 10DL DT	ODN 10DL DR	LED	PIN	-12 dBm •••	-22- -35 dBm	830 ±30	DC to 10 Mbps	10^{-9}	Y	N	Indiv. leads	NEC D-type	0-50	••	NRZ	11	3.5k	GI 50	50	N	1.4x 1.3x 3.5†††	13	1015
OT4000	OR4000	LED	PIN	.125	10	820	50	$<10^{-9}$	Y	N	mnt. on PCB	AMP	0-55	1.6	any (TTL)	10	3k	100 µm	100	Y	5x 10x1	10	575
OT8100	OR3110	Laser	APD	3.5	.3	800-850	150 Mbps NRZ	$<10^{-9}$	N	Y	44pin edge	Amph.	0-55	7	ECL	40	13k	50 µm	70	Y	11x16 x1.5/ x4	19	
OT5100	OR5100	Laser	PIN	1	7.9	800-850	150 Mbps NRZ	$<10^{-9}$	N	Y	44pin edge	Amph.	20-40	7	ECL	21	7k	50 µm	70	Y	11x16 x1.5/ x4	19	1500
OT8000	OR8010	Laser	APD	3.5	.08	800-850	50 Mbps NRZ	$<10^{-9}$	N	Y	44pin edge	Amph.	0-55	7	TTL	46	15k	50 µm	70	Y	11x16 x1.5/ x4	19	
OT5000	OR5000	Laser	PIN	1.0	2.0	800-850	50 Mbps NRZ	$<10^{-9}$	N	Y	44pin edge	Amph.	20-40	7	TTL	27	9k	50 µm	70	Y	11x16 x1.5/ x4	19	1400
OT8000	OR8000	Laser	PIN	3.5	2.0	800-850	50 Mbps NRZ	$<10^{-9}$	N	Y	44pin edge	Amph.	0-55	10.4 max.	TTL	32	10k	50 µm	70	Y	11x 16x 1.7	19	
OT8100	OR8100	Laser	PIN	3.5	7.9	800-850	150 Mbps NRZ	$<10^{-9}$	N	Y	44pin edge	Amph.	0-55	10.4 max.	ECL	25	2.5k	50 µm	70	Y	11x 16x 1.7	19	

Table 2.1 - Component Matrices (Continued)

Below are given two further examples of component matrices, manufacturers's names omitted. The first is for cabled fibers, again characterized by about twenty parameters, some of which remain unspecified. This can make use of such tables frustrating since then one must contact the manufacturers directly for what may appear to be promising components. The second table is for optical connectors. Notice the complete absence of prices.

Model number	Number of fibers	Fiber index type	Fiber core diameter (μm)	Overall coated diameter (μm)	Cladding diameter (μm)	Cable diameter (mm)	Cable weight (kg/km)	Minimum bend radius (mm)	Tensile strength rating (kg)	Attenuation rating (dB/km)	Attenuation wavelength (μm)	Numerical aperture	Dispersion rating (ns/km)	Bandwidth capacity (MHz-km	Factory unit lengths (km)	Fiber material	Jacket material	Price ($/m for 1 km)	Price ($/m for 1-10 km)
226102	2	GI	100	500	140	3.0x6.0	16	50	108	7	.85	.30		20	1.0	G	PU		3.29
227001	1	GI	50	250	125	3.8	13.5	50	113	6	.85	.20		200	1.0	G	PVC		1.16
227002	2	GI	50	250	125	3.8x7.6	27	50	227	6	.85	.20		200	1.0	G	PVC		2.14
227006	6	GI	50	250	125	8	40	100	227	6	.85	.20		200	1.0	G	PVC		
227012	12	GI	50	250	125	14	155	150	218	6	.85	.20		200	1.0	G	PVC		
227018	18	GI	50	250	125	18	260	200	218	6	.85	.20		200	1.0	G	PVC		
227101	1	GI	50	500	125	3.0	8	50	54	6	.85	.21		200	1.0	G	PU		1.24
227102	2	GI	50	500	125	3.0x6.0	16	50	108	6	.85	.21		200	1.0	G	PU		2.35
227201	1	GI	50	250	125	3.8	13.5	50	113	4	.85	.20		400	1.0	G	PVC		1.30
227202	2	GI	50	250	125	3.8x7.6	27	50	227	4	.85	.20		400	1.0	G	PVC		2.41
227206	6	GI	50	250	125	8	40	100	227	4	.85	.20		400	1.0	G	PVC		
227212	12	GI	50	250	125	14	155	150	218	4	.85	.20		400	1.0	G	PVC		
227218	18	GI	50	250	125	18	260	200	218	4	.85	.20		400	1.0	G	PVC		

Model number	Insertion loss (dB)	Insertion loss after 1000 matings (dB)	Number of connects/disconnects before insertion loss changes significantly	Operating temperature range (°C)	Fiber diameter (outside cladding dia. in microns)	Mounting type	Dimensions	Weight	Number of fiber terminations available	Housing material	Mounting time (minutes)	Military use	Industrial use	Offline use	Fiber to fiber coupling	Expanded beam coupling	Strength member tie-offs	Thermoplastic	Bulkhead mountable	Component receptacle available	Fiber polishing necessary	Index matching fluid required	Adhesives necessary	Environmental seal at joint	Price in large quantities
906-200-7XXX	~1.0			0 +70	140- 250	ALL			1	MET	15	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	
906-109-XXXX	~1.0			-55 +125	125- 140	ALL			1	MET	15	Y	Y	Y	Y	N	N	Y	Y	Y	Y	N	Y	Y	
906-110-XXXX	~1.0			-55 +125	125- 200	ALL			1	MET	15	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	
906-113-XXXX	~1.0			-55 +125	250	ALL			1	MET	15	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	
906-120-5XXX	~1.0			0 +70	125- 250	ALL			1	MET	15	N	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	N	

Given the topology/multiple access protocol combination (T,P) and the component matrices, the task now is to find candidate optical components. The following procedure achieves this:

1- estimate aggregate bit rate (in Mbps) appropriate for T and system power margin M;

2- determine worst-case passive link length, L;

3- find candidate OT/OR pair from link matrix, respecting the aggregate bandwidth B and the bit error rate, E. Determine from the matrix the optical loss budget, U;

4- find candidate fiber (cable) OF, couplers OC (OTC, ORSC, OTSC as needed), connectors OCON, splices OS and switches OX (as needed);

5- calculate total losses in worst-case passive link due to components found in step 4 above; if these losses exceed the sum of U and M, then attempt to find a better OT/OR combination. If this fails, attempt to find better performing fibers, couplers, etc. If the latter fails, then exit to step S2 of the main procedure and propose a different (T,P) combination;

6- (candidate component search successful) calculate total costs (if all costs are available). If the cost budget is not respected, repeat steps 3 and 4 above in attempt to find a set of components satisfying the cost constraints (as well as all others, of course) If this search fails, then exit to the main procedure, step S1 to revise the basic requirements.

In this procedure, it has been assumed that already existing OT/OR pairs are to be used. If this is not the case, then one must find a "matching" pair by scanning the OT and OR package matrices separately. If one is to build these packages oneself, then one must scan the source and detector matrices, leaving the rest of the transmitter and receiver design to the next step, S4, of the main procedure.

Notice that there are a number of matching problems implied by steps 3 and 4 above, such as the following:

-source and detector wavelengths with the fiber (cable) wavelength;

-core diameter of fiber pigtails of the OT/OR packages with that of the fiber (cable);

-similar fiber matching between the arms of couplers and the fibers or pigtails to which they are to be connected.

As of this writing, the above procedure has been partially computerized (see Chapter 2, Section 2.4)). The resulting program is the first step towards a general interactive design procedure for fiber optic local area networks. Although the current version is very simple, yet its modular design permits addition of more sophisticated and subtle design rules. Current plans call for the construction of a generalized production-based CAD procedure along the lines of such expert systems as MYCIN (BARR'82) embodying these design rules: MYCIN is an interactive program created by artificial intelligence researchers at Stanford University for computer-assisted diagnosis of infectious diseases. The system provides the human user with diagnostic and therapeutical information. The technique used, namely a production system with backwards chaining (to give a very simplified description), are applicable to the design problem considered here.

The purpose underlying the computerization of the above design process is twofold:

1- to encode all the known heuristic design rules;

2- to relieve the human user of the tedium of scanning numerous component tables in order to obtain an optimal selection of components.

As the optical fiber industry matures, both these steps will take on greater importance, the first since, with the development of more complex systems, designers will be obliged to formalize their design rules and the conditions under which they apply, the second since component proliferation will favor creation of extensive databases of component data. The coupling of a flexible interactive CAD procedure with such databases seems, therefore, inevitable.

In the above discussion, no explicit attention was given to the system rise time calculations. For LAN's using OT/OR packages and following manufacturer's descriptions, this calculation usually is not necessary. However, if one must select the OT and OR packages separately or if one must design them oneself using sources and detectors selected from the component database, then this calculation must be carried out when tha data rate is above 45 Mbps (FREE'82). This calculation would then be added to step 3 above. The program of Section 2.4 implements this calculation.

S4 - Network Interface Hardware and Software Selection

The purpose of this step is to interface the optical subsystem to the network devices and, as such, falls outside of the scope of the present study. Nonetheless, a few words must be directed to this step.

If, in the preceding step, an OT/OR pair was selected from the data link matrix database, details of the electrical interface are usually supplied. For slower networks, interfaces such as the EIA RS-232, RS-422, might be built in, whereae for faster networks, TTL or ECL might be specified. In both cases, one has to construct the protocol machinery. This is problematical at higher bit rates since one must have high-speed buffers which are not yet available on an off-the-shelf basis.

S5 - Verification of Requirements

The purpose of this step is to allow the designer to examine the configuration proposed so far and to loop back to previousd steps so desired. This might be the case if he feels the current proposed configuration can be improved by tightening or relaxing network constraints, depending upon the circumstances. In the computerized procedure of Appendix 2, this step is included. Recall that steps P2, P3, and P4 have implied tests on requirements, looping back to previous steps if necessary.

S6 - Displaying and Storing Proposed Configuration

The computerized procedure of Section 2.4 displays the final proposed configuration (currently only the optical subsystem derived in step S3) and stores it under a name provided by the designer. This stored configuration can be recalled by the designer, modified if so desired and stored under the same or a different name.

2.3 Design Matrices for Fiber Optic LAN's

From a design procedure will flow a detailed specification of a network. Such a specification may be considered as a list or a vector which may be listed in tabular form along with specifications for other networks. This gives, in effect, a design comparison matrix for the class of networks considered. Moreover, for a given configuration, one may vary certain parameters and observe the effect of this action on other parameters. Thus, one can create design matrices for these networks, much as one creates the component matrices mentioned in the preceding section.

For the procedure described in the preceding section, a list of about twenty key parameters was determined and is illustrated in Table 2.2. A sample configuration is described in Table 2.3. This table is essentially the table used for the comparisons given in Chapter 3.

2.4 - A Simple CAD Program for Fiber Optic LAN's

In Figure 2.2, the overall structure of the CAD program mentioned in the preceding sections is given. This program does not yet incorporate the heuristic design rules needed nor does it use the MYCIN-like production system approach. For a first cut for a configuration, it merely matches the most powerful OT with the most sensitive receiver and the fiber having least loss. The user can then examine the configuration proposed, namely details of the components selected, the power budgets, total cost, etc. If he desires, he may examine the component matrices and choose the components directly, in which case the system automatically repeats the various system calculations, rejecting the choice if the power margin is not respected. When the user is satisfied with the configuration, he may store it under the name of his choice.

A sample session with this program is given in Figure 2.3. The purpose of this example is not so much to yield a realistic design, but rather to illustrate the flexibility and potential of the system. While implementing the MYCIN-like full approach would be a non-neglible task, the current system could be considerably improved to the point of giving a useful design tool in the following way:

1- replace the sample component matrices by more complete, realistic ones;

2- include an OT/OR link matrix. The current version of the program scans separate matrices, one for the transmitters, the other for the receiver (packages). By default, the revised system would start from the link matrix, falling back upon the separate matrix approach only if directed by the user or by failure to find a viable OT/OR pair in the link matrix. Moreover, explicit consideration must be give to the source/detector/fiber wavelengths using fuzzy criteria. Again, the system could use a default criterion, for example, that these wavelengths must lie within certain bounds, which the user could change if he so desired.

3- the component matrices should be expanded to include more technical details;

4- the program does not suggest a topology/ multi-access protocol combination nor does it calculate by itself the aggregate bit rate needed. These features should be added to the next version of the program.

Table 2.2 - Key Parameters for Fiber Optic LAN's

While the total number of parameters needed to completely specify a fiber optic LAN is quite high (we have seen from the preceding table that each component requires about twenty different parameters), for the current project only the most essential are retained. Clearly, the next version of the CAD procedure described in this chapter must include fuller specification or choice.

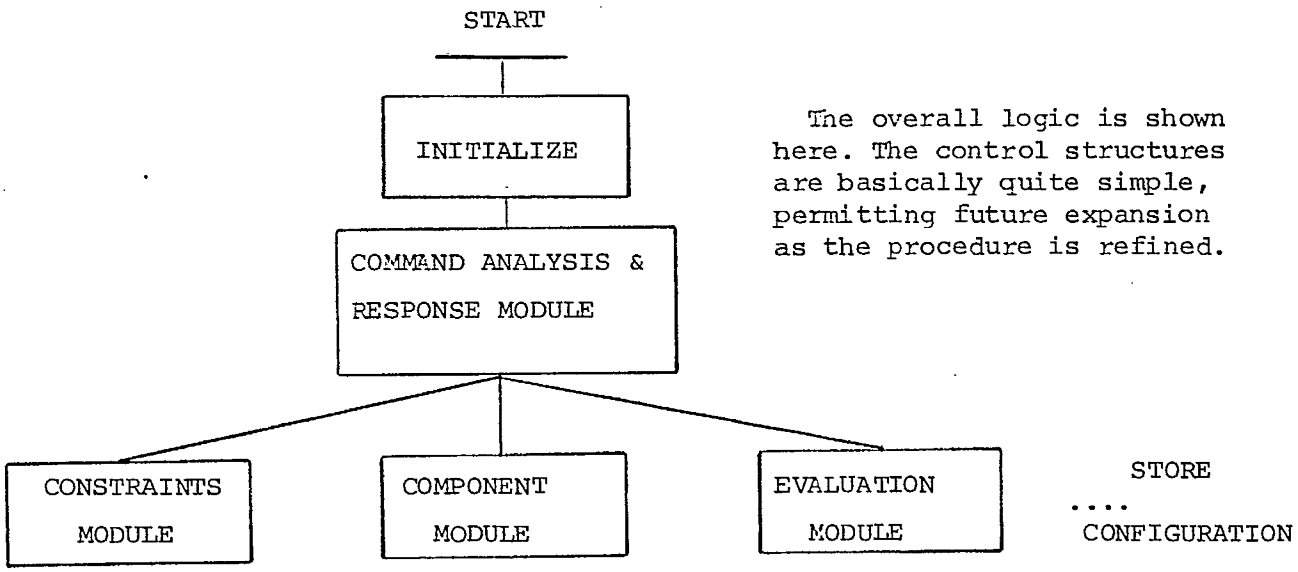
1 - Manufacturer
2 - Network Name
3 - Operational Status (experimental prototype, commercially availible)
4 - Date Placed in Service (if availible)
5 - Services Offered
6 - Span
7 - Bit Rate
8 - Topology
9 - Organization (centralized, partially distributed, distributed)
10 - Multi-Access Methods
11 - BER
12 - Number of Nodes
13 - Number of Terminals
14 - Fault-Tolerance
15 - Coding Scheme (NRZ, RZ, Manchester)
16 - Fiber Type
17 - Fiber Core Diameter
18 - Fiber Outer Diameter
19 - Fiber Windows
20 - Source Type (LED, LD)
Source Power
21 - Source Wavelength
22 - Detector Type
Detector Sensitivity
23 - Detector Wavelength
24 - Coupler Characteristics
25 - Switches (Optical)

Table 2.3 - Values of Key Parameters for a Sample Configuration

To illustrate the use of the parameters of Table 2.2, the NASA Goddard Space Flight Center network developped by the MITRE corporation is examined (CRES'82).

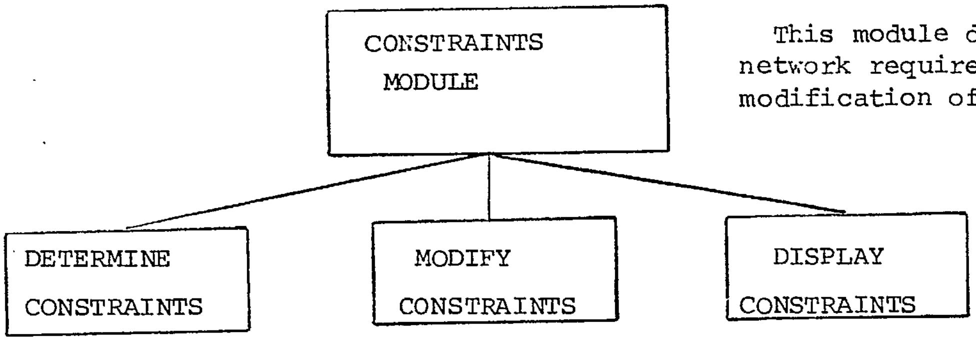
1 - NASA/MITRE
2 - NASA GSFC Fibre Optic Local Area Network
3 - Experimental, under development
4 - Partially operational in 1982.
5 - Services: digital rates, 10 bps to 10 Mbps per user,
frames of 4800 bits.
6 - Span: 1.6 km (length of legs of bus)
7 - Bit Rate: aggregate bit rate estimated to be greater than 70 Mbps,
100 Mbps for finished version, 50 Mbps for prototype.
8 - Topology: rooted tree using tee couplers in one version,
star couplers in another version.
9 - Organization: centralized
10 - Multi-Access: slotted TDMA
11 - BER : less than 10**-9
12 - Number of Nodes: in prototype 3, in finished version 100 (?).
13 - Number of Devices per Node: 2-8
14 - Fault-Tolerance: nor specified.
15 - Coding Scheme: NRZ (shown to be problematical with AC-coupled
receiver; Manchester probably preferable)
16 - Fiber Type: GI (graded index, glass-on-glass)
17 - Core Diameter: 50 u
18 - Outer Diameter (O.D.): 125 u
19 - Fiber Window: not specified, 850 u (?)
20 - Source Type: Exxon OTX5100, LED @ 780-850 nm
275 Mbps
power greater than 1000 uW
rise time less than 1.5 ns
price: $1,100
21 - Detector Type: Exxon ORX5100, PIN, 850 nm (?)
.1 - 150 Mbps
BER: 10 ** -9
minimal detectable power: 5 uW @ 830 nm.
24 - Couplers: Version 1: biconically fused tapered 40/40, 60/20, 75/5
insertion loss 20 %
Version 2: 6 legged transmissive star, -7.78 down per leg,
-2 dB excess loss.
Allowable optical power budget: 35 dB.

Figure 2.2 - A Simple CAD Program for Fiber Optic LAN's

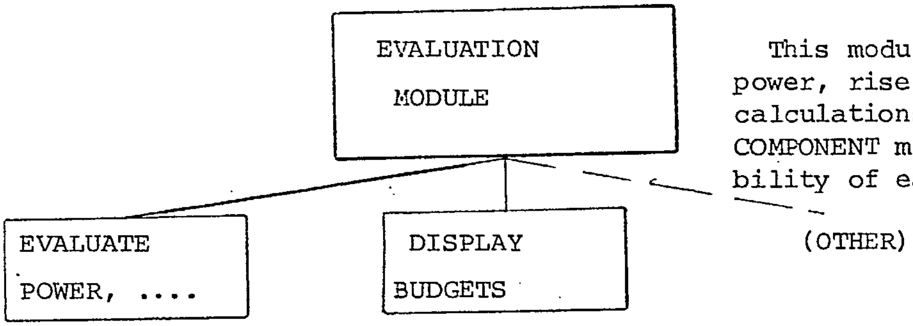


The overall logic is shown here. The control structures are basically quite simple, permitting future expansion as the procedure is refined.

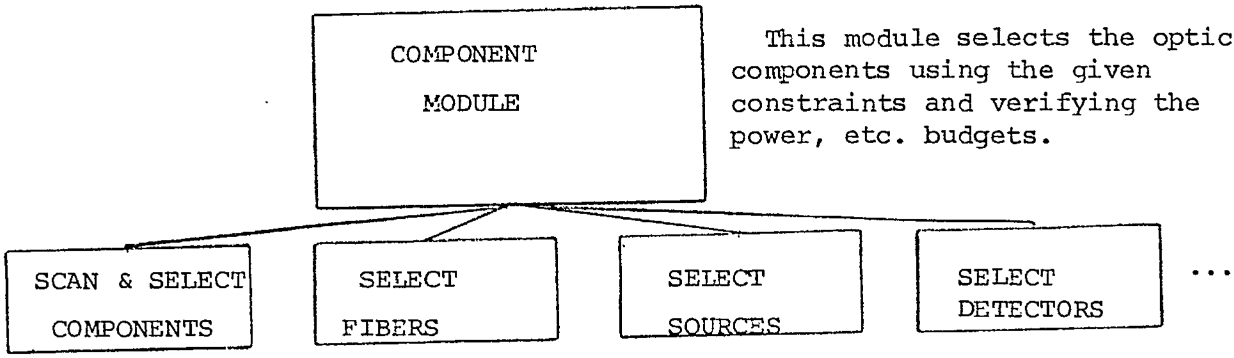
(ALL MODULES RETURN TO THE COMMAND MODULE)



This module determines the basic network requirements or permits modification of existing ones.



This module carries out the power, rise time and cost budget calculations. It is used by the COMPONENT module to check feasibility of each choice proposed for components by the select procedure.



This module selects the optical components using the given constraints and verifying the power, etc. budgets.

This module references the component database, BAZAR. The latter has its own procedures for building the various sub-databases needed.

Figure 2.3 - Sample Session with the CAD Program of Figure 2.2

```
run lucifer             (COMMENTS IN CAPITAL LETTERS' PARENTHESIZED)

                                    Systeme        L U C I F E R

                                Conception assistee de reseaux locaux.
                                 (LAN COMPUTER-ASSISTED DESIGN)

 - Desirez-vous la documentation ? n    (ASKS IF DOCUMENTATION DESIRED...USER ANSWERS 'NO')

 - Nom de la configuration ? najmeh  (ASKS FOR NAME OF CONFIGURATION...USER GIVES 'NAJMEH')
 Nouvelle configuration: najmeh   (PROGRAMMER INDICATES THAT THIS IS A NEW CONFIGURATION)

 CHOIX DES CONTRAINTES. (REQUIREMENTS OR CONSTRAINTS MODULE)
 - Donnez un estime du cout du reseau en millier de $ ? 1000  (USER INDICATES COST EST.)

 Vous devez fournir soit (1) le debit maximal du systeme,
                         (2) la bande passante requise.
 - Lequel pouvez-vous fournir , 1 ou 2 ? 1        (USER INDICATES BIT RATE: HERE  150 Mbps)
 - Debit maximum prevu (Mega bits/sec) ? 150

 Voici les topologies courantes de reseaux :
                        0- Point a point
                        1- Etoile active.
                        2- Etoile passive.        (PROGRAMM PRESENTS TOPOLOGIES
                        3- Anneau.             IT CAN CURRENTLY HANDLE...)
                        4- Bus.
                        5- LOOP BUS.
 - Lequel preferez-vous ? 2         (USER SELECTS PASSIVE STAR)

 - Nombre maximal de noeuds prevus dans le systeme ? 32 (USER SPECIFIES NUMBER OF NODES, 32)
 - Nombre maximal de terminaux par noeud ? 20   ( NOW HE SPECIFIES 20 TERMINALS PER NODE)
      (N.B.- ONLY THE FIRST IS USED NOW IN THIS SIMPLE VERSION OF THE PROGRAM)
 - Estimez la distance maximale entre deux noeuds relies (metres) ? 1500   (USER SPECIFIES
                                     INTERNODAL (MAX.) DISTANCE AS 1500 m )
    Voici les niveaux de qualites possibles :
                        1- Minable      1E-2  erreur/sec
                        2- Normal       1E-8  erreur/sec
                        3- Excellent    1E-10 erreur/sec   (CHOICE OF BER'S)
                        4- SUPER        1E-12 erreur/sec

 - Lequel preferez-vous ? 2   (CHOOSES 10^-8  bps)

    Voici les methodes d'acces au reseau :
                        1- CSMA/CD
                        2- Multiplexage en temps.
                        3- Passage du JETON.
 - Lequel preferez-vous ? 2   (USER CHOOSES TDMA....PROGRAM DOES NOT YET USE THIS)

 - Desirez-vous une organisation repartie ? oui  (USER CHOOSES DISTRIBUTED ORGANIZATION,
                                                  AGAIN' NOT YET USED)

          CONTRAINTES.
 Vous pouvez            0- Quitter cette etape.
                        1- Afficher les contraintes du reseau.      (A MENU OF CHOICES
                        2- Reecrire toutes les contraintes.       IS PRESENTED)
                        3- Modifier certains des contraintres.
```

Figure 2.3 (Continued)

```
 - Votre choix 0,1,2 ou 3 ? calcul    (USER REQUESTS DETAILS OF POWER BUDGET CALCULATION)
Puissance de l'emetteur                   8.45 dB
Format de modulation                     -6.00 dB
Emetteur fibre couplage perte             0.00 dB
Perte totale dans la fibre               -1.05 dB
Perte totale due aux epissures           -0.50 dB    (N.B.:  THESE VALUES ARE BASED
Perte due a la configuration            -16.75 dB     ON COMPONENTS SELECTED BY THE
Detecteur fibre couplage perte            0.00 dB     PROGRAM...FOR NOW TEST VALUES
                                       ----------     ONLY AND NOT MEANT TO BE
Puissance au detecteur                  -15.85 dB     REALISTIC)
Marge de degradation de temperature      -2.00 dB
Marge d'interference intersymbole        -2.00 dB
                                       ----------
Puissance disponible au detecteur       -19.85 dB
Puissance necessaire au detecteur       -70.00 dB
                                       ----------
MARGE D'EXCES DU SYSTEME                 50.15 dB


 Vous pouvez              0- Quitter cette etape.
                          1- Afficher les contraintes du reseau.
                          2- Reecrire toutes les contraintes.
                          3- Modifier certains des contraintres.
 - Votre choix 0,1,2 ou 3 ? 0      (GO ON TO NEXT STEPS)

       LUCIFER.
 Vous pouvez :            0- Quitter LUCIFER.
                          1- Modifier les contraintes du reseau.
                          2- Choisir le materiel necessaire.
                          3- Faire afficher certains calculs.
 - Votre choix ? 2                (USER DEMANDS TO SEE COMPONENT LISTS...HE CAN
       CHOIX DU MATERIEL.          SELECT HIS OWN IF HE WISHES)
       CHOIX DE LA FIBRE.
       Fibre             Db/Km  Type Brins  NA     Bande   Lgr  Mat   Prix
  1: 22001                 6.0   SI    1   0.34    25.00   1.0  PCS   1.65
  2: OFC-5610-1K          10.0   SI    1   0.22   200.00   1.0  G     3.00
  3: Cie Lyonnaise         3.0   GI    1   0.22   200.00   1.1  G     2.60
  4: G50/125.0710-24       0.7   GI   24   0.20  1000.00   1.0  SI    4.00
  5: 242                   7.0   GI    2   0.30    20.00   1.0  G     3.50
 - Quelle fibre preferez-vous ?  (NO RESPONSE HERE PASSES US ON TO THE NEXT STEP)

       CHOIX DE L'EMETTEUR.
      Source         Puissance  Type    Frequence   Rise  Demi-vie    Prix
  1: 698-073EG1       2.3E-02   LED          0.82     12  3.5E+05    90.00
  2: TXA 003 A-B-C    1.0E-02   LED          0.90     20  1.0E+06   300.00
  3: C86003E          1.0E-01   LED          0.82     10  2.0E+05   850.00
  4: FCC1770          5.0E+00   Laser        0.82     20  1.0E+04  3000.00
  5: CO DIG           7.0E+00   ILD          0.85      1  3.6E+05  5000.00
 - Lequel choisissez-vous ?           (SAME AS ABOVE)

       CHOIX DU DETECTEUR.
      Recepteur  Sensibilite  Type      Range      Bande    Forme      Prix
  1: 698-072DG1      6.0E-03   PIN      15.00       2.00     NRZ     600.00
  2: RXD 511         2.4E-04   PIN      15.00      10.00     RZ      235.17
  3: RXD004          2.0E-05   APD      14.00      10.00     MTR     500.00
  4: CRM-100         3.0E-04   PIN      16.00       4.00     MTR     225.00
  5: E02SLR          1.0E-07   APD       5.00       8.00     RZ     6700.00
 - Lequel choisissez-vous ?   (SAME AS ABOVE)
```

Figure 2.3 (Continued)

```
     MATERIEL.
Vous pouvez :          0- Quitter cette etape.
                       1- Afficher les materiaux.       (PROGRAM PERMITS EXAMINATION OF
                       2- Choisir la fibre optique.    COMPONENTS OR MODIFICATION)
                       3- Choisir l'emetteur.
                       4- Choisir le recepteur.
                       5- Choisir le connecteur.
- Votre choix (0-5) ? 1   (USER ASKS TO VIEW COMPONENTS CHOSEN)
Liste du materiel choisi.
     Fibre              Db/Km  Type Brins  NA     Bande    Lgr   Mat   Prix
0:    Meilleur            0.7   GI   24   0.20  1000.00   1.0   SI    4.00
    Source         Puissance  Type   Frequence   Rise   Demi-vie    Prix
0:    Meilleur       7.0E+00   ILD        0.85      1   3.6E+05   5000.00
    Recepteur    Sensibilite  Type     Range     Bande    Forme     Prix
0:    Meilleur       1.0E-07   APD      5.00      8.00      RZ     6700.00
Vous pouvez :          0- Quitter cette etape.            (AGAIN, USERS CHOICE IS
                       1- Afficher les materiaux.       REQUESTED....)
                       2- Choisir la fibre optique.
                       3- Choisir l'emetteur.
                       4- Choisir le recepteur.
                       5- Choisir le connecteur.
- Votre choix (0-5) ? 0   (USER CHOOSES TO LEAVE THIS MODULE)

Vous pouvez :          0- Quitter LUCIFER.
                       1- Modifier les contraintes du reseau.
                       2- Choisir le materiel necessaire.
                       3- Faire afficher certains calculs.
- Votre choix ? 0    (USER NOW LEAVES LUCIFER)

- Faut-il garder cette configuration (O-N) ? oui   (PROGRAM ASKS IF THIS CONFIGURATION
                                                    IS TO BE SAVED...USER ANSWERS 'YES')
  Configuration: najmeh            (PROGRAM PRINTS OUT DETAILS OF CONFIGURATION,
                                                         STORES THE CONFIGURATION AND EXITS)
  Cout prevu : 1000 K$ ,  Debit : 150 Mega bits/sec
  Nombre de noeuds : 32,  Distance maximum :    1.5 Km  ,20 Terminaux/noeud
  Taux d'erreur acceptable : STANDARD  (1E-8  Erreur/s)
  Organisation prevue : Etoile passive Repartie       Acces : Multiplexage

Liste du materiel choisi.
     Fibre              Db/Km  Type Brins  NA     Bande    Lgr   Mat   Prix
0:    Meilleur            0.7   GI   24   0.20  1000.00   1.0   SI    4.00
    Source         Puissance  Type   Frequence   Rise   Demi-vie    Prix
0:    Meilleur       7.0E+00   ILD        0.85      1   3.6E+05   5000.00
    Recepteur    Sensibilite  Type     Range     Bande    Forme     Prix
0:    Meilleur       1.0E-07   APD      5.00      8.00      RZ     6700.00
  Cout total :    566.72 K$
Configuration ... SAUVEE ! dans : najmeh (CONFIGURATION STORED WITH NAME 'NAJMEH')

             Fin du travail sur  L U C I F E R .
```

2.5- A System Model for Fiber Optic LAN's

At the physical level, a LAN is simply a collection of components, links, and an interconnexion scheme indicating the manner in which the links join the components. By components here is meant optical sources (transmitters, transmitter packages), optical detectors (receiver packages), couplers, and connectors. Splices may also be considered as a kind of component in the present argument. By link is understood an optical fiber or cable segment relating two components.

With this terminology in mind, a simple system model for fiber optic LAN's is presented below. This model is specially suited for the study of passively coupled systems, although in a purely formal sense it may be extended to active topologies as well.

Let

$$L(1),\ L(2), \dots, L(n)$$

be the (unidirectional) links of a given network and let

$$L = \operatorname{diag}\left[\ L(1),\ \dots\ ,\ L(n)\ \right]$$

$$= \left[\ L(i,j)\ \right],$$

where

$$L(i,i) = L(i) \quad \text{and}$$

$L(i,j) = 0$ for i different from j, $i,j = 1, \ldots , n$;

and

$K = [K(i,j)]$

be the link-component incidence matrix, where

$K(i,j) = 1$ if $L(i)$ is connected to $L(j)$,

$= 0$ otherwise, $i,j = 1, \ldots , n$.

The matrix K indicates which link is incident upon which other, that is, connected to another through a coupler or a connector (which may be viewed as a degenerate kind of coupler, as may be splices as well). Links may also be incident upon sources and detectors as will be explained below. Note that L(i) might be connected (coupled) to several links as well as to L(i) and likewise that L(j) may receive several afferent links as well as L(i) (see Figure 2.4). Moreover, to consider reflexions in the coupler, one might consider that L(i) is connected, via the coupler, to itself. Now let

$C = [C(i,j)]$

be the coupling matrix where

$C(i,j)$ = coupling coefficient of $L(i)$ to $L(j)$, $i,j= 1 , \ldots , n$.

Note that $C(i,j)$ is not zero only if $K(i,j) = 1$.

The coupling coefficient $C(i,j)$ might be considered as being the power transfer ratio for the afferent port to which $L(i)$ is incident and the efferent port to which $L(j)$ is incident (see the discussion below on the interpretation of the symbols $L(i)$, $C(i,j)$, etc.).

Some links will originate at a source and others will terminate at a detector. One may treat sources and detectors as "terminal couplers" for purposes of the present discussion.

Let

$$I = \mathrm{diag}[\ I(1),\ \ldots.\ ,\ I(n)\ ]$$

and

$$O = \mathrm{diag}\ [\ O(1),\ \ldots\ ,\ O(n)\ ]$$

be respectively the input and output diagonal matrices where

$I(i)$ = source input to i-th link $L(i)$ if $L(i)$ originates at a source, and

= 0 otherwise;

$O(i)$ = output from i-th link $L(i)$ if $L(i)$ terminates on a detector, and

= 0 otherwise.

Consider now the matrix

$$Q = L * C = [\ L(i) * C(i,j)\ ],\ i,j = 1,\ \ldots\ ,n\ ,$$

where * may be taken as a generalized multiplicative operator. Now consider,

$$Q^{\wedge}m = Q * Q * Q * \ldots * Q \quad \text{(m-times)},$$

where the generalized product * is defined as follows:

$$A * B = [A(i,j)] * [B(i,j)] = [C(i,j)]\ ,\ i,j = 1,\ \ldots\ ,\ n$$

with

$$C(i,j) = F/k{:}[\ A(i,k) * B(k,j)\ ]\ ,\ i,j,k = 1,\ \ldots\ ,\ n\ ,$$

and F/k: is some function over k applied to the products A(i,k) * B(k,j). For example, F/k: might be taken as the conventional summation with * real multiplication to give the usual definition of matricial product. Here, however, we shall take F/k: to be the

$$\mathrm{MAX}\ /k\ ,$$

that is, F/k will select the product having largest value.

Now, the matrix

$$K^{\wedge}m = Q^{\wedge}m * L = L * Q * L * Q * \ldots . * L * Q * L$$

(m occurrences of Q)

gives the products of the form,

$$(1) \qquad K^m(i,j) =$$

$$L(i)*C(i,i1)*L(i1)*C(i1,12)*L(i2)*C(i2,i3)*\ldots*L(iq)*C(iq,j)*L(j)$$

$$(q=m-1)$$

where the path

L(i) to L(i1), L(i1) to L(i2), L(i2) to ...., L(iq) to L(j) ,

represents the maximal path of length m+1 from the origin end of L(i) to the destination end of L(j). Recall that each element

$$Q^m(i,j) \quad \text{of} \quad Q^m = Q * Q^{m-1}$$

is given recursively by

$$Q^m(i,j) = \mathrm{MAX}/k\colon \left[\, Q(i,k) * Q^{m-1}(i,j) \,\right] \;,\; i,j,k = 1 \,,\, \ldots \,,\, n \,,$$

$$m = 1,\ 2,\ 3,\ \ldots\ .$$

Premultiplying K^m by the diagonal input matrix I and postmultiplying by the output matrix O, gives

$$I * K^m * O = [\, I(i) * Q^m(i,j) * O(j) \,] = [N^m(i,j)]$$

where

(2) N^m(i,j) =

I(i)*L(i)*Q(i,i1)*L(i1)*Q(i1,i2)*...*Q(iq,j)*L(j)*O(j),

i,j = 1, ... , n and m = 1, 2, 3, ...

(same set i1, i2, ... , iq as in Eqn. (1) above)

If L(i) and L(j) are terminal, then I(i) and O(j) are not zero and the expression of Eqn. (2) gives the optical details of the maximal path of length m+1 through the network from source I(i) to detector O(j).

The symbols I(i), L(i), Q(i,j), O(j) , ... used above may be interpreted in several ways:

1- as numerical measures of optical power ratios:

I(i) - power emitted by the source,

L(i) = a * len(i) - optical attenuation of i-th length where

a = fiber attenuation=loss ratio per km and (for given window)

len(i) = length of i-th link , km.

Q(i,j) = power coupling coeffcient from coupler input port to which L(i) is afferent and from which L(j) is efferent.

O(j) = receiver sensitivity or other parameter such as coupling ratio into receiver.

2- as symbolic pointers to lists containing detailed information about each element. For example, I(i) = [P , lambda, r, ...] ,

where P is the power emitted by the source,

lambda is the source wavelength,

r is the rise time (nsec), etc.

L(i) = [len,a(1),lambda(1),a(2),lambda(2),NA,OD,CD,D,M,...] ,

where

len is the length of L(i),

a(i), lambda(i) the attenuation and attenuation wavelengths of the i-th window,

NA the numerical aperture,

OD the outer diameter,

CD the core diameter,

D the modal dispersion,

M the material dispersion,

and so forth.

3- as symbols for the measures of (1) (or other).

In the first case (1), N^m(i,j) gives a numerical value, namely the total optical loss for the most lossy path of length m+1 from source i to detector j. In the third case, the Eqn. (2) gives the algebraic equation for this loss. Under the second interpretation, the symbolic expression for N^m(i,j) gives, via the lists to which the elements of N^m(i,j) point, a detailed optical description of the indicated path from i to j.

If the first interpretation above is used, then a condition for feasibility of the network, as far as optical power budgets are concerned, may be given as

(3)

$$\underline{\text{norm}}\,[N^m(i,j)] = S \quad , \quad m = 1,\ 2,\ \ldots\ ,$$

where

$$\underline{\text{norm}}\,[A(i,j)] = \text{absolute value of } A(i,j), \quad i,j = 1,\ 2,\ \ldots\ ,n$$

and

S = the power margin.

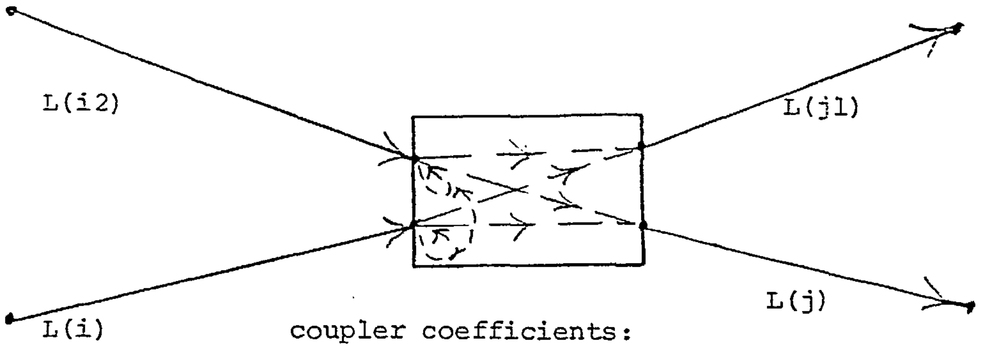
For networks whose incidence graphs have no cycles, N^m becomes the zero matrix when there are no paths of length m+1. For networks with cycles, m can in principle tend to infinity with non-zero elements (which represent the paths through the network of length m+1, either symbolically or numerically according to the interpretations mentioned above). Eqn. (3) gives the basic condition that the power losses not exceed a given (global) power margin. Clearly, this could be refined to consider power margins for individual receivers O(i) if so desired.

In Figure 2.5, a simple example is given showing the numerical values (first interpretation given above) for a simple network.

Notice that the model developped is essentially computationally oriented and is not meant to be the basis of an analytical approach. Once again, as for the procedure described in the preceding sections, the procedures representing the operations of this model will be coupled with the appropriate databases. Moreover, the design procedure may evoke this model for its own purposes.

The model given applies specifically to LAN's that use passive couplers. As was pointed out in the preceding sections, however, the trend is towards network architectures that avoid the loss problems posed by using passive optical couplers. The most promising structures are variants of the active ring configuration. In this case, the problems in the optical domain reduce to that of point-to-point links, as far as such things as power and rise-time budgets are concerned. Problems such as jitter or other synchronisation problems are not purely optical in nature. Therefore, the model developped in this section would not be applicable in its current form. However, if one returns to the second interpretation given above, i.e., interpreting the elements of N^m symbolically, then one can characterize an active node as being a kind of coupler and the "coupling" coefficients for such a node as descriptions of the electro-optical properties of the node. Such descriptions would evoke the appropriate mathematical or algorithmic procedures needed to study, for example, phenomena such as jitter.

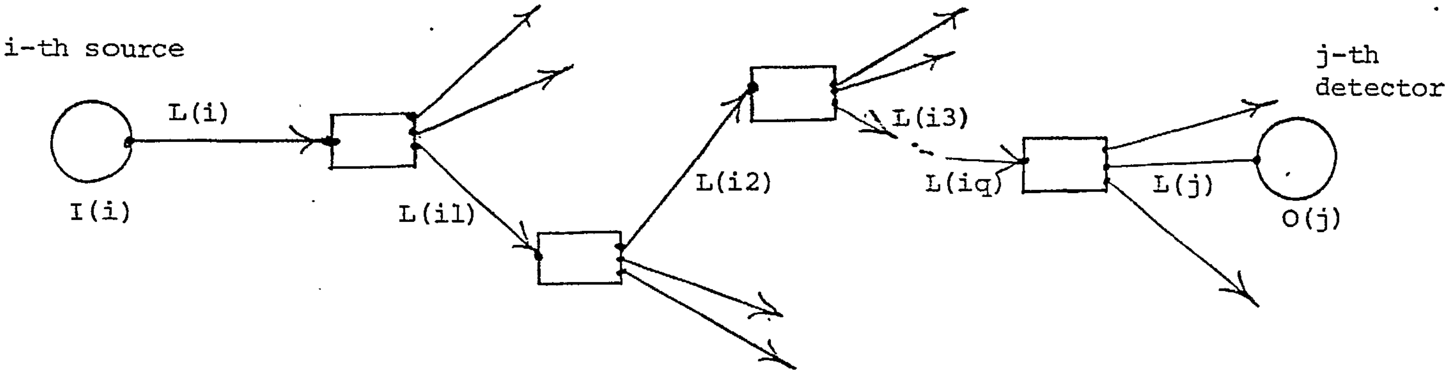
To explore further the implications of the last paragraph would lead one out of the range of this study.



coupler coefficients:

$$C(i,j),\ C(i,j1),\ C(i1,\ j),\ C(i1,\ j1)$$

For reflexions : $C(i,i)$, $C(i,\ i1)$, ...



Path i to j (from source i to detector j) :

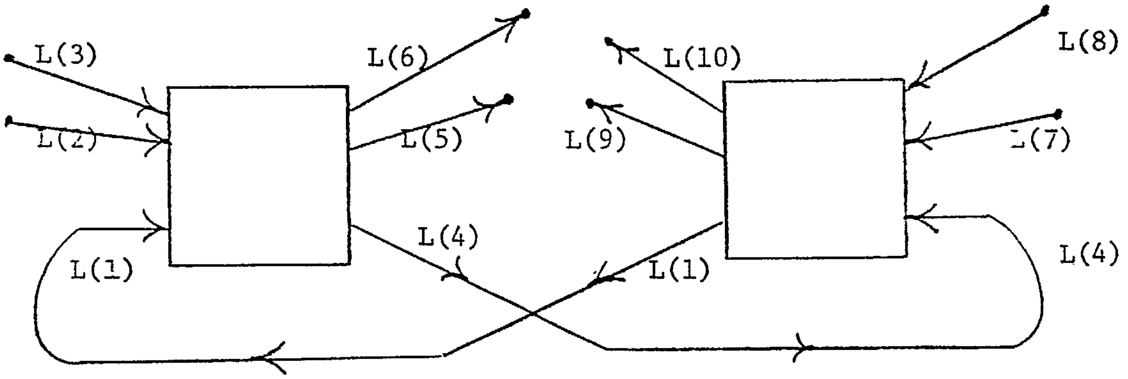
$$I(i) * L(i) * C(i,i1) * L(i1) * C(i1,12) * L(i2) * \dots C(iq,j) * L(j) * O(j)$$

path of length $m+1$ if ther are $q=m$ couplers

Figure 2.4- A Simple System Model for Optical Fiber LAN's

The link-coupling relationships are indicated below. In general, a link is coupled to another link through a passive device such as a connector, coupler, or splice. The case of terminal couplings, that is of a source to a link or of a link to a detector permit inclusion of the latter devices in the model (see text). In a purely formal sense, as is mentioned at the end of Section 2.5, one might consider coupling through an active node, that is, through the electro-optical conversions and the internal electrical and computer manipulations. This might be useful in a computerized database coupled version of the model to study such phenomena as jitter or the like.

Figure 2.5- A Simple Computational Example for a Passively-Coupled LAN



Incidence matrix K

$$\begin{matrix}0&0&0&1&1&1&0&0&0&0\\0&0&0&1&1&1&0&0&0&0\\0&0&0&1&1&1&0&0&0&0\\1&0&0&0&0&0&0&0&1&1\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\1&0&0&0&0&0&0&0&1&1\\1&0&0&0&0&0&0&0&1&1\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\end{matrix}$$

Coupling Matrix C

$$\begin{matrix}0&0&0&.3&.3&.3&0&0&0&0\\0&0&0&.3&.3&.3&0&0&0&0\\0&0&0&.3&.4&.2&0&0&0&0\\.25&0&0&0&0&0&0&0&.23&.24\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\\.31&0&0&0&0&0&0&0&.28&.23\\.22&0&0&0&0&0&0&0&.25&.27\\0&0&0&0&0&0&0&0&0&0\\0&0&0&0&0&0&0&0&0&0\end{matrix}$$

Link Matrix L

diag (.5,.25,.25,.5,
.25,.25,.25,.25,.25)

```
CB1L=CB*L=L*C*L
PATHS OF LENGTH 2, ONE COUPLER

 0  0  0  .075  .0375  .0375  0  0  0  0
 0  0  0  .0375  .01875  .01875  0  0  0  0
 0  0  0  .0375  .025  .0125  0  0  0  0
 .0625  0  0  0  0  0  0  0  .02875  .03
 0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
 .03875  0  0  0  0  0  0  0  .0175  .014375
 .0275  0  0  0  0  0  0  0  .015625  .016875
 0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
```

```
CB2L=CB1*L=L*C*L*C*L
PATHS OF LENGTH 3, TWO COUPLERS

 .009375  0  0  0  0  0  0  0  .43125E-2  .0045
 .46875E-2  0  0  0  0  0  0  0  .215625E-2  .00225
 .46875E-2  0  0  0  0  0  0  0  .215625E-2  .00225
 0  0  0  .009375  .46875E-2  .46875E-2  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
 0  0  0  .58125E-2  .290625E-2  .290625E-2  0  0  0  0
 0  0  0  .004125  .20625E-2  .20625E-2  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
 0  0  0  0  0  0  0  0  0  0
```

Figure 2.5- A Simple Computational Example for a Passively-Coupled LAN

(continued)

```
PATHS OF LENGTH 4, THREE COUPLERS
 0  0  0  .140625E-2  .703125E-3  .703125E-3  0  0  0  0

 0  0  0  .703125E-3  .351563E-3  .351563E-3  0  0  0  0

 0  0  0  .703125E-3  .351563E-3  .351563E-3  0  0  0  0

 .117188E-2  0  0  0  0  0  0  0  .539063E-3  .5625E-3

 0  0  0  0  0  0  0  0  0  0

 0  0  0  0  0  0  0  0  0  0

 .726563E-3  0  0  0  0  0  0  0  .334219E-3  .34375E-3

 .515625E-3  0  0  0  0  0  0  0  .237188E-3  .2475E-3

 0  0  0  0  0  0  0  0  0  0

 0  0  0  0  0  0  0  0  0  0
```

The network shown uses two passive star couplers configured so that a terminal of one star can access all other terminals. Ideally, one would wish that the coupling coefficients L(1) to L(4), C(1,4) and L(4) to L(1), C(4,1) be negligible to avoid echos. In this example, however, this was not assumed. The examples given show the losses incurred on the various paths as explained in the text. The link matrix L, not shown here, has for L(i) the loss of the link ... this was to simplify the example. Thus, for the path L(1) to L(4) that passes through the first coupler, then the second and back through the first again, namely

K^3(1,4)

we have the value 0.00140625 or about 29 dB loss.

In this example, the effects of the input and output matrices have not been indicated. The point was to show the basic calculations (using the numeric interpretation of the model).

N.B.: The matricial output was obtained using a simple formatting system to conserve space. The reader should have no difficulty in interpreting these, however.

3- Summary of Current Trends

In this section, a number of contemporary fiber optic local area network activities are summarized. In some cases, the networks exist as finished products, available on the marketplace. In others, the networks are in varying stages of development, ranging from theoretical studies, sometimes accompanied by experimental backup, to laboratory prototypes. As information on these different networks was at times incomplete at the time of writing, the comparison tables given at the end of this chapter contain many blank entries. Nonetheless, this table should give the reader a good overview of the field.

The networks presented in this chapter permit the following general observations:

1- the multi-access protocoles are of critical importance to the designer in determining high throughput, low delay;

2- CSMA/CD type protocoles are used up to 32 Mbps and ring token protocoles for bit rates exceeding 50 Mbps;

3- token rings dominate for now the high-speed commercially available networks (50-100 Mbps);

4- a variant of the token protocole method apparently works at 1 Gbps on a loop-bus architecture in a laboratory prototype.

3.1- CSMA/CD Networks (Ethernet Compatible)

Certainly, one of the first local area networks to attract a great deal of attention is the Ethernet developped by the Xerox Corporation. This network has stimulated the creation of a number of look-alikes as well as versions to be implemented on standard broadband coaxial cable systems (see THURB'82 for an overview). Therefore, it is natural that fiber optic versions be developped. Two such versions are presented below, each one using slightly different approaches. The first is the Xerox Corporation's active star based Fibernet II whereas the second is Codenet, a passive star based system developped for Ungermann-Bass' Net/One jointly by Ungermann-Bass, Siecor, and the Codenoll Corporation.

Besides the two efforts mentioned above, there are, of course others. Apparently Nippon Electric Corporation and Toshiba have developped Ethernet compatible 10 Mbps CSMA/CD networks. The NEC network uses a tree architecture, whereas the Toshiba network (in prototype form) uses a passive star coupled bus (ASIA'83, EDPJ'82). These networks are summarized in Table 3.1 at the end of this chapter.

Fibernet II (RAWS'82a,b)

Fibernet II uses and active star repeater to create the equivalent of the baseband coaxial cable "ether" channel (Figure 3.1). Collision detection is implemented electrically in the 25 port star repeater on a backplane which behaves like a small Ethernet and which is electrically compatible with the standard 10 Mbps Ethernet coaxial cable. Span of the network of about 2.5 km. Using 8-channel multiplexers (Figure 3.2), the network could handle up to 200 stations, whereas by cascading the repeaters on their backplane Ethernets, over a thousand stations might be accomodated. Finally, the fiber star network might be used as a backbone to interconnect Ethernet segments (Figure 3.3).

Figure 3.1 - Fibernet II Topology

Stations are interconnected through an active star repeater, two fibers per station for both directions. The XCVR units handle the optical transmitting and receiving units.
(Adopted from RAWS'82)

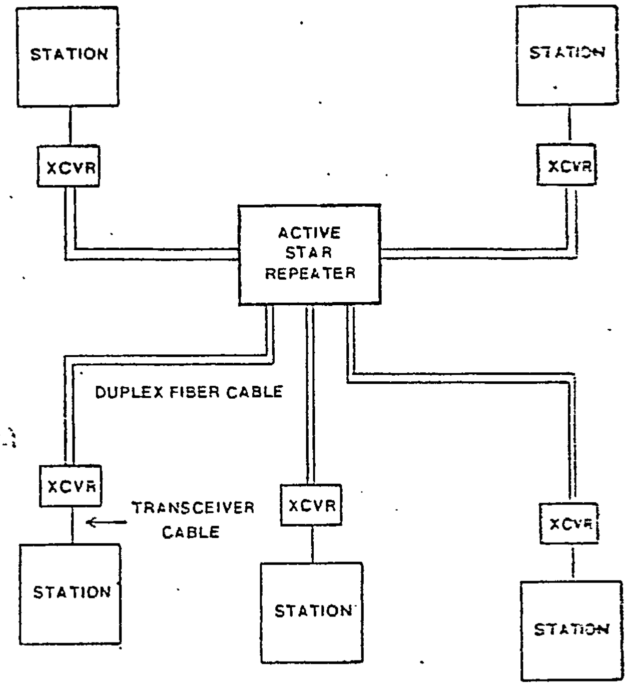


Figure 3.2 - Stand-Alone Fibernet II with 8-Port Concentrators

The concentrators or multiplexers permit up to eight stations to access the network, thereby avoiding excessive installation of fiber cable.

(Adopted from RAWS'82)

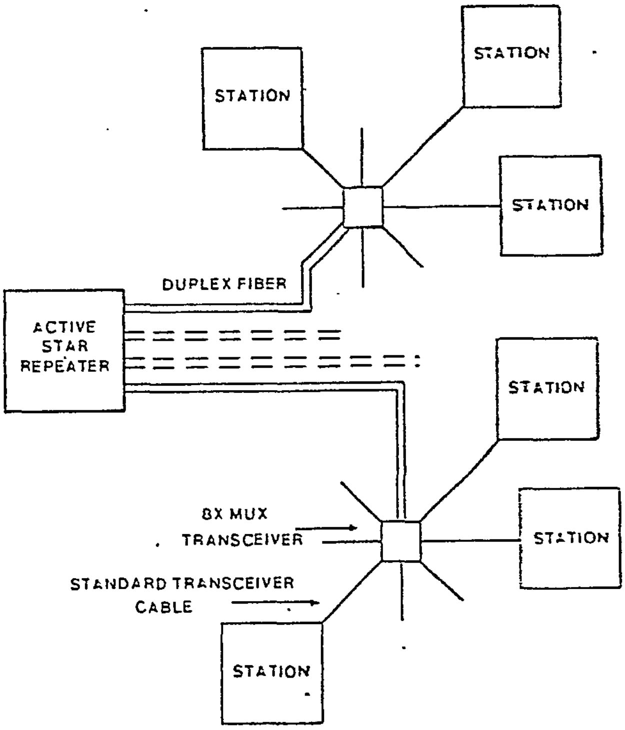
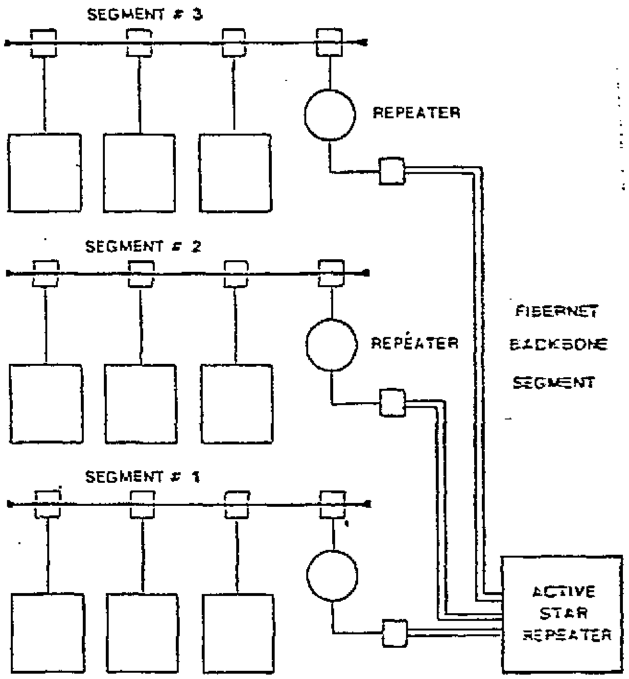


Figure 3.3

Backbone Fibernet II Interconnecting Several Ethernet Segments

(Adopted from RAWS'82)

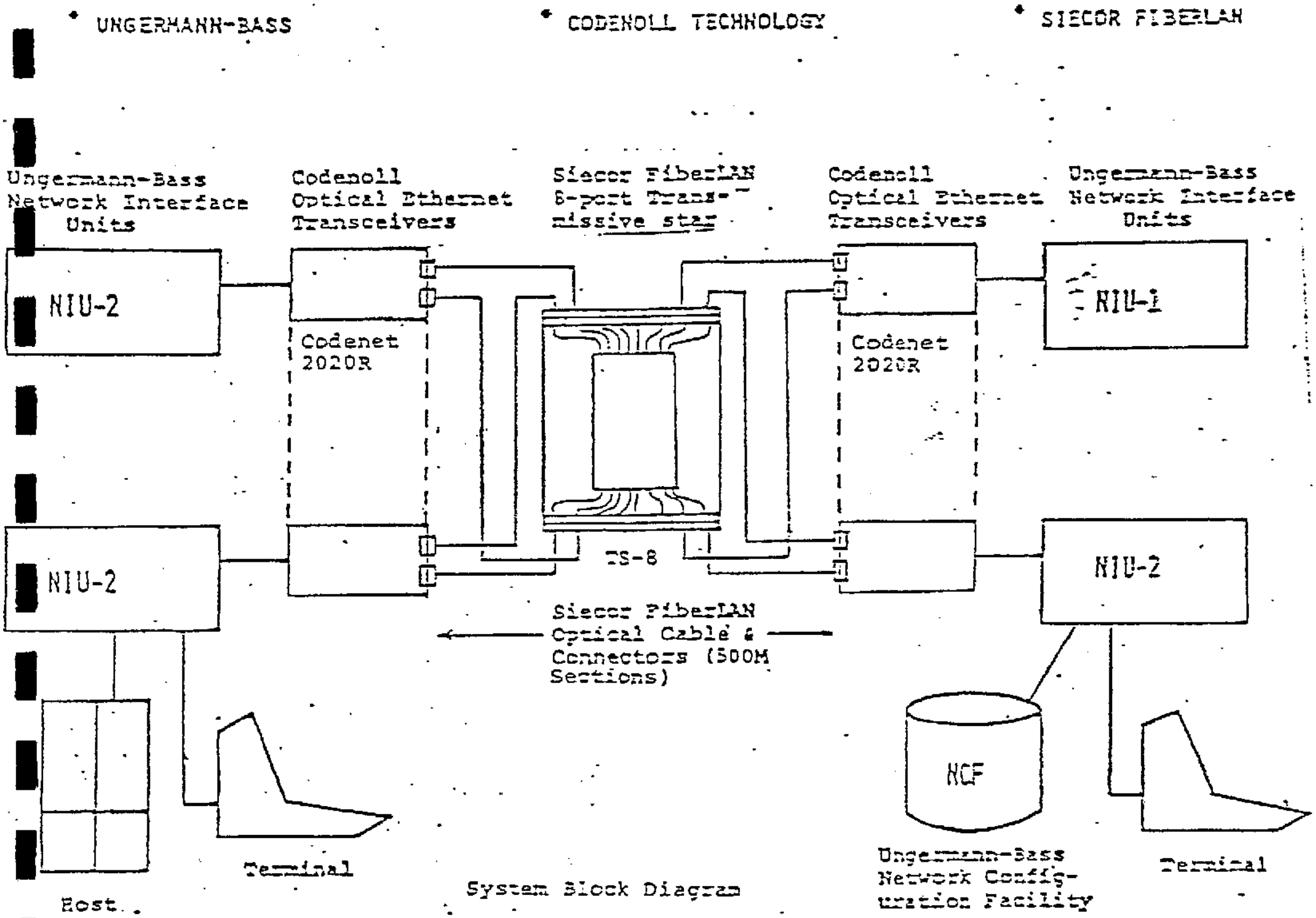


Codenet (JONES'82, CODE'82)

Another Ethernet compatible effort uses an 8-port passive transmissive star coupler to implement the "ether" cannel. The collision detection mechanism is distributed, as opposed to the centralized version of Fibernet II, and is implemented in the station nodes. The latter are Ungermann-Bass' NIU's or network interface units, capable of supporting up to 24 serial RS-232 ports each, or various other combinations of serial and parallel ports. Thus, a sixteen node configuration would support several hundred terminal devices. Extensions of the network might be achieved through making the star active, as in Fibernet II, or by the use of repeaters. These alternatives, as well as some system data are summarized in Figure 3.4.

Figure 3.4 - A Fiber Optic Version of Net/One

(Adopted from JONES'82)



System Block Diagram

Figure 3.5 - Some Details Concerning Codenet

(Adopted from JONES'82)

EQUIPMENT DETAILS

Siecor FiberLAN Passive Transmission System

TS-8 transmissive star

- -8 port
- -star and terminations mounted in 19 inch rack-mount chassis
- -interface via Siecor connectors
- -12.5 dB worst-case loss (including connector loss)
- -2.3 dB worst-case port-to-port variation (including Connector loss)

Optical connectors

1 dB typical loss

Optical cable

- -model 244, 100 micron core, 140 micron outer diameter
- -dual window fiber
- -typical loss: 6 dB/km at 850 nm, 5 dB/km at 1300 nm
- -bandwidth greater than 100 Mhz-km

Kevlar strength members, flame retardant sheath (VWI)

Alternate schemes for increasing the number of nodes

- -series connections of stars through a repeater
- -active star
- -node multiplex: use electrical multiplexing to increase the number of terminal served by an optical node

Using node MUX, repeaters and large node count stars, a 1024 terminal system meeting Ethernet specifications can be constructed:

- -2 each, 65 port stars, one repeater, 2.8 km max terminal separation
- -1 each, 128 port star, 0.9 km max terminal separation

3.2- Nippon Telegraph and Telephone's Call for Bids (NTT'83)

An interesting recent development is the call for bids put out by the Japanese Nippon Telegraph and Telephone Public Corporation (NTT) to U.S. firms to develop medium-scale, passive star coupled CSMA/CD networks at 32 Mbps. The star is to be 32 or 100-port depending on the system specified. This reflects Japan"s current interest in pushing office automation and factory automation, to say nothing of exports.

3.3- Hub Type Networks

An interesting class of networks has recently evolved in an attempt to overcome some of the deficiencies of the Ethernet CSMA/CD type networks. This class uses an ingenious centralized selection- broadcast mechanism, hence the term hub

Hubnet (BOUL'82, LEE'82)

Hubnet is being developped by the University of Toronto's Computer Systems Research Group in collaboration with CANSTAR. A prototype has been built and tested.

Hubnet's designers set about to determine a network architecture that would overcome the following shortcomings of Ethernet:

1- poor performance under heavy traffic conditions;

2- low efficiency at high bandwidths;

3- (in the optical domain) coupler (tap) losses in linear bus configurations.

As a consequence, an innovative architecture was derived in which these shortcomings would appear to have been eliminated. The key idea is to shrink the "ether" channel to a point (the hub) at which an incoming signal is selected and broadcast to all outgoing lines (Figure 3.6). While one incoming signal is being handled, signals arriving on other input lines are blocked, causing their transmitting units to time out and try again. There are, therefore, no collisions in the Ethernet sense. In the case of several signals arriving simultaneously when the hub is quiescent, one is chosen arbitrarily.

Hubnet may be expanded by the use of subhubs as shown in Figure 3.7. A comparison of Hubnet's (expected) performance with that of Ethernet (hence, presumably, Fibernet II), is given in Figure 3.8.

Figure 3.6 - Hubnet

The NAC's or network access controllers, communicate through a centralized hub in the manner described in the text. Each NAC sends one fiber to the hub's selection side and receives on fiber from the hub's broadcast side. An incoming signal is selected and broadcast to all NAC's, including the one transmitting.

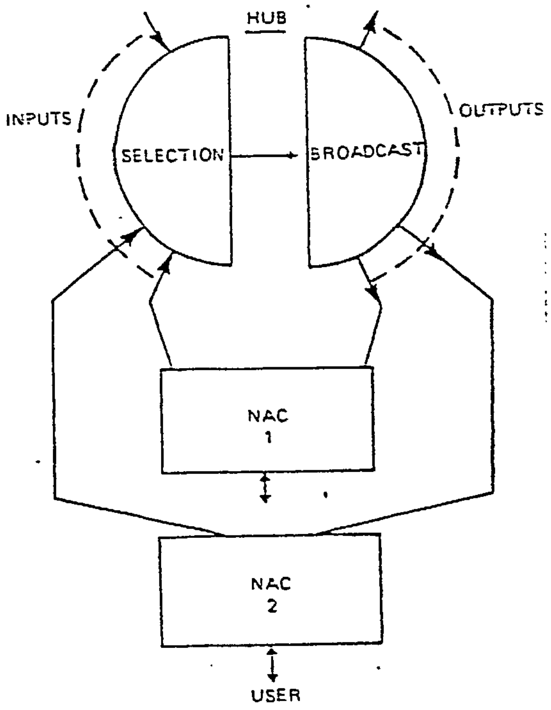


Figure 3.7 - Cascaded Version of Hubnet

Replacing the NAC's of the preceding figure by subhubs as shown here, the network ca be greatly expanded. Signals to be broadcast must work their way up to the parent hub, passing through the selection mechanism twice before being broadcast down to all other NAC's.

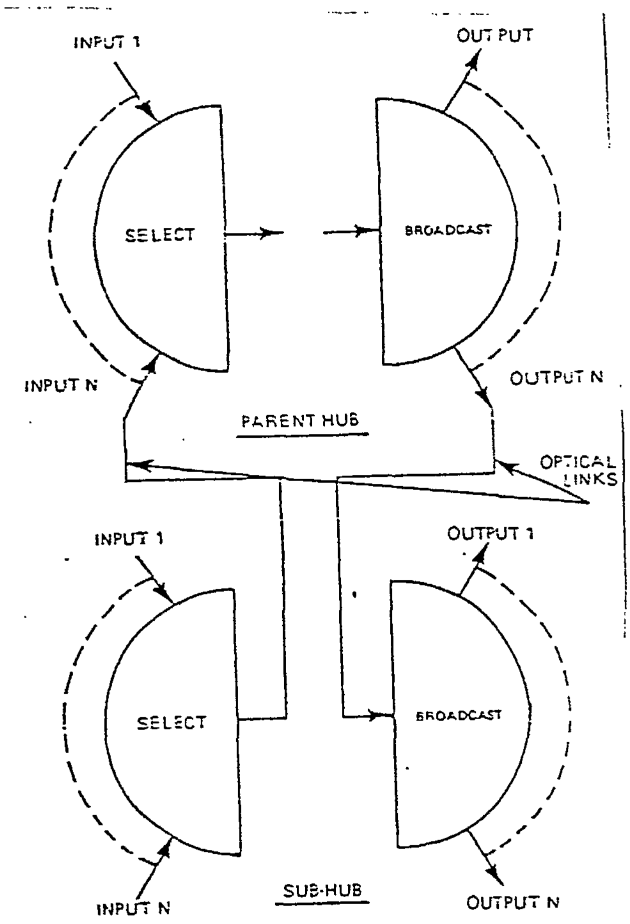


Figure 3.8 - Comparison of Hubnet with Ethernet

Parameter	Hubnet	Ethernet
data rate	50 Mbps	10 Mbps
span	open	2.5 km
max. # of stations	65,536	1024
medium	optical fibers	coaxial cable
topology	rooted tree, star	bus
message protocol	variable frame message size full acknowledgement delivery	variable frame message size best effort delivery
link control	multiple access echo detect of retry	CSMA/CD

A configuration similar to Hubnet has been proposed by Albanese (ALBA'82a), but his "hubs" use a reflective star coupler and a priority scheme ("traffic cop") to resolve conflicting access. At this writing, the author is unaware of the existence of a working prototype of this configuration.

3.4 - Non CSMA/CD Buses

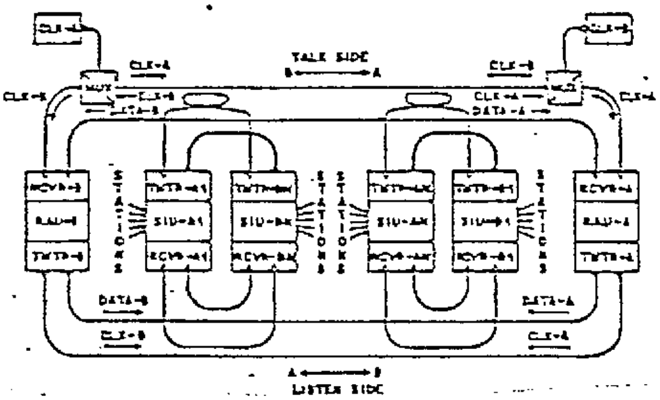
A number of uni- and bi-directional buses have been developped recently. One example, using a passive transmissive star-coupled topology as in Codenet but operating at much higher bit rates, was developped by ITT Electro-Optical Products Division as part of a NASA data base management system for archiving and retrieving satellite data (PORT'82). This network uses a 16 x 16 fused biconical taper star coupler and operates at 100 Mbps (thus, far beyond the range of efficiency of CSMA/CD protocols). Maximum network span without repeaters is 2 km. Bit error rate is less than 10**-10 bps.

Another approach to bidirectional buses is that adopted by Albanese (ALBA'82b) and is illsutrated in Figure 3.9. This network, using a loop-bus topology, allows two functionally distinct networks to coexist on the same fiber. This is done by using 4-port couplers and transmission at different wavelengths for the two directions. Due to limitations of current coupler technology, the number of nodes is limited in the best case to about thirteen for a 100 Mbps system. Polling and TDMA are used for access. A unidirectional variant called XBN (for Experimental Broadband Network) has been implemented by Hubbard and Albanese (HUBB'82). It uses dynamically assignable TDMA plus contention access methods simultaneously at a bit rate of 16.384 Mbps.

Figure 3.9 - Bidirectional Fiber Optic Bus

(Adopted from ALBA'82)

Two independent networks operate simultaneously, transmitting information in opposite directions and at different wavelengths. The information of network A flows clockwise while the information of network B flows counterclockwise. The two networks share all the optical hardware.



In Canada, work is undeway on a joint project between the Communications Research Center of the Department of Communications, CANSTAR, and Sperry-Univac to develop a shipboard data bus with half-duplex connexions at 10 Mbps (JOHN'82). Several topologies including a hybrid linear and a hybrid star configuration are being examined. A critical element of these configurations are the hybrid star couplers and the asymmetric 4-port fused biconical tapered couplers used.

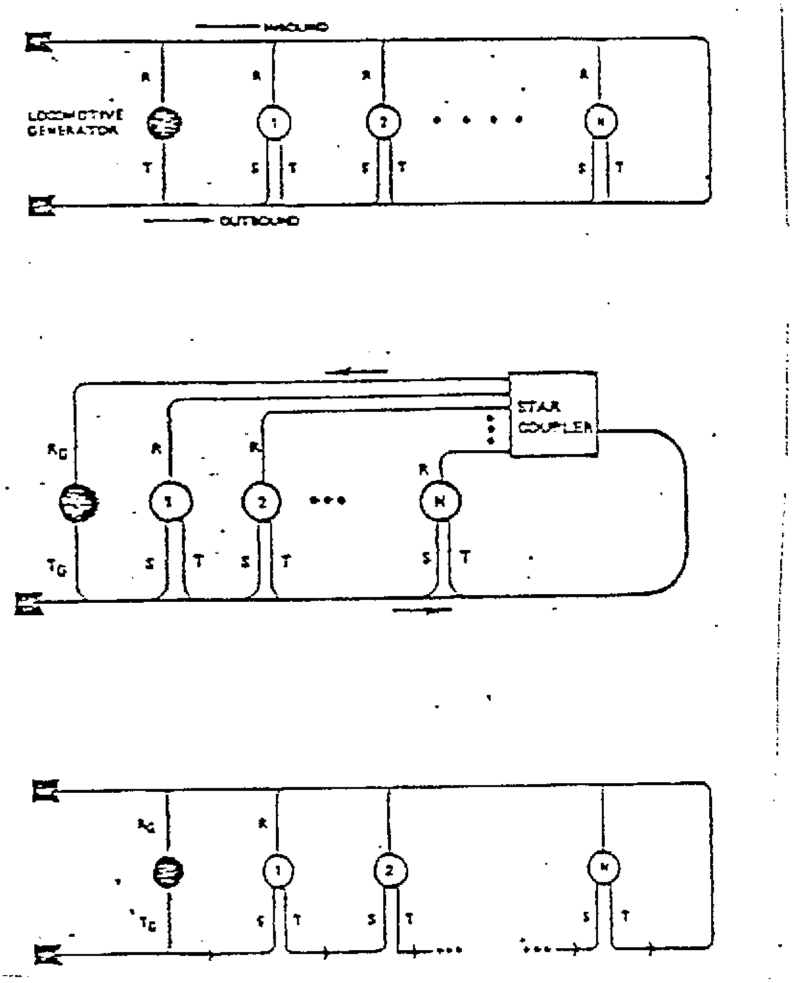
Finally, an ingenuous architecture has been recently proposed by Tseng and Chen at TRW (TSEN'82,'83), namely D-Net. D-Net may be realized using several topologies as illustrated in Figure 3.10. In this network, a specialized node called the "locomotive generator" generates trains that define the access windows for the nodes. The result of this is an efficiency near 1 and, therefore, unlike Ethernet or Fibernet II, high bit rates, say 100 Mbps, may be used. Network delay is tightly bounded so that packetized voice is feasible.

According to a recent papr (TSEN'83), an experimental prototype of D-Net has been built with transmission rate of 1 gigabit per second including six packet-switched television channels at 82 Mbps each. A variant of this type of network has been reported by Gerla, Yeh, and Rodriguez (GERL'83) at the UCLA School of Engineering.

Figure 3.10 - D-Net Topologies

The first topology is a loop-bus with the locomotive as shown. The second uses a star coupler for the inbound leg and the third is an "open" ring.

(Adopted from TSEN'82)



3.5 - TDMA and Token Passing Rings

At this writing, there are a number of important efforts to develop high-speed token passing ring networks, especially in Japan. Moreover, it appears that the American giant, the International Business Machines Corporation, leans towards such architectures for local area networks (independently of the transmission medium used), although as of yet no official company policy has been publically announced. The domination of IBM in the computer markets makes this point very interesting, given the impact upon the marketplace the company's decision will potentially have.

Several examples of token ring networks are cited in Table 1 given later on in this chapter. For now, consider as a typical example, the C&C-Net Loop 6770 built by the Nippon Electric Corporation, Limited. This network operates at 32 Mbps and includes such fault-tolerance mechanisms as node bypassing in the case of a node's crashing, alternate path selection if a fiber is broken, and battery power back-up. The ring consists of two optical fiber loops transmitting in opposite directions. Under normal circumstances, one loop is idle and on standby whereas the other is active. Since the nodes are active, bypassing is achieved by electronic switching as opposed to opto-mechanical. This network is illustrated in Figure 3.11.

An interesting approach to passive ring configurations is that of the Communication Laboratory of the Mitsubishi Electric Company in Japan with their 50 Mbps network BILNET (for bidirectional passive loop-structured network , see ITO'81, OSHI'82). This network, illustrated in Figure 3.12 transmits bidirectionally on the same fiber using WDM, one wave-length for one direction, the other for the opposite direction (840 and 900 nm respectively). Normally the ring is "open", that is, via an optical switch, the loop is broken at one point. This prevents signals from circulating more than once around the loop and thus creating echo interference. However, if the fiber cable is broken elsewhere, the switch closes, thus insuring continuity of operation. Since the ring is passive, failure of a node as such should not bring down the network. Unfortunately, this network involves concatenating passive tee couplers, hence optical losses restricting the number of such tees to about thirteen, as mentioned earlier.

There are a number of ring networks that have been developped in Japan in addition to the ones mentioned above. These include the following:

-Facom 2881 and 2883 of Fujitsu;
-H-8644 Loop Network of Hitachi;
-SIGMA of Hitachi;
-Loop 6530 and 6830 of NEC.

These networks are included in Table 3.1 at the end of this chapter.

Figure 3.11 - C&C-Net Loop 6770

An active token passing ring with extensive backup.

(Adopted from KIYO'82)

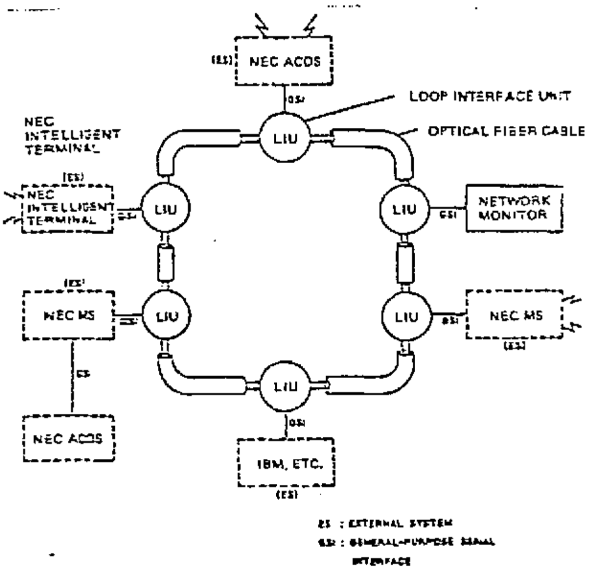
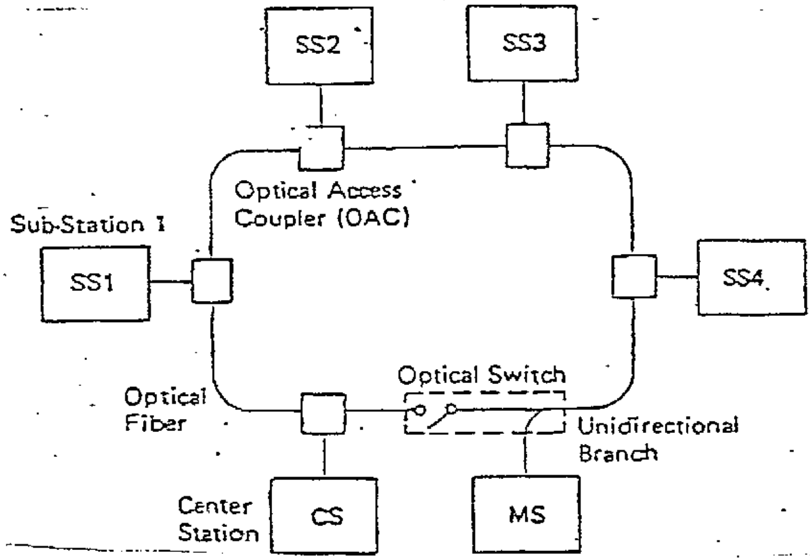


Figure 3.12 - BILNET

A passive two-way ring using WDM with automatic recovery mechanism

(Adopted from ITO'81)



3.6 - Fail-Safe Nodes

Networks with fail-safe nodes are of great interest to the designer who is considering active configurations in which failure of one node would interrupt the operation of the network, for example, an unidirectional active ring. Bypass mechanisms such as that used in C&C-Net Loop 6770 are one way of handling this problem. However, there are other approaches such as that suggested by Albanese at Bell Laboratories (ALBA'82). A 16 Mbps ring network was proposed whose nodes, based upon efficient 4-port couplers, allow automatic (i.e., non-switched) bypass if the active portion of the node goes down. Finley and Vo-Dai examined this configuration and seem to have isolated a problem with echo interference that is not handled correctly. If this problem turns out to be not too serious, then fail-safe nodes would permit implementation of large-scale ring networks using optical fibers similar to C&C-Net Loop 6770 mentioned above.

3.7 - PBX-like Networks

Use of a centralized switch for LAN's offers the simplicity of the familiar circuit-switched telephone network, completely bypassing the multi-access problems associated with rings and passive stars. The penalties to be paid would be the need for expensive intelligence and duplication at the switch site and access mechanisms to the nodes. For now, the price seems still too high to pay, but with the effects of economies-of-scale, this might not remain a serious barrier. A major problem is that of constructing a broadband switch that is capable of switching very high bit rate channels.

A recent development of a broadband opto-electronic switch by E. Hara (HARA'82) would permit 64 kbps and a video channel to be multiplexed on one fiber, allowing voice, video, and data on the same system. Hara's switch has been tested experimentally and is now under construction by Foundation Instruments in Ottawa. This switch uses optical fiber methods internally to deliver signals to its cross-points with highly acceptable crosstalk losses. For further details, the reader is referred to the paper of Hara mentioned above. Hara proposes this switch as the basis of a network for office communication systems and for high-rise building complexes.

3.8 - Summary

The major characteristics, when known, of the configurations presented in the preceding sections are summarized in the following table (Table 1).

Table 3.1 - Comparison of Various Fiber Optic LAN's

	Fibernet II	Codenet	Hubnet	Two-Way Bus
topology	active star	passive star	star hub	loop-bus
organization	centralized	distributed	distributed	distributed
access	CSMA/CD	CSMA/CD	hub access	centralized polled TDMA
bit rate	10 Mbps	3.4 Mbps	50 Mbps	100 Mbps
span	2.5 km	0.9-2.8 km	open	-
max. # nodes	200-1000	200-1000	65,536	13
fault-tolerance	-	-	-	-
fiber core	100 um	100 um	100 or 50 um	-
fiber O.D.	140 um	140 um	140 um	-
fiber type	step-index	G.I.	G.I.	-
fiber window	-	850, 1300 nm	-	-
source	LED	LED	LED	LED/LD
detector	PIN	PIN	PIN	PIN/APD
coding	Manchester	Manchester	-	-
error rate	(less than 10**-9 in all cases, presumably)			

Table 3.1 (continued)

	D-Net	C&C-Net	NASA/ITT	Hara's PBX
topology	several	active ring	passive star	active switched star
organization	distributed	distributed	centralized	centralized
access	"locomotive"	token	TDMA	circuit-switched TDMA
bit rate	100 Mbps	32 Mbps	100 Mbps	55.5 Mhz, 10 Mbps sampling
span	-	2.0 km	2.0 km	-
max.# nodes	-	126	16	-
fault-tolerance	-	bypass and	-	-
fiber core	-	50 um	50 um	-
fiber O.D.	-	125 um	125 um	-
fiber type	-	G.I.	G.I.	-
fiber window	-	-	-	-
source	-	LED/850 nm	LD/820 nm	-
detector	-	PIN	APD	-
coding	-	RZ	Manchester	-
error rate	(presumable less than 10**-9 bps)			

Table 3.1 (continued)

	FACOM 2831 (Fujitsu)	FACOM 2883 (Fujitsu)	H-8644 (Hitachi)	Loop Network (Hitachi)
topology	active ring	active ring	active ring	active ring
organization	-	-	-	-
access	TDMA	TDMA	token passing	TDMA
bit rate	4 Mbps	33 Mbps	32 Mbps	32 Mbps
span	3 km	9 km	2 km	2 km
(max loop length	96 km	576 km	100 km	-)
max.# nodes	32 (?)	54 (?)	50 (?)	-

(other details lacking at this writing)

Table 3.1 (continued)

	Loop 6530 (NEC)	Loop 6830 (NEC)	BRANCH 4800 (NEC)	(Prototype) (Toshiba)
topology	active ring	active ring	tree	passive star
organization	-	-	-	distributed
access	hybrid	hybrid	CSMA/CD	CSMA/CD
bit rate	32 Mbps	32 Mbps	10 Mbps	10 Mbps
span	7 km	12 km	1 km	1.5 km

(other details not available at this writing)

Table 3.1 (continued)

	SIGMA (Hitachi)	BILNET (Mitsubishi)
topology	active ring	passive ring
organization	-	-
access	TDMA	TDMA
bit rate	32 Mbps	50 Mbps
span	2 km	-
max.# nodes	64	around 13
fault-tolerance	dual fibers, switch-over, loop-back	
fiber core	50 um	
fiber O.D.	125 um	
fiber window	830 nm	
source	LED/@ 830 nm	
detector	PIN	

(Remaining details not available)

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Appendix 1 - An Automated Bibliographic System for Fiber Optic LAN's

A computerized bibliographic database system for documenting literature on fiber optics and on fiber optic local area networks was developped as an adjunct to this project. The system may be used to develop individually tailored bibliographic databases on nay technical subject. With the system, two databases on optical fibers have been created: one on optical fiber technology in the large contains about 3000 entries covering the period 1977 to 1980 approximately. This database is in continual expansion and should grow by several thousand entries in the new few months. The second database consists of references to fiber optic LAN's and related subjects, including a few general LAN references. It is restricted in size compared to the large database and one expects its growth to be less rapid, It contains now only about a hundred and fifty references.

The system allows the following interactive operations:

1- input of new entries in the database of one's choice. The input phase allows viewing and correcting of the entry if needed;

2- modification of existing entries. This permits correcting or changing entries in the database one wishes.

3- scanning or browzing in the database of one's choice. This is handy for real-time scrutiny of the contents of the database. Simple search commands help one navigate about in the database.

4- off-line printing of the whole database (in alphabetical order of the first author's surname).

5- off-line printing of a "KWIC"-ed version of the database on the keywords of one's choice. This was not part of the original program, but was obtained automatically by the establishment of a link between two of the University's computing systems, one of which has a sophisticated batch form of the KWIC procedure.

As a simple example of the application of this system, two KWIC-ed lists are shown: in the first, the KWIC was applied to the large database (BANCO.DAT) using the keywords "bus" and "buses". The second example used the keywords "local", "area", and "network(s)" applied to the specialized database.

The system developped is very simple and was designed to allow the researcher to conveniently computerize his bibliographic databases and to scan, revise and update them. The system was written in PASCAL and should, therefore, be reasonably portable. It is currently on the Laval University's PDP-11 RSTS/E system and will probably be moved to a VAX-780 system early in the Fall Trimester 1983.

For complete documentation on the system, see:

Drouin, G.: Banque de donnees bibliographiques, rapport de projet de these, ete 1982, Departement d'informatique, Universite Laval, Cite Universitaire, Quebec, G1K 7P4.

Copies of this report and of the program may be obtained by contacting the author.

Limited access to the current system may also be permitted. Interested parties should contact the author.

A1- Sample KWIC-ed Listings for BANCO.DAT and IFOC.DAT.

In the following examples, the permuted titles appear arranged according to the keywords mentioned in the text above. The keyword appears approximately in the center of the page, the title permuted accordingly, and the author's name at the far right. This is a standard, simple KWIC index format.

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 WER246I  FILESIZE 3,470,715 BYTES
 WER054I  RCD IN    25709, OUT    25709
 WER169I  TPF LEVEL     5
 WER052I  END SYNCSORT   OPT= H,  BANCO000,SORTK   ,



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      OPTICAL BY-PASS SWITCH FOR FIBER OPTIC DATA  BUS SYSTEMS                                   Nunoshita, 1
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            AN EIGHT-TERMINAL FIBER OPTICS DATA  BUS USING TEE COUPLERS                          Altman, E.E0
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 N-FILM WAVEGUIDES FOR A COMP UTER COMMUNICATION  BUS.                                           Becker, R.A1
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                        AN INTRODUCTION TO LOCAL  AREA NETWORKS                                                 Clark,D.D.,1
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                                      OVERCOMING  LOCAL AND LONG-HAUL INCOMPATIBILITY                           Sherman, R.0
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MULTI-ACCESS PROTOCOLS FOR OPTICAL FIBER-BASED	LOCAL AREA NE TWORKS	Finley, M.R0
D-NET, A NEW SCHEME FOR HIGH DATA RATE OPTICAL	LOCAL AREA NE TWORKS	Tseng, C-W.0
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	LOCAL AREA NETWORK USING OPTICAL TRANSMISSION	Tanaka, S. 1
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DATA DISTRIBUTION WITHIN A	LOCAL NETWORK USING FIBER OPTICS	McCaskill, 1
A PROTOTYPE CSMA/CD	LOCAL NETWORK USING FIBER OPTICS	Jones, J.R.1
LARGE SCALE INTEGRATED SERVICE	LOCAL NETWORK USING OPTICAL F IBER DATA HIGHWAY	Takahashi, 1
AN ELEMENT OF THE ALL OPTICAL	LOCAL NETWORK: THE DISTRIBUTOR -CONCENTRATOR	Gentric, A.0
TOKEN PROTOCOL FOR HIGH-SPEED FIBER-OPTICS	LOCAL NETWORKS	Gerla, M., 1
MINI-TUTORIAL ON DISTRIBUTION AND	LOCAL NETWORKS	Rawson, E. 0
MAKING A CASE FOR TOKEN PASSING IN	LOCAL NETWORKS	Miller, C.K0
APPLICATIONS OF FIBER OPTICS TO	LOCAL NETWORKS	Rawson, E.G1
	LOCAL NETWORKS-BROAD STANDARDS, MANY IMPLEMENTATIONS ARE ON T	Allan,R. 1
	LOCAL NETWORKS-ETHERNET CONTROLLER CHIP INTEFACES WITH VARIE	Joshi, S. P0
	LOCAL NETWORKS-SILICON OUTSTING SOFTWARE IN NETWORK SYSTEMS	Bursky, D. 1
	LOCAL NETWORKS-TOKEN PASSING CASHES IN WITH CONTROLLER CHIP	Stieglitz, 0
BOLINK: AN OPTICALLY LINKED LABORATORY COMPUTER	NETWORK	Yajima, S.,0
TICAL FIBER APPLICATIONS IN THE NASA DEEP SPACE	NETWORK	Lutes, G. 0
DESIGN.ISSUES FOR A FIBRE OPTIC LOCAL	NETWORK	De Grandi, 1
HUBNET: A GLASS FIBER 50 MB/S LOCAL AREA	NETWORK	Boulton, P.0
A FEASIBILITY STUDY ON PACKETIZED VOICE/DATA	NETWORK	Takahashi, 0
MULTI LOOP FIBER	NETWORK	Keiser, G. 0
FIBER OPTIC INFORMATION	NETWORK	Kosman, K.J0
THHE EXPERIMENTAL BROADBAND	NETWORK	Hubbard, W.1
LOCAL AREA	NETWORK (LAN)	anon. 0
TECHNOLOGIES FOR	NETWORK ARCHITECTURE AND IMPLEMENTATION	Smith, F.D.0
A LOCAL-AREA COMMUNICATION	NETWORK BASED ON A RELIABLE TOKEN -RING SYSTEM	Bux,W.,Clos0
INTERACTION OF	NETWORK DESIGN AND FIBER-OPTIC COMPONENT DESI GN IN LOCAL ARE	Rhodes, N. 0
NOVANET: A FIBER-OPTIC	NETWORK FOR CONTROL SYSTEMS	Hill, J.R.,1
A FIBER OPTIC LOCAL AREA	NETWORK FOR HIGH-RISE BUILDINGS	Hara, E.H. 1
A FIBER OPTIC	NETWORK FOR RAILROAD AND BUILDING APPLICATION	Ishida, S. 1
CARTHAGE: A MULTISERVICE LOCAL	NETWORK ON A FIBER OPTICS LOO P	Favre, J.L.1
SIGMA	NETWORK SYSTEM	Hitachi Cor0
LOCAL NETWORKS-SILICON OUTSTING SOFTWARE IN	NETWORK SYSTEMS	Bursky, D. 1
DATA DISTRIBUTION WITHIN A LOCAL	NETWORK USING FIBER OPTICS	McCaskill, 1
A PROTOTYPE CSMA/CD LOCAL	NETWORK USING FIBER OPTICS	Jones, J.R.1

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          A PROTOTYPE [illegible] LOCAL  NETWORK USING FIBER OPTICS                          Jones, J.
      LARGE SCALE INTEGRATED SERVICE LOCAL  NETWORK USING OPTICAL F IBER DATA HIGHWAY        Takahashi, I
                                LOCAL AREA  NETWORK USING OPTICAL TRANSMISSION               Tanaka, S. I
IVE STAR-CONFIGURED FIBER-OPTIC LOCAL COM PUTER  NETWORK WITH DATA COLLISION SENSING         Rawson, E.G
         FAIL-SAFE NODES FOR LIGHTGUIDE DIGITAL  NETWORKS                                    Albanese, A
          TECHNOLOGIES FOR LOCAL AREA COMPUTER  NETWORKS                                     Cotton, I.W
                AN INTRODUCTION TO LOCAL AREA  NETWORKS                                      Clark,D.D.-1
                 FIBER OPTICS AND LOCAL AREA  NETWORKS                                       Coden, M.H
        APPLICATIONS OF FIBER OPTICS TO LOCAL  NETWORKS                                      Rawson, E.G
 DESIGN  TOOL FOR LOCAL BROADBAND COMMUNICATION  NETWORKS                                    Triboulet, 1
    APPLICATIONS FOR FIBER OPTICS IN LOCAL AREA  NETWORKS                                    Personick, 1
                                      COMPUTER  NETWORKS                                     Tannenbaum
R OPTIC COUPLERS FOR USE IN LOCAL AREA MILITARY  NETWORKS                                    Nelson, A.R
       MAKING A CASE FOR TOKEN PASSING IN LOCAL  NETWORKS                                    Miller, C.K
        MINI-TUTORIAL ON DISTRIBUTION AND LOCAL  NETWORKS                                    Rawson, E. G
OKEN PROTOCOL FOR HIGH-SPEED FIBER-OPTICS LOCAL  NETWORKS                                    Gerla, M., 1
       A NEW APPROACH TO MULTI-SERVICE IN-HOUSE  NETWORKS                                    Fudemoto,I.I
  THE TOPOLOGICAL DESIGN OF DISTRIBUTED COMPUTER  NETWORKS                                   Gerla, M. a
AND FIBER-OPTIC COMPONENT DESI GN IN LOCAL AREA  NETWORKS                                    Rhodes, N.
F COAXIAL CABLE AND FIBER OPTICS FOR LOCAL AREA  NETWORKS                                    Reale, T. a
     APPLICATION OF FIBER OPTICS TO LOCAL AREA  NETWORKS                                     Hanson, D. 1
       HUBNET: A 50 MB/S GLASS FIBER LOCAL AREA  NETWORKS                                    Lee, E.S. a
ATA RATE TRANSMISSION TO LOCAL AREA FIBER OPTIC  NETWORKS                                    Husbands, C
              FIBER OPTICS FOR LOCAL AREA  NETWORKS DEVELOPMENTS IN JAPAN                    Pelisbuk, M.
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File: DR0:2119,38IMIFOC.NEW(60)

//SPAGAT JOB (314159,SPAG,0,100),GDROUIN,TYPRUN=COPY
/*ROUTE. PRINT LOCAL
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A2- An Interactive Session with BANCO

In the following, an interactive session with BANCO is illustrated. BANCO is self-documenting: if the user needs instructions on how to use its different features, he need only respond to the question asked by the program each time the principal modules are called. For example, in the following example, the user has chosen the printing module (MODULE D'IMPRESSION) and the program asks

DESIREZ-VOUS LES INSTRUCTIONS? (OUI - NON)

(DO YOU WISH TO SEE THE INSTRCUTIONS?)

and the user answers O(UI) or N(ON) as he sees fit. Please consult the example and the principle should be clear.

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run banco
********************************************************************************
*** SYSTEME BANCO ***  Job 18  11-Jul-83    19:15

[PRINC] DEFINISSEZ LE NOM DU FICHIER?
        NOM PAR DEFAUT -" DR1:BANCO.DAT

TAILLE DU FICHIER:   3145 BLOCS
[PRINC] Commande? [Fin,Impr,Kwic,Modif,Rech,Saisie] i

********************************************************************************

***  MODULE D'IMPRESSION  ***

[IMPR] DESIREZ-VOUS LES INSTRUCTIONS? (OUI - NON)  n

[IMPR] Commande? [Down,FIN,Mont,Nombr,Tout,Va]  n

 3007 FICHES ENREGISTREES
[IMPR] Commande? [Down,FIN,Mont,Nombr,Tout,Va]  vk


1-AUTEUR=Kagawa, S.; Kaneda, T.; Mikawa, T.; Banba, Y.; Toyama, Y.; Mikami, O.
2-TITRE=Fully ion-implanted p+-n germanium avalanche photodiodes
3-REVUE/EDITEUR=Applied Physics Letters
4-PAGES=Vol. 38, No. 6
6-DATE=March 1981

[IMPR] Commande? [Down,FIN,Mont,Nombr,Tout,Va]  d3


1-AUTEUR=Kagawa, S.; Kaneda, T.; Mikawa, T.; Banba, Y.; Toyama, Y.; Mikami, O.
2-TITRE=Fully ion-implanted p+-n germanium avalanche photodiodes
3-REVUE/EDITEUR=Applied Physics Letters
4-PAGES=Vol. 38, No. 6
6-DATE=March 1981

1-AUTEUR=Kahn, I.
2-TITRE=Fiber optic applications-video & audio components-recent experiences
3-REVUE/EDITEUR=Fiberopticon.
5-VILLE=Boston, Mass.
6-DATE=May, 22-23 , 1978.

1-AUTEUR=Kahn, R.; Witte, H.H.; Schicketanz, D.
2-TITRE=Pulse propagation through multimode fibers.
3-REVUE/EDITEUR=Opt. Commun.
4-PAGES=No: 4, P: 352-353.
6-DATE=1972.
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FICHE POINTEE-" Kahn, R.; Witte, H.H.; Schicketanz, D.

[IMPR] Commande? [Down,FIN,Mont,Nombr,Tout,Va]  vh


1-AUTEUR=Haggerty, J.S.
2-TITRE=Growth of titanium and chromium strengthened sapphire fibers.
3-REVUE/EDITEUR=AFML-TR-73-2, Cont. F33615-72-C-1956.
5-VILLE=Cambridge, MA"
6-DATE=22 Jan 1973.

[IMPR] Commande? [Down,FIN,Mont,Nombr,Tout,Va]  m3


1-AUTEUR=Haggerty, J.S.
2-TITRE=Growth of titanium and chromium strengthened sapphire fibers.
3-REVUE/EDITEUR=AFML-TR-73-2, Cont. F33615-72-C-1956.
5-VILLE=Cambridge, MA"
6-DATE=22 Jan 1973.

1-AUTEUR=Guttman, J. et al.
2-TITRE=Simple Connector For Glass Fiber Optical Waveguides
3-REVUE/EDITEUR=Electronics Communications
4-PAGES=Vol. 29, No. 1
6-DATE=1975

1-AUTEUR=Guttman, J. et al.
2-TITRE=Optical Fiber Stripeline Coupler
3-REVUE/EDITEUR=Applied Optics
4-PAGES=Vol. 14
6-DATE=1975
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FICHE POINTEE-" Guttman, J. et al.

[IMPR] Commande? [Down,FIN,Mont,Nombr,Tout,Va]  fin


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[PRINC] Commande? [Fin,Impr,Kwic,Modif,Rech,Saisie] f

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*** SYSTEME BANCO ***  11-Jul-83    19:17
*** SESSION TERMINEE ***

Ready
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