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Synchronization Issues of a Customer Premises Network Based on Cell Transmissions over Fiber Channel Interfaces

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Abstract: *This paper presents a new synchronization method for cell-based high-speed Customer Premises Networks. The method is based on the functionality resulting from combining functions of the Fibre Channel with the basic features of the pure ATM. The main advantages of the proposed method are its implementability even in very high speed links, the low bandwidth overhead required for the coding scheme and the low synchronization acquisition time. Various results concerning the performance of the proposed method are presented and its improved performance over other synchronization methods is verified. The proposed method may be used in installations where a huge amount of information is exchanged between locally based computing units and a connection to B-ISDN is provided.*

I. INTRODUCTION

Asynchronous Transfer Mode (ATM) was decided to be the most promising access technique for use in local and wide-area networks due to its flexibility and service-independence. The ATM is based on relaying fixed length cells and on virtual channel connections established before actual data transfer[1], [2]. The Broadband-ISDN and the Synchronous Optical Network (SONET) technologies were the areas of initial application of ATM, but soon the ATM technology was also considered for other communication environments [2]. Since the ATM functionality forms a low-level bearer service independent of the supported applications, adaptation functions must be performed for enhancing this low-level service to distinct classes of applications. Four different service classes have been defined so far and five different types of adaptation functions have been proposed. Initially, a single terminal was connected at a given access point of an ATM network but lately, multiple terminals have been organized for sharing a given access point to the ATM network. This access point is called User Network Interface (UNI) and is capable of supporting multiple and different services. The concentration of terminals through a single UNI forms a Customer Premises Network (CPN). The CPN forms a special type of network at the customer side and there are different types of CPN with different service requirements like bit rate, error performance, throughput and also different structural requirements like flexibility, expandability, interworking etc. Since CCITT has not determined how the terminals of a CPN must be interconnected, various topologies have been proposed up to now. The physical connections of CPN nodes are point-to-point channels between adjacent nodes or between network switches, interfaces and hosts. These channels can use various transmission media, like coaxial cable, fibre etc. and support various transmission speeds and formats (like pure-ATM and framed-ATM). The network switching functions can be performed either at local switches or using algorithms distributed in the CPN nodes.

In our development, the CPN access method has been based on the buffer insertion technique [3]. Each node receives the upstream traffic, rejects the idle and error cells, removes the cells destined to this node and transmits its own cells if there are no upstream cells in its passing-through buffer. Using various network statistics the access method determines if a node cell will be transmitted or the node must defer. The multiplexing of various node services is performed by the access method using the QOS parameters determined during each service connection establishment. The idle cells are used for decoupling the differences in the transmission speed between adjacent nodes and are inserted in the outgoing cell stream when no user cells are available.

In this paper, the synchronization problems of such a high speed CPN will be discussed and a new method will be presented. The presentation will be based only on the physical layer functions, since bit and byte timing synchronization, asynchronous cell multiplexing in the physical medium and header error detection and correction are implemented at this layer. The network nodes are connected using point-to-point links forming a single ring. The physical layer was developed to provide to the ATM layer the services determined by the CCITT recommendations and is based on the functionality of the Fibre Channel [4] and the B-ISDN protocol reference model [2].

Section II gives a concise description of the techniques used for high speed data transmissions, emphasizing the synchronization issues of bit, byte, cell and frame recovery. The proposed coding scheme and synchronization method are described in Section III. In Section IV the performance of the proposed method is

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analyzed and is compared with the method used in ATM networks. Section V gives a short presentation of the actual implementation of the proposed method.

II. CODING SCHEMES AND SYNCHRONIZATION METHODS FOR HIGH-SPEED LINKS.

In communication systems timing agreement (otherwise called synchronization) is required in various levels, starting from the clock level and moving up to bit, byte, frame, packet, message etc. [5]. There are various criteria for determining synchronization achievement, like the autocorrelation function of the synchronizing sequence, the Hamming distance etc., but always the principle is to use the shortest possible sync sequence and to minimize the false sync cases. Many synchronization methods have been proposed up to now which handle the bit synchronization problem as independent of the timing recovery in higher layers. Codes like the Pseudonoise (PN) or the Barker codes can be used for synchronization at different levels by introducing redundant information in the user data. Another method uses coded words with self synchronizing properties. In this case, a combination of patterns with code-violation or of non-valid data patterns are transmitted to achieve synchronization. This is the case of the 8B/10B code used in the Fibre Channel [4]. The redundancy introduced by the coding scheme allows the proper selection of the valid code-words for maximizing the Hamming distance. The characters transmitted in the FC are of two types, data or special. The combination of special and data characters result in the generation of transmission words which are appropriate for determining characters boundaries. The basic advantages of the 8B/10B code are its DC balance, its near optimum run length and digital sum variation and the minimization of encoding time, making it appropriate for high speed transmissions. For optical transmissions, various block codes or bit insertion codes can be used which are bit-sequence independent (BSI), the bit rate increase is kept low and simple circuits can be used [6]. The scrambled NRZ code used in the optical interface of ATM networks does not increase the actual bit rate but does not satisfy the BSI condition for use in higher transmission rates. The ATM uses also the CMI code (a special type of 1B2B code) for its electrical interface, which has good signal balance but requires twice the information rate as clock frequency.

Some of the above mentioned codes (like the FC codes) provide special characters outside the data alphabet for performing character synchronization, frame delimiting, supplementing the error detection mechanism etc. The ATM performs the functions of byte synchronization, cell delineation, rate decoupling of adjacent nodes and error protection of the cell switching information, using various mechanisms which are independent of its line code. These mechanisms include correlation of the header bits with its CRC, use of idle cells, single-bit error correction etc.

For detecting the boundaries of frames, packets or cells and keeping synchronization, various mechanisms have been proposed [1]. The most interesting methods are the use of empty cells, the use of the HEC code and the use of periodic cells as framing patterns. The use of empty cells has the disadvantage that, in heavy loaded situations, it can take some time to acquire synchronization. The use of the HEC cell delineation method, which is used in ATM, has the disadvantage that malicious simulations of HEC in the cells' payload will result to incorrect synchronization. The periodic cell synchronization method reduces the available channel bandwidth and fast synchronization (desynchronization) can be resulted.

In our application, the requirement was to develop a CPN operational in higher speed than the available ATM interfaces, since a large amount of data has to be exchanged between its internal nodes (interactive CAD systems, multimedia applications, scan of large data bases etc.) and to use the basic principles of ATM technology in order to be easily connected to B-ISDN through an UNI. The maximum offered load was estimated to be 800Mbit/sec and the nodes were interconnected using fibre links. For minimizing the system cost, the use of multimode fibre was decided and the development of a new physical layer was considered. The new physical layer had to provide to the ATM layer the services determined in the CCITT recommendations, to operate in higher cell rates and to be implementable with commercially available components and programmable devices.

III. THE CODING SCHEME AND THE SYNCHRONIZATION METHOD.

After considering various coding schemes and transmission systems, the Fibre Channel (FC) was decided to be the basic technology for developing the physical layer. The disadvantage of using the 8B/10B code of FC in a cell-based environment, where single error corrections are required, is that due to its coding structure, two unacceptable conditions can be met. First, an error bit in the transmitted serial stream may be spread into two bits in the decoded data making the single error correction capability of the Transmission Convergence sublayer non-applicable. Second, a code violation may be obtained erroneously, due to an error occurred in a previous bit position, which altered the Running Disparity of the bit stream, but did not result in a detectable error at the respective transmission character [4]. For these reasons, the user data were encoded using the 4B1C code [6], while the 8B/10B code was used only for control and synchronization purposes. The 4B1C code is applied twice in each data byte, one time for each nibble, while the idle cells, which are used at the physical

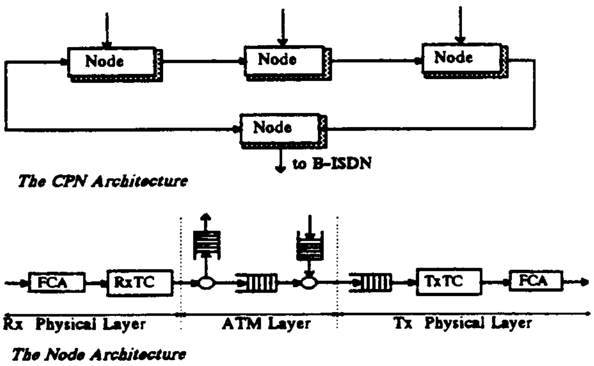

Fig. 1. The CPN and the Node Architecture.

layer for cell rate decoupling and cell delineation, are constructed as a sequence of K28.5 and D21.5 (FC terminology) bytes. Following the above mentioned coding scheme, the Fibre Channel requirement that the maximum run-length of the encoded data does not exceed five bits is satisfied and the correct phase relationship of the extracted clock with the received data is maintained.

Instead of using the ATM idle cells, which are 53 bytes long, a smaller group of bytes is used, which is called Idle Order Set (IOS). Each IOS is composed of two identical transmission words, each transmission word consisting of four characters, two K28.5 special characters and two D21.5 data characters. K28.5 is the Fibre Channel special character used as the first character in each control transmission word. Since the 4B1C coding is used for the user data, the K28.5 character contains code violation and, before achieving synchronization, it can also be detected erroneously at the receiver side in the incoming serial bit stream, as a result of a combination of two consecutive data bytes, as it is shown in Table 1. In order to minimize this false sync case, two consequent K28.5 characters have been used in the IOS structure. The D21.5 characters have been selected to conform with the FC idle words structure and are used mainly for maintaining the clock synchronization. These two D21.5 characters are not used in the cell delineation procedure and other patterns can be used to support Operation, Administration and Maintenance (OAM) functions. As it will be shown in the synchronization method description, the IOS length must be equal or greater to the cell header length which is five bytes long (five characters after the line coding). For that reason, the IOS was selected to be eight characters long. The Idle Order Sets are used also for the cell rate decoupling mechanism. They are generated at the transmitter side and are removed from the receiver in order to absorb the differences of the actual clocks from their nominal frequencies.

The CPN has been formed using point-to-point connections between adjacent nodes (Figure 1) and the discussion of the physical layer can be based on the characteristics of a point-to-point link interconnecting two devices which communicate using the Fibre Channel functions and the ATM method of cells transmission, with the modifications described above. The physical layer of each node is subdivided into two sublayers. The lower sublayer, which is called Fibre Channel Adapter (FCA), is related with the functionality of the Fibre Channel and deals with physical medium aspects. The upper sublayer, which is called Transmission Convergence (TC) sublayer, deals with the cell stream multiplexing/demultiplexing, cell header error detection and correction, IOS insertion and extraction and coding/decoding of data.

The lower part of the physical layer is based on the Fibre Channel architecture and uses the FC-0 functions of the Fibre Channel (transmission media adaptation, transmitters, receivers and their interfaces) and a combination of the 8B/10B and 4B1C transmission codes. The physical layer uses some of the FC-1 functions (bit and transmission-word boundaries synchronization) and also contains the required functionality for adapting ATM cells to the Fibre Channel Datagrams. As a Fibre Channel Datagram is considered the information (number of user cells) contained between two IOSs. Each IOS is used simultaneously as the End Delimiter of the current datagram and as the Start Delimiter of the new datagram. The length of a datagram may vary between zero (two consecutive IOSs) and the maximum number of cells de-

Table 1.

Special Character	K28.5	K28.5	D21.5	D21.5
Binary equivalent	0011111010	0011111010	1010101010	1010101010

IOS structure

XX 00 1 1 1 1 1 0	1 0 XX X XXXXX
XXXX XXX 0 0 1	1 1 1 1 0 XXXXX

Special Combinations of valid data words which result to a K28.5 Character when they are transmitted serially

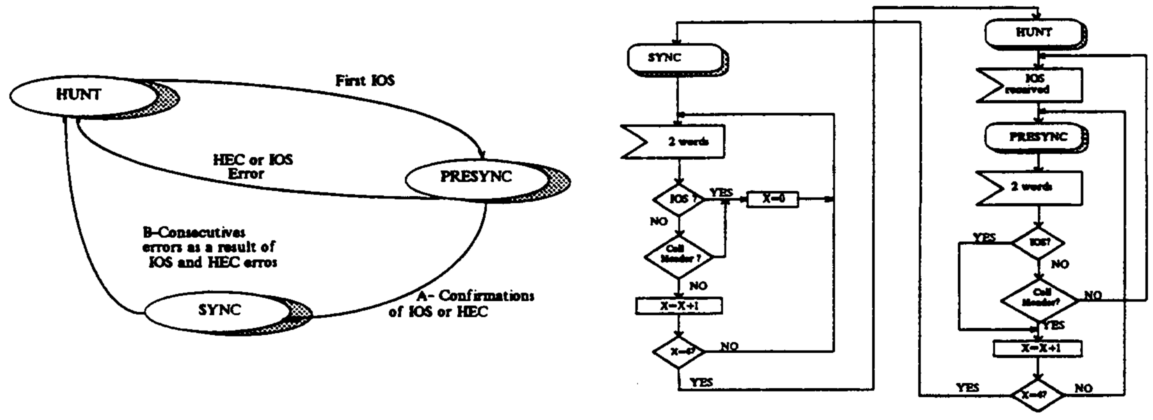

Fig. 2. The synchronization method state diagram.

termined by the cell rate decoupling parameter. The FC Datagrams are reconstructed when they pass through a network node and new frame delimiters are generated, while the contained data (cell burst) are modified. This modification may include IOS substitution with data cells or the insertion of IOSs for supplementing the used 'destination release' scheme at the ATM layer.

In the transmit direction, the physical layer accepts complete cells from the ATM layer and generates the fifth byte (Header Error Check - HEC) of the cell header. Then the cell is passed through the Fibre Channel Framer module which generates the appropriate FC frame format and multiplexes the ATM cells in its structure. Since fixed length cells are used in the CPN, a cell delineation mechanism must be implemented. This mechanism is based on the 'HEC' method and on the 'Indication of IOS'. The IOSs are generated in the Transmission Convergence sublayer when there is no cell available from the ATM layer, or when the number of user cells transmitted after the last IOS has exceeded a predetermined threshold. At the receiving side, the IOSs are detected and removed at the TC sublayer where the cell delineation mechanism is implemented.

Bit synchronization and character boundary detection are achieved at the Fibre Channel Adapter. The FCA Receiver is capable of detecting K28.5 characters and performs timing resynchronization when this pattern occurs in the serial bit stream. Whenever the resynchronization part of the FCA Receiver is active and a K28.5 character has been detected, an indication is provided. This indication is used by the synchronizer of the TC sublayer for performing the synchronization algorithm.

As it is shown in Figure 2, initially the synchronizer is in the HUNT state and the resynchronization part of the FCA Receiver is activated for detecting K28.5 characters and performing character boundaries detection. The resynchronization part remains active as long as the synchronizer is not in the SYNC state. Whenever a valid IOS has been detected, the synchronizer changes to the PRESYNC state, the characters' boundaries are considered detected and the synchronizer validates both the cell headers and the IOS structure. In each cell or IOS boundary, two validation modules are triggered. The HEC module tries to confirm the existence of a cell by validating its fifth byte using the CRC method, while the IOS module tries to match the first eight characters with the IOS structure. If a valid indication is available at the end of the eight character, a new cell or IOS boundary is determined. Then the synchronizer waits for this new boundary to restart the boundary validation procedure. If the synchronizer is in the PRESYNC state, the internal counter is increased once or twice depending on the valid indication. A user cell results to one time increase, while an IOS signals for two times increase, since it contains two FC transmission words. These validation procedures are performed in parallel and by using the

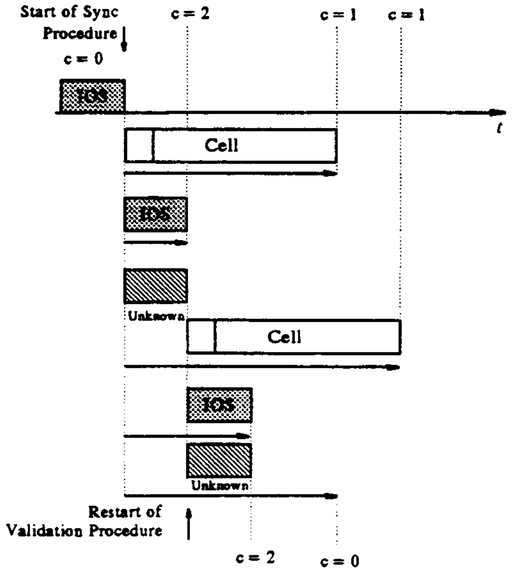

Fig. 3. Synchronization timing cases.

character stream, so high processing rate can be achieved, especially compared with the pure ATM cell delineation procedure which is performed on the serial bit stream.

If no valid indication is available at the end of the eight character, the validation procedure is restarted immediately and the internal counter is decreased. Figure 3 gives timing details of the synchronization method for the different cases of boundary estimation. At the same time, a new cell or IOS boundary is estimated, assuming that errors occur in a cell header with higher probability than on an IOS. Using this assumption, the new cell or IOS boundary is calculated by adding 53 character times to the previous boundary. If the cell header or IOS validation procedures do not give a positive result for a second time, the internal counter is decreased again and as the value of the next boundary is considered the one estimated previously.

When cell or IOS boundaries have been confirmed and the internal counter has its maximum value, the synchronizer switches to the SYNC state and the resynchronization part of the FCA Receiver is deactivated. When m consecutive cells or IOSs have been received with errors, the system is considered to be desynchronized and the synchronizer switches back to the HUNT state for resynchronization.

Following the above described method, cell delineation, cell rate decoupling and HEC validation can be easily performed in very high speed connections using simplified hardware structure compared with the structure used in the ATM interfaces. Figure 4 shows the functional organization of the physical layer based on the description given above.

IV. SYNCHRONIZATION METHOD PERFORMANCE

For measuring the performance of the proposed synchronization method, the following three criteria have been used: the resynchronization acquisition time, the imposed delay and the bandwidth efficiency. Resynchronization acquisition time is the time elapsed from the detection of loss of synchronization (entering the HUNT state) up to the acquisition of full synchronization (entering the SYNC state). Cell delay is the time elapsed from the arrival of a cell in the output queue up to the beginning of its transmission. Bandwidth efficiency (BE) is the ratio of the maximum value of the user available rate versus the actual bit rate in the physical medium. In order to perform these measurements, two analytic simulation models of the physical layer were developed using the SIMSCRIPT II language, one for the standard ATM structure and the other for the proposed method. The model performance was measured under various traffic conditions, always assuming that the user cell interarrival times follow an exponential distribution.

In the ATM standard, the synchronization time has a fixed value and is equal to seven times the cell duration (assuming that no transmission errors occured during the synchronization procedure). In the proposed method the synchronization time is not fixed and depends on the user offered load. Before examining the relation of the mean synchronization time with the offered load, the curve of Figure 5 must be studied. In this figure the mean value of the distance of two consecutive IOSs is given for various traffic conditions. This parameter is of a great importance, since the resynchronization procedure in the proposed method begins when an IOS is detected. As long as the offered load is low, the inter-IOS distance is very small and becomes greater than the duration of a cell when the traffic load is 90% of its maximum value.

As it was described previously, the mean synchronization acquisition time, t_{SAT}, is the sum two timing variables. The first variable, which is called HUNT state time - t_{HUNT}, is the time between loss of synchronization and the first detection of a valid IOS. This variable is determined by the value of the inter-IOS distance for a given offered load. The second variable,which is called PRESYNC state time - $t_{PRESYNC}$, is the time required for detecting a number of correct 'HEC' and 'IOS' indications. Figure 6 shows the mean synchronization acquisition time versus the offered

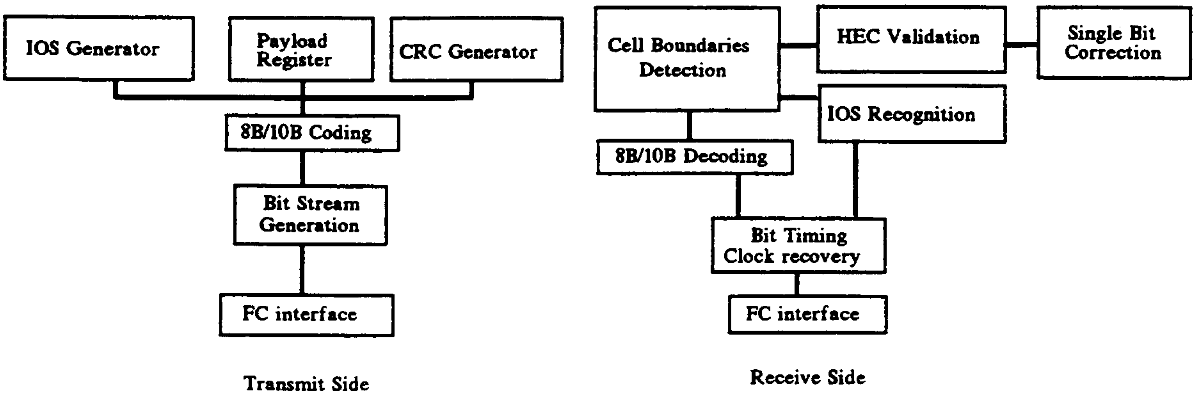

Fig. 4. The physical layer functional organization.

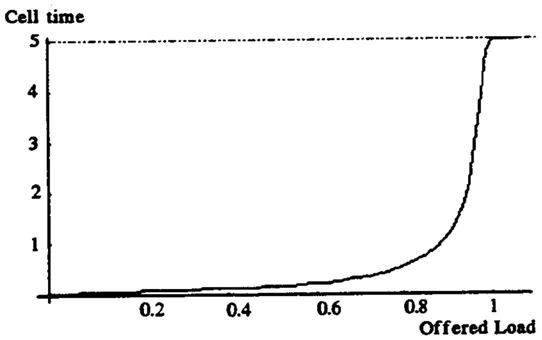

Fig. 5. The inter-IOS distance.

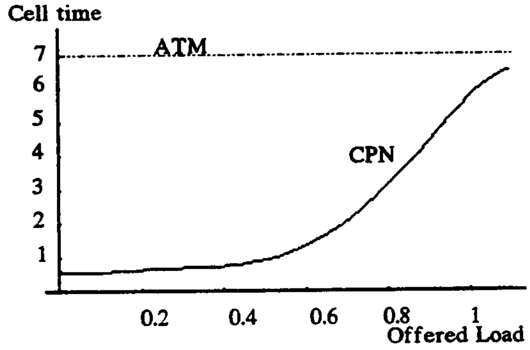

Fig. 6. The synchronization aquisition time

load both for the ATM and the proposed method. The ATM t_{SAT} is constant, independent of the traffic conditions and equal to seven cell times. The CPN t_{SAT} is not constant and varies between 0.6 and 6.2 cell times, but always is lower from the ATM t_{SAT}. The CPN t_{SAT} is mainly affected from the value of inter-IOS distance, since this value affects both t_{HUNT} and $t_{PRESYNC}$ variables.

Figure 7 shows the mean cell delay for the ATM and the CPN methods. When the traffic load is less than 95% of its maximum value, the performance of both methods is identical but the CPN method has lower delay values in heavy traffic conditions.

The ATM bandwidth efficiency is 96.3%, since for every 26 user or unassigned cells, an idle cell is inserted. In the proposed method the bandwidth efficiency is 97.0%, since for every 5 user cells, an IOS is inserted. So, the bandwidth efficiency is the same for the two methods.

V. IMPLEMENTATION METHOD DISCUSSION.

The CPN physical layer has been implemented using commercially available components and a custom chip-set, prototyped using FPGAs. The Fibre Channel Adapter (FCA) is composed of a GaAs TAXI chip-set and optical interface devices while the Transmission Convergence uses the custom chip-set. The physical layer structure is

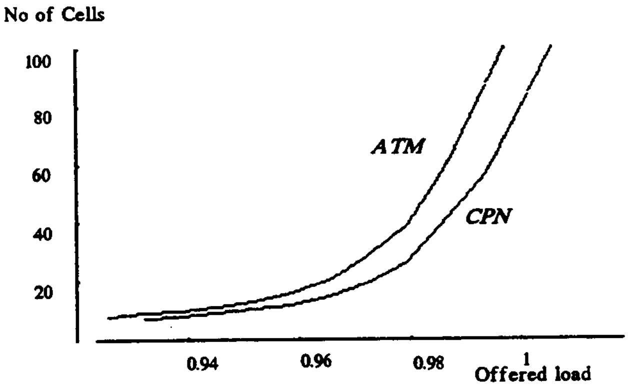

Fig. 7. The cell delay function.

shown in Figure 8. The TC transmitter is composed of the Tx Cell Processing part (TxCP) and the TxFC Framer, achieves 100 Mbytes/sec transfer rate and has been implemented in a XC3164 FPGA. The TxCP receives user cells from the ATM layer and generates the HEC byte of the cells' header. The TxFC Framer adapts user cells into FC frames by generating IOSs following the timing specifications described above. The FCA Transmitter is a commercially available GaAs IC, which receives a 10-bit parallel bus and generates the NRZ bit stream for driving the optical transmitter.

The FCA Receiver accepts the NRZ serial data from the optical receiver, recovers the data clock by using its internal clock recovery PLL, re-establishes byte boundaries using the SYNC (K28.5) pattern and generates 10-bit synchronous parallel bus for further processing by the Transmission Convergence sublayer. The TC receiver performs the receive functions of the physical layer, such as cell delineation, HEC validation and correction, IOS extraction and has been implemented using a XC3195 FPGA. The TC receiver is composed of the Rx Cell Processing part (RxCP) and the RxFC Framer. The RxFC Framer recognizes the data semantics, removes the FC delimiters and regenerates the ATM cells. The RxCP implements the synchronization method, validates the HEC field of the cells' header, performs single-bit error correction whenever it is required, and passes user cells to the ATM layer for further processing. The interface between the TC chip-set and the FCA has been implemented using CMOS/PECL and PECL/CMOS level translators since the Fibre Channel Adapter operates in PECL levels.

For the optical interface implementation, the FTM-8500 (Tx) and FRM-8500 (Rx) data link modules of FINISAR Corp. have been used. These modules use short wavelength lasers to transmit data at Gb/s rates through multi-mode fiber (62.5/125). They have been operated in 1 Gb/s with 10^{-14} bit error rate. An FCC-2000 controller is used for achieving full control and performance monitoring of the upstream and downstream optical links. In the transmitting side the optical power launched into the fiber is controlled while the received op-

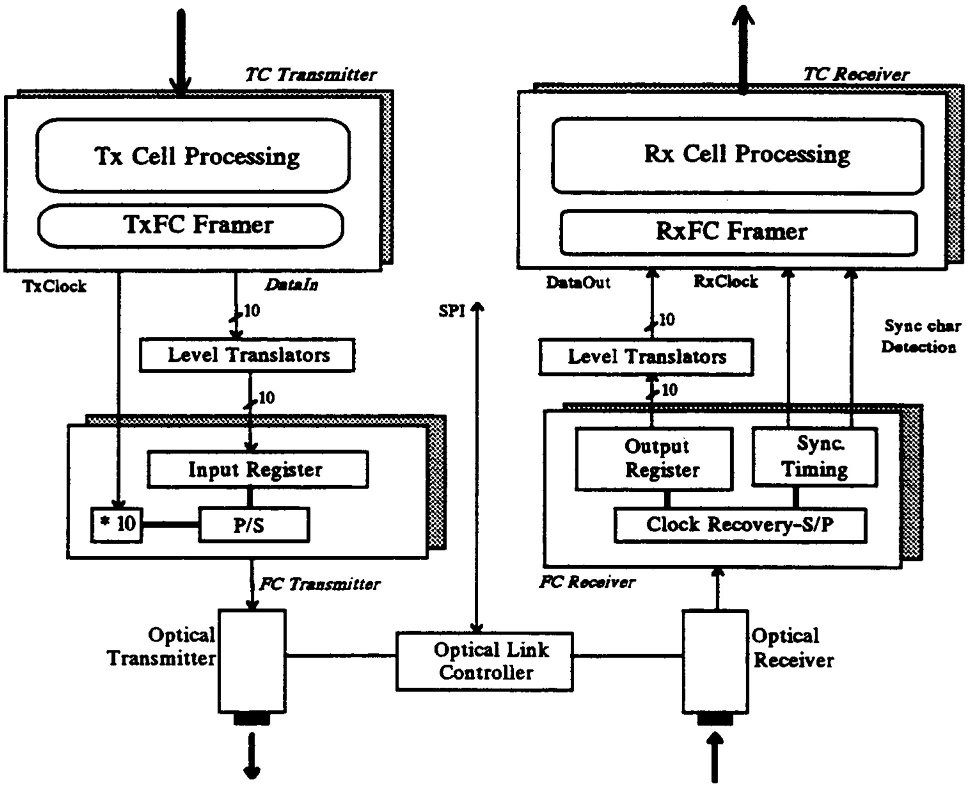

Fig. 8. The physical layer structure.

tical power in the photo diode is measured in combination with the module temperature.

VI. CONCLUSIONS

In this paper, a new synchronization method for use in cell-based installations of CPNs has been presented. The presented method is very efficient in terms of bandwidth overhead and synchronization time and supports the implementation of various functions (cell delineation, cell header error detection and correction, synchronization etc.) for transmitting a cell stream using the basic functions of the Fibre Channel. Due to the parallel structure of the physical layer and of its functional simplicity, a high cell transmission rate of 1.88 Mcells/sec (800 Mbit/sec) can be achieved using commercially available FPGAs.

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