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CROSSTALK REDUCTION FOR NETWORK MULTICORE FIBER WITH MANAGEMENT CORE AND SPECTRUM METHOD

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ABSTRACT

Crosstalk is a problem in increasing the transmission capacity of multicore fiber networks. This research aimed to reduce inter-core crosstalk in multicore fiber networks. The method used was core allocation, i.e the core management and the spectrum slot. This method employs parallelization of two algorithms. First, the core prioritization algorithm which is based on the structural core of multicore fiber. Second, the core classification algorithm which is based on the required bandwidth connection. The research result indicated that this method worked well and effectively reduced the number of overlapping spectrum, so that it reduced the inter-core crosstalk of multicore fiber to 59.76%. It was concluded that the proposed method can reduce crosstalk problem in multicore fiber networks.

Keywords: *Core Classification, Core Prioritization, Crosstalk, Multicore Fiber.*

1. INTRODUCTION

Traffic demand in the telecommunications network and multimedia service continues to increase in the future so that require high bandwidth access and unlimited [1-2]. Research on the transmission media to solve dynamic traffic continues to be done by studying the optical fiber network which is a high-speed communications technology [3-4] and has a large transmission bandwidth capacity [5]. Communication using optical fiber networks have data transfer at higher speed compared to using twisted pair cable, infrared, and radio for wireless communications [4]. Single-mode optical fiber network can overcome the lack of transmission capacity, which indicates that the transmission capacity is dramatically increased compared to the conventional transmission network. [6]. However, transmission capacity per fiber will soon reach the maximum limit for single-mode fiber [7-9]. Multicore Fiber (MCF) is an optical fiber-based technology utilizing space-division multiplexing (SDM) [8]. MCF has multiple cores in transmitting signals so that it can support real-time communication [10] and the data is transmitted in parallel by distributing data to multiple cores simultaneously to can achieve transmission capacity is much larger than the single-mode optical fiber [7,10]. At this time, the MCF network transmission capacity has reached 1 Pbps [7]. However, one of the important problems that exist in the MCF is crosstalk [7,11-12] ie the transmission signal interference because the signal from one channel arrives in other channels [13]. The signals transmitted on multiple cores would interfere with each other, becoming noise so that there will be degradation that has a serious impact on the process of data transmission, capacity and transmission distance in optical networks [6].

Research on crosstalk reduction on MCF has been done by [7-9] relating to the core assignment and allocation of spectrum slot. Reference [7] uses a first-fit algorithm and random algorithm to evaluate the value of crosstalk per slot. The use of both these algorithms was to fill the spectrum without a gap by utilizing cores and spectrum effectively in MCF network, due to the characteristics of less fragmentation. The two algorithms work by filling the spectrum without gaps by utilizing cores and spectrum effectively in optical networks, due to the less fragmentation. This reference shows that first-fit algorithm produces less crosstalk per slot compared to random algorithm. However, the use of the two algorithms tend to concentrate which results more crosstalk in MCF. It is therefore important to avoid overlap in the adjacent cores spectrum in order to reduce crosstalk. Reference [8], used the core classification

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algorithm as a comparison against first-fit and random algorithm. The use of "core classification" algorithm is based on the required bandwidth. But in optical networks there are several connections that require different bandwidth needs of different handlers. The results show the method they propose also depend partly on the structure or number of cores on the MCF.

Therefore, this study proposes a network bandwidth management customized for MCF cores regardless of the structure or the number of cores. Reference [9] uses a first-fit, random, classification and proposal algorithm for evaluating the value of crosstalk per MCF network slot. The use of classification and the proposal algorithms has shown good results in reducing intercore crosstalk MCF. However, the algorithms are still generating significant crosstalk value and results of their study did not mention the value of crosstlalk for each MCF core. Therefore, it is important to check the algorithms for efficient core use and spectrum slot utilization in MCF.

References [7-9] shows that the crosstalk effects on MCF depends on the setting of the signal spectrum and core. It was assumed that the signals of the same frequency transmitted simultaneously on all cores in a single fiber. Therefore, this study approached the problem of crosstalk in MCF related to core and frequency slot from the optical network perspective. Furthermore, the study proposes core management methods to reduce crosstalk and management of the spectrum slots to reduce fragmentation. The proposed method is based on two election algorithms associated with crosstalk and fragmentation [9]. First, the core prioritization algorithm, based on the structure of the MCF. This algorithm allocates cores to avoid filling the adjacent cores to reduce crosstalk. Second is the core classification algorithm based on the bandwidth required in the connection. This algorithm reduces fragmentation spectrum by allocating uniform bandwidth connections for each core. Thus, this study aims to minimize MCF inter-core crosstalk. The results of this study are useful increasing MCF network transmission capacity with low crosstalk.

2. RELATED WORKS

Multicore Fiber can increase the transmission capacity on a fiber optic network compared to single-core [6,7,10,11,12,14-16]. Reference [10] has formulated a core scheduling algorithm as an optimization problem in core utilization of heterogeneous multi-core systems. The results show that; the proposed algorithms are suitable for use in MCF network as an optimal solution for scheduling problem in multiprocessor architecture. However, the most significant issues of the MCF is crosstalk [7,11-12]. Reference [15] has proposed a form of heterogenous MCF cores and structural design in order to reduce crosstalk and reference [6] conducted experiments on the performance of MCF structure that showed an increase in transmission capacity. References [7-8] experimented by modeling signals that have the same frequencies transmitted simultaneously on all cores in the MCF. However, due to the dynamic nature of network traffic, it is necessary to have a low-crosstalk MCF. Therefore, this study attempted to reduce crosstalk by doing core management and spectrum slot on MCF network. MCF in combination with SDM could potentially enable the transmission of 700 Tbps [17]. However, to further improve the transmission capacity to 1 PBPs [7], it is necessary to investigate the possibility of increasing the number of cores and scalability of transmission capacity. Therefore, this study used three number of cores MCF, namely 7-core [6].

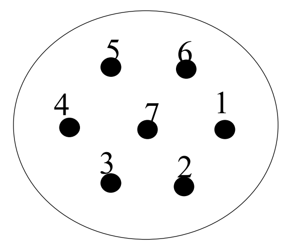

Figure 1: 7-MCF Structure

It is important to consider crosstalk impairment so that MCF network could be efficient. Reference [18] shows the formulation to reduce MCF crosstalk, but this formulation applies only and is limited to their experimental model. Therefore, it is necessary to have a crosstalk model so as to improve efficiency in network cores and MCF with spectrum management. Reference [7] modeled crosstalk on the MCF network which occurred on the adjacent cores. They tried to reduce the overlap spectrum that causes crosstalk by means of core management and spectrum with a simple modeling. Later reference [8] performed core management by way of allocating core MCF to reduce crosstalk. The simulation results showed that the probability of blocking and crosstalk could be reduced. However, the core allocation method [8] still depend on the amount and structure of the MCF. Therefore, this study proposes core management

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and MCF slot frequency network regardless of MCF network's core amount and structure.

Crosstalk is a disturbance when the signal from one channel arrived to another, which would be the noise in other channels [13]. Crosstalk occurs at wavelengths that are separated and have been filtered. A small portion of the optical power, which should expire in certain channels (in particular filter output) ends in the adjacent channels. It is very important to prevent crosstalk in MCF network system. Therefore, to increase its capacity and flexibility, it is necessary to have the appropriate signal routing techniques to achieve a low crosstalk value. One of the proposed solutions to increase MCF network capacity with low crosstalk is by applying core allocation and spectrum slot.

In a fiber optic network, the signal spectrum is not actually flat in the frequency domain. However, in this study was be modeled to be simpler, by modeling the flat light signal spectrum in the frequency domain as shown in Figure-2. The impact of crosstalk to the cores are different regardless of frequency. However, in this study, it was assumed that the effect of crosstalk to the cores is the same regardless of frequency and MCF structure.

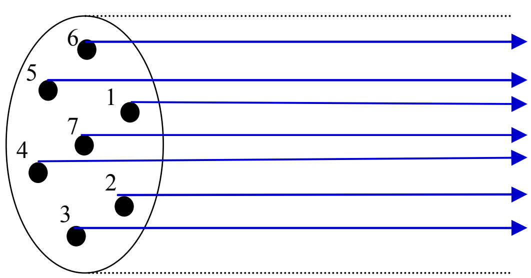

Figure 2: Signal Spectrum in 7-MCF

Crosstalk between cores within the MCF network produced by propagation of optical signals between two adjacent cores is very close [7,13]. Therefore, the effects of crosstalk occur when signals with same frequency are transmitted in adjacent cores [7-8]. In this study, the MCF crosstalk occured when the transmission of signals on two adjacent cores only when using the same frequency slot. In Figure-3 we illustrate the crosstalk modeling, A (core 6 - core 1) and B (core 1 - core 2) were considered as crosstalk, while the C (core 2 - core 4) were considered not crosstalk because the cores are not adjacent. Based on the structure of the MCF in Figure-2, the optical signal in the 7-MCF, for the central core at most is affected by six other core and signals in all the other cores are affected at most 3 cores. In this study, the spectrum slots on any number of cores that cause crosstalk to target slot is defined as crosstalk index.

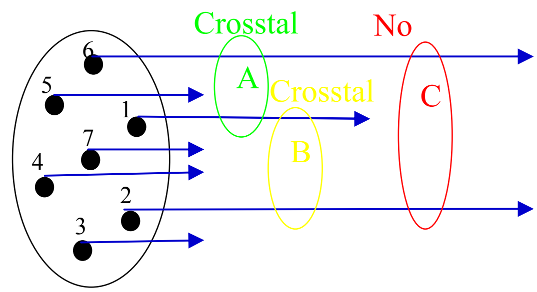

Figure 3: Crosstalk Between Adjacent Cores

The problem in increasing the transmission capacity of MCF is the inter-core crosstalk. Research on reducing crosstalk on MCF has been done by previous researchers. Reference [11] shows that variations in the fabrication and characteristics of bending has a very important impact on the crosstalk in the MCF. The offered design produced low crosstalk as well as the effect of bending radius towards crosstalk would be randomly statistically average. Reference [12] formulated coupled-mode equations that take into account the effect of bending and according to this formulation, MCF crosstalk is a stochastic value that indicates the inter-core crosstalk can vary depending on the bending radius. Reference [18] revised the coupled-mode theory and the theory of coupled-power for MCF crosstalk. The simulation results based on these two theories show that the theory of coupled-power can be effectively be used to investigate MCF crosstalk, and show that the statistical properties of the MCF bend to be different from one another. Reference [19] formulated the amount of crosstalk based on the coupled-mode theory and the theory of coupled-power considering the random fluctuations in the longitudinal direction. This formulation gives the amount of crosstalk in MCF between the central core and one outer core, depending on the power-coupling coefficients of MCF as well as the transmission distance of a network. The results also showed that the formulation is consistent with experimental result that crosstalk is also dependent on the wavelength. Reference [16] proposed a method of measuring MCF crosstalk statistically by searching wavelengths. This method, using a trench-assisted fiber that can measure extremely low MCF crosstalk, and the results show that the stochastic behavior depends on the state of polarization crosstalk and pressure on the MCF.

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Reference [7], indicated that the method used to reduce the crosstalk still depends on the design of the structure of the MCF since it involves structural arrangement of isolated MCF cores. However, from the perspective of the cladding diameter, insulated structures such as these tend to have a larger diameter than uninsulated MCF. Therefore, it is necessary to reduce crosstalk in MCF without depending on the structure of cores per MCF. Reference [16,19], MCF crosstalk depends on the transmission distance and signal frequency, in this study, the researchers reduced crosstalk with the management of core and slot spectrum from the perspective of the optical network without involving the structure of isolated core and without depending on the transmission distance and frequency signal.

3. MATERIALS AND METHODS

3.1 Material

The author did a simulation and evaluate the performance of the proposed algorithm through a simulator developed in Visual Basic 6 on a computer. The proposed method was evaluated in two different ways. The first is "Proposed I" and the second one is "Proposed II". "Proposed I" is a method that adopts the core prioritization algorithm and core classification algorithms. 'Proposed II" is a method that adopts the core prioritization algorithms and core classification algorithm based on connection priority. Both the proposed method will be compared with the "Random" method. It adopts the random algorithm which allocates core and frequency spectrum slot randomly.

This study uses a type of MCF structure with 7 core. As an illustration, a connection that require three kind of bandwidth (Blue, Green and Red), which correspond to three, four and five frequency slot, with the total frequency slot per core was W=320. This research, assumed that the frequency slot width is 12,5 GHz so that the total slot spectrum resources per core is 4 THz (C-band).

Optical connection requests between Tx-Rx is assumed to have been set up for connection requests in accordance with the flowchart in Figure-4. In this study, the connection request has a constant service time and the time between Tx-Rx follow exponential distribution. MCF core and frequency spectrum slot are readily available to meet the need of the proposed algorithms. So the focus of this research is the core signal routing by allocating core and frequency slot in transmitting data in a predetermined bandwidth. The results of the simulation were collected. It was then analyzed to find the crosstalk per slot in the MCF network.

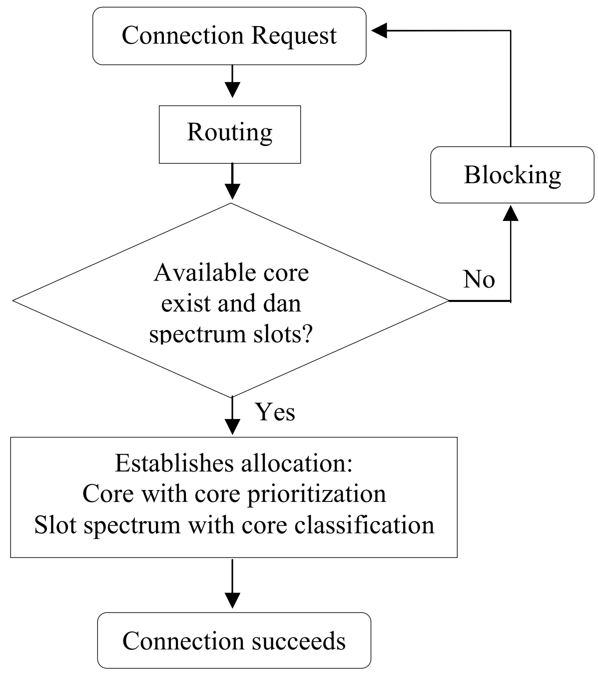

Figure 4: Flowchart of Systems Research

3.2 Method

In Multicore Fiber Network (MCF), the use of the same frequency spectrum slots on all cores are rarely used simultaneously in one time [7]. This means that crosstalk on MCF can be minimalized by proper regulation and management core frequency spectrum slot. This study uses core prioritization algorithm for core management and core classification algorithm for managing the frequency spectrum slot.

The process of allocating core in this study is different from the core allocator priotitization in [9]. In this case, we modify the algorithm's policy to always to avoid the use of adjacent core aimed at reducing crosstalk by allocating core ordered by priority.

Figure-5 provides an example of the determination of core priority in MCF-7. Here is the step-by-step in determining the priority core, based on "core prioritization" algorithm for 7-MCF:

Step-1: All cost (Ci) in each MCF core initialized to zero = 0.

Step-2: Core-1 was chosen as the first priority core (P1), so the cost of each core adjacent to core-1 (C2, C6 and C7) will increase.

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Step-3: Core-3, core-4, and core-5 have the lowest cost (C3 = C4 = C5 = 0). In this case core-5 was chosen as the second priority core (P2).

Step-4: Core-3 has the lowest cost (C3 = 0). In this case core-3 was chosen as the third priority core (P3).

Step-5: Core-2, Core-4, and core-6 have the lowest cost (C2 = C4 = C6 = 2). In this case core-6 was chosen as the fourth priority core (P4).

Step-6: Core-2 and core-4 have the lowest cost (C2 = C4 = 2). In this case core-2 was chosen as the fifth priority core (P5).

Step-7: Core-4 has the lowest cost (C4 = 2). In this case core-4 was chosen as the sixth priority core (P6).

Step-8: Core-7 has the lowest cos (C7 = 6). In this case core-7 was chosen as the seventh priority core (P7) and this is the last step of the algorithm for all cores are already prioritized according to the above steps

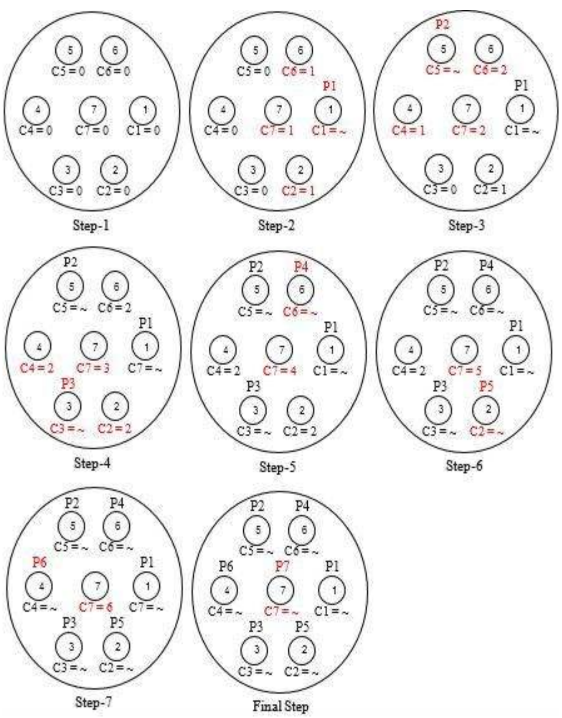

Figure 5: Stages of The Core Prioritization Algorithm in 7-MCF

The increasing number of users will impose limits on data communication. This is due to the congestion that is influenced by a large number of users who share the same frequency spectrum and a limited frequency spectrum at lower frequencies [1]. With the growth of traffic then there are various connections that require different bandwidth. It is important to solve the problem of fragmentation in the domain of the frequency spectrum slot. The core classification algorithm aims to reduce fragmentation spectrum by allocating bandwidth connections that are uniform for each core. In this study, we assumed three types of connections that require different bandwidth. Here illustrated with three slots frequency (Blue), four slots frequency (Green) and five-slot frequency (Red). Although there are only three types of bandwidth required by the connection in this case, one core can be used by two or more types of bandwidth connection when the amount of bandwidth connections are more than the number of MCF cores.

The core classification process in this research is different from the classification in [9]. In this case, we classify the bandwidth connection to be allocated to the core with two classifications. The first classification is that all bandwidth connections have the same priority and the second classification is a prioritization process applied for connections that have more bandwidth capacity.

Figure-6 shows the use of the spectrum in the 7-MCF. Figure-6.a shows spectrum usage without the core classification, Figure-6.b and Figure-6.c shows spectrum usage with core classification. This study classified MCF core per number of slots according to required frequency. Classified core is defined as a connection that requires the same bandwidth to be allocated. Figure-6.b adopts first classification, in which Core-1, the Core-4, Core-6 and Core-7 are classified cores for connections that require four-slot frequency, Core-2 and Core-5 for connections that require three slots and frequency Core-3 for connections that require five slots frequency. Figure-6.c adopted the second classification, in which Core-1, 3-Core, Core and Core-5-6 are classified cores for connections that require four-slot frequency, Core 2 and Core-4 for connections that require three slots frequency and Core-7 for connections that require five slots frequency. The classification composition shown on Figure-6.b and Figure-6.c is based on core priority on Figure-5. This shows there is no fragmentation spectrum in the classified core as the core only has one type of connection that requires the same bandwidth. However, if no classified cores are available for the required bandwidth connection, then classified cores for different bandwidth will use the last prioritized core, in this regard Core-7.

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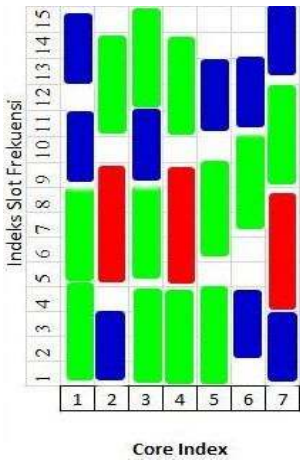
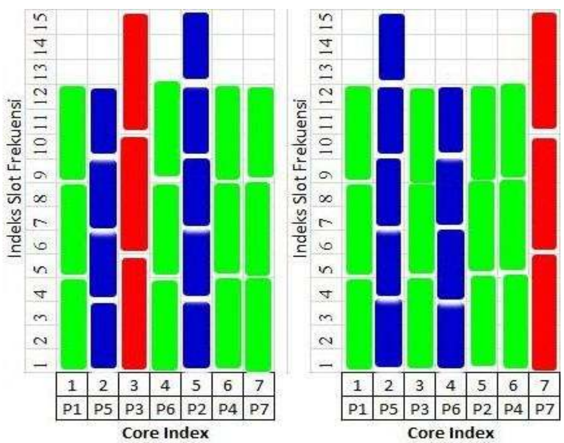


(a)



(c) (d)

Figure 6: Illustration Spectrum Utilization; a) No-Core Classification, b) Core Classification 1, c) Core Classification 2

4. RESULT AND DISCUSSION

The result of the research which is based on the analysis of core prioritization and core classification algorithm in MCF that has 7 core per fiber shows good performance in reducing MCF crosstalk. The results of simulations and calculations for each methods are shown in Figure-7 and Table 1.

Figure-7 shows the core allocation and spectrum slot filling for 7-MCF simulation result for each algorithms. Figure-7.a is the simulation result of "Random" method usage, where it results in bandwidth fragmentations, which is in accordance to the algorithm's rule that allocates core and spectrum slot randomly. Figure-7.b and Figure-7.c shows the proposed method simulation result which shows that this algorithms could reduce fragmentation, with no bandwidth fragmentation because of regular spectrum slot in accordance to the proposed algorithm's rule by giving the same bandwidth connection to the same core. The proposed method avoids placing the same spectrum slot for adjacent cores to reduce crosstalk. The result of this research shows that there is no empty gap in the spectrum slot in MCF core so that it does not generate bandwidth fragmentation for all MCF cores. From the perspective of inter-core crosstalk, it appears that the proposed method works well in reducing core crosstalk due to the allocation of core in order of priority by avoiding the use of adjacent cores. The "Random" method indicates a poor performance in reducing fragmentation and crosstalk compared to the proposed methods, "Proposed I" and "Proposed II" respectively, because both methods adopt core priorization and core classification. The "Proposed II" method shows better performance compared to "Proposed I" because "Proposed II" adopts core classification algorithm which uses prioritization process for the classified maximum bandwidth connection load, while the "Proposed I" method does not employ bandwidth prioritization.

Table-1 shows the evaluation of crosstalk value per slot for each core on a 7-MCF. Crosstalk per slot is the average of spectrum slot value pairs that result in crosstalk because each spectrum slot has the same frequency and are in the adjacent cores. In other words, crosstalk per slot is the frequency spectrum slot arrangement that produces crosstalk. Referring to this definition, crosstalk per slot is a relative measurement that depends on the size of fixed MCF. In this study, crosstalk per slot on 7-MCF for core (1-6) is a maximum of three, while the core (center) 7 a maximum of six. "Random" method shows a poor performance because of crosstalk between all cores in MCF. The proposed methods, "Proposed I" and "Proposed II" successfully reduce the number of MCF cores that experienced crosstalk. This reduction is due to the fact that the proposed method has a core priority policy and core classification that allocates core sophisticatedly by avoiding filling the adjacent core in order to avoid crosstalk. From the perspective of crosstalk value of each slot per each MCF core, it shows that the proposed method shows good performance in reducing the amount of crosstalk value per slot compared to the "Random" method. The higher the crosstalk value per slot, the more bad connection occurs because of the larger blocking probabilities.

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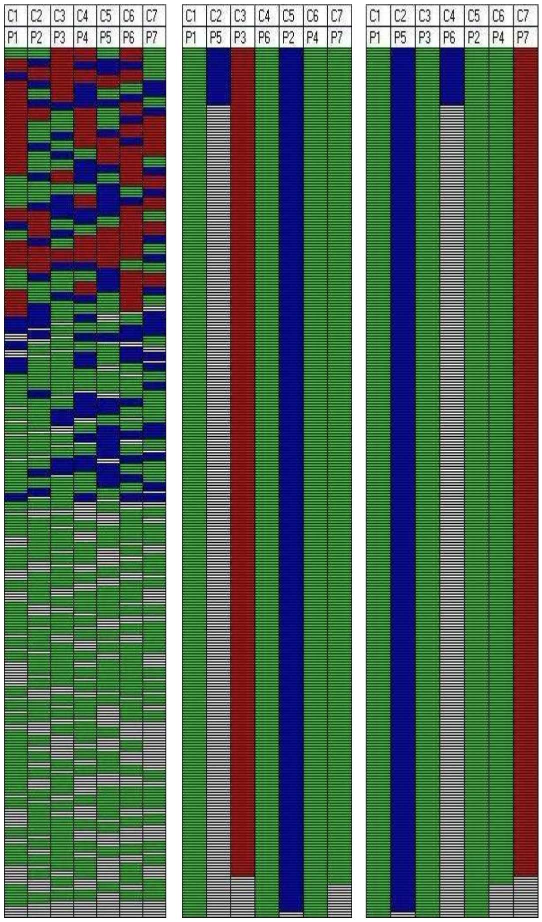

Figure 7: The Simulation Results Frequency Slot Allocation in 7-MCF; a) Random, b) Proposed I, c) Proposed II

Table 1: Crosstalk per Slot in 7-MCF.

Core	Method		
	Random	Proposed I	Proposed II
1	1.344	1.963	0.963
2	1.341	0	0
3	1.291	0	0
4	1.106	0.963	0
5	0.975	0	0.963
6	1.184	1.963	1.925
7	2.328	2.888	0
Total crosstalk per slot/fiber	9.569	7.777	3.851
Reduction crosstalk per slot/fiber		18.75%	59.75%

5. CONCLUSSION

In this study, the proposed method by combining the core prioritization and core classification algorithm applied to the MCF network works well and is able to minimize fragmentation and reduce crosstalk per slot between cores in the MCF. The simulation results showed that the "Proposed I" method could reduce crosstalk in MCF amounting to 18.75%, while the "Proposed II" method amounting to 59.76%. This means that the amount of spectrum overlaps that cause crosstalk between cores on the MCF can be reduced.

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