Programmable Availability in Photonic Network by Adaptive Selection of Forward Error Correction and Parallel Mapping into Flexible Ethernet Calendars

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***Abstract*—We propose a novel network design scheme which realizes programmable availability in photonic network to meet various KPIs of 5G/6G network slices. The scheme consists of novel FEC selection, data mapping, and route diversity accommodation algorithms to achieve variable availability. We successfully confirmed programmable availability in numerical simulations in COST266 model network.**

Keywords*—*programmable availability, FEC, FlexEthernet

I. Introduction

In 5G and future 6G networks, various slices including Ultra-Reliable and Low Latency Communications (URLLC), enhanced Mobile Broadband (eMMB) massive Machine Type Communication (mMTC) which have different sets of Key Performance Indicators (KPIs) should be designed and provided [1,2]. As for reliability or resiliency, programmable availability will be essential feature to meet diversified level of reliability in such slices or applications.

For Mid-Haul and Back-Haul optical network for 5G and future 6G network, further upgrade of FlexEthernet standard will be needed [3]. This is a standard-based enhancement to FlexEthernet [4, 5] that can ensure data to travel from network ingress to network egress in a highly predictable latency, which is similar to Time-Division Multiplexing (TDM) options such as Optical Transport Network (OTN).

Legacy approaches for higher availability, such as 1+1 protection providing hitless protection, suffer a maximum cost of 100% of the spare resource. Automatic protection switching will also need 100% of spare resource and will suffer service interruption from switching time. Shared protection with centralized control approach requires less spare resource, but cannot avoid long service interruption resulted from computation time of restoration path. The inversely Aggregated Networking with Programmable Protection architecture (iANP^2) [6] can provide hitless protection with reduced spare resource.

In this paper, we propose further extension of Sliced Channel Layer (SCL) in G.mtn [3] incorporating with iANP^2 programmable protection architecture [6]. We insert Forward Error Correction (FEC) redundancy layer on top of the SCL. The FEC redundancy can be designed to meet the required availability. The generated code word will be interleaved to FlexEthernet Calendars. We successfully confirmed programmable availability in computer simulation in COST266 pan-European network.

II. Proposed design scheme

Basic mechanism of our approach consists of FEC encoding of information bits and mapping of coded words into FlexEthernet Calendars.

A. Proposed Approach for programmable availability

Figure 1a depicts an example of FlexEthernet traffic accommodation. There are two client flows (red and green). These two flows are accommodated into the FlexEthernet (FlexE) calendar slots (in this example, 10 Gbps per slot) using the function of FlexEthernet Shim [7]. There are various accommodation options as shown in Fig. 1a. The Red one preferred distributed mapping and the Green one mapped on the single link.

Proposed approach is shown in Fig. 1b. In addition to the FlexEthernet Shim, we insert FEC encoding/decoding blocks as shown in the Figure. For traffic flow which needs higher availability (Red), incoming data flows are encoded by appropriate code and converted into code words. And then, they are mapped into FlexEthernet Calendars. In the receiver side, mapped Calendars are collected and code words are recovered. Then the code words are input to FEC decoder block. As the output of the decoder block, original data flows are recovered. Depending on the added redundancy, we can recover the original data flow even in some link failures. When we encoded with BCH(15, 5), three bit errors can be corrected [8]. Thus, when we broke up into more than 15 links, we can recover the original data flow at up to 3 links failures.

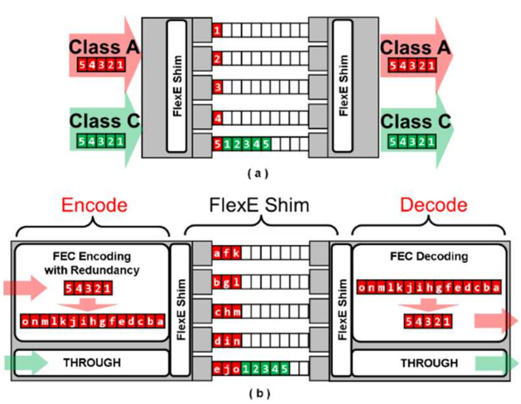

Fig. 1. (a) Conventional FlexEthernet accommodation , (b) Proposed scheme

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On the other hand, for data flow that requires no enhanced availability, the bit stream go through the encoding/decoding blocks without any FEC redundancy. Therefore, it will suffer connection loss even in a single link failure.

Note that the term "link" will have various options including Ethernet, OTN, and wavelengths. In this paper, we suppose it as an optical wavelength generated and received by optical transponders. Then we supposed transponder failures for evaluation of availability. We computed availability by changing outage probability of the transponders for various demand types.

B. FEC code selection algorithm

There will be various options in FEC code selection. We should select FEC code which meets required availability and allowable redundancy amounts. For example, if the bit rate of original data flow was 50 Gbps and the required availability level (correctable bit loss) was 0.2 (20%), and the size of Flex Ethernet slots was 10G, the algorithm returns BCH(15, 5) [8]. When we assume to use block codes, in the algorithm, we should consider the limitation related to bit blocks (the number of correctable bits is reduced depending on how the bit blocks were separated). If all bits of one block are included in one slot, they cannot be corrected/recovered when only one slot/link is lost. Therefore, the algorithm must selects a code, so as to the bits in the same block be separated into different slots as many as possible. The parameters used in the FEC selection algorithm are described in Table I, and the proposed algorithm is shown in Fig. 2.

III. Outage Simulation

In this work, we evaluated availability of three classes of service flows by numerical simulations. For evaluation, we defined "Impact Parameter" as a criteria where the needed availability for each class is satisfied or not. We used Python3 with networkX library for simulations.

A. Preparation for Outage Simulation

We used "Cost266" model network for numerical evaluation [9, 10]. It is a pan-European network which has 37 nodes and 57 edges. For simplicity, we supposed 80 links (wavelength) which has 100 Gbps capacity. This is a typical wavelength number in 100 G C-band digital coherent optical systems. In addition, the FlexEthernet calendar slot size is assumed to be 10 Gbps (10 slots on each link). We supposed three classes of demand types with different KPIs: reliability-sensitive, delay-sensitive, and others as shown in Table II. Figure 3 shows an example of the accommodation patterns (for simplicity, only 10 links are shown). Depending on the class types, we changed accommodation patterns. For class A (reliability-sensitive) demand type, we searched multiple edge disjoint routes and accommodated the demand into multiple links as shown in Fig. 3. For class B (delay-sensitive) demand type, we select single shortest route and accommodated into multiple links. For class C (no requirement) demand type, we select single route and accommodate it so as to achieve higher usage of each link without no intention to distribute. When the network is fully occupied and no further demand can be accepted, we terminated the process. The result network after the above accommodation process is used in the next outage simulations.

TABLE I. Parameters used in the FEC selection algorithm

Symbol	Description
γ	Bit rate of original data (assuming a client flows)
SlotSize	Slot size of the FlexE calendar
$Rate_{correctable}$	Required rate of tolerance against bit loss (correspoinding the amount of correctable errors)
n	Codeword (or block) bits of the current code
k	Data (or massage) bits of the current code
t	Correctable numer of bit errors
SelectedCode	Selected code (output)

Algorithm 1 FEC code selection algorithm

Input: γ , $SlotSize$, $Rate_{correctable}$ and a set of candidate codes
Output: $SelectedCode$

for $Code_{tmp}$ in candidate codes **do**
  if $(Rate_{correctable}) \leq (t/n)$ **then**
    $\gamma_{encoded} \leftarrow \gamma * (n/k)$
    Calculate the bit rate after encoding γ when using $Code_{tmp}$
    $SlotsCount \leftarrow \lceil \gamma_{encoded}/SlotSize \rceil$
    Calculate how many slots are needed when using $SlotSize$
    (round up to integer.)
    $Bits \leftarrow \lceil n/SlotsCount \rceil$
    Calculate how many bits of the same block are included per slot
    (round up to integer, which means a case of maximum bits.)
    $SlotsCount_{correctable} \leftarrow \lfloor t/Bits \rfloor$
    Calculate how many slots can be corrected.
    (round down to integer, which means a worst case.)
    if $(\gamma_{encoded} * Rate_{correctable}) \leq (SlotsCount_{correctable} * SlotSize)$ **then**
      if $SelectedCode$ is null **then**
        $SelectedCode \leftarrow Code_{tmp}$
        The current code is selected if there is no selected code before then
      else if $(n_{SelectedCode}/k_{SelectedCode}) \geq (n/k)$ **then**
        $SelectedCode \leftarrow Code_{tmp}$
        Compare the current code's redundancy with the already selected code's if there is the selected code
      end if
    end if
  end if
  (go to a next candidate code)
end for
return $SelectedCode$

Fig. 2. The FEC selection algorithm

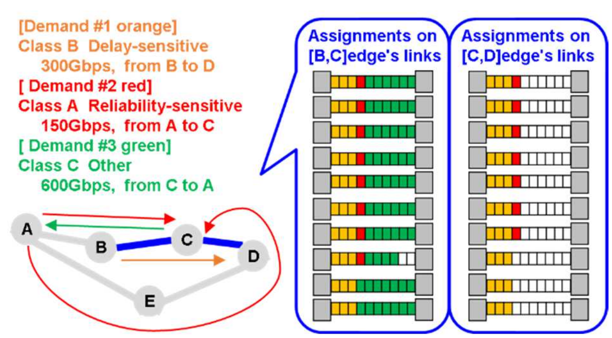

Fig. 3. Example of demand accomodation

TABLE II. Demand types

Type	Class	Bit rate after encoding	Bit rate before encoding	Tolerance against loss
Reliability-Sensitive	A	150 [Gbps]	50 [Gbps] [a]	30 [Gbps]
Delay-Sensitive	B	300 [Gbps]	100 [Gbps] [a]	30 [Gbps]
Other	C	600 [Gbps]	600 [Gbps][b]	0 [Gbps]

a. BCH(15, 5) and FlexE calendar slot size of 10 Gbps are applied.

b. No encoding (Class C has no tolerance against loss).

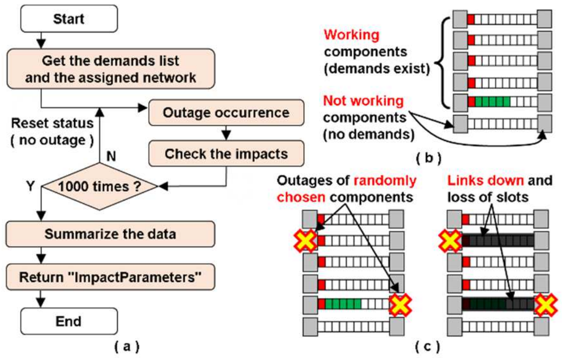

Fig. 4. (a) Outage simulation diagram, (b) Working/not working components, (c) Outages and link downs

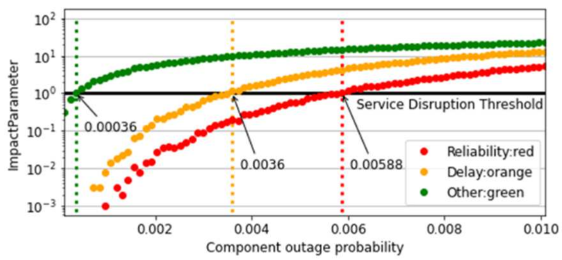

Fig. 5. IP for three demand classes

B. *Outage Simulations*

At first, we supposed outage probabilities of transponders in the model network. Then we have carried out the following processes to evaluate their impact on three classes of demands. Here, we defined the “Impact Parameter (IP)” as a criteria of the impact on various demands. IP is calculated by dividing the number of repetitions (1000) into the sums of impact counts per demand type to get the averaged value. When we got the value of IP higher than 1.0, it means that we will have some failures or disruption in more than one demand. If we could achieve IP of less than 1.0, we can say that some failures in transponders being masked by our proposed scheme and has no impact on demands. Thus we can design the availability of network service by adjusting the redundancy of FEC. Figure 4a shows the basic block diagram of the outage simulations.

Note that in this simulation, we only considered working components which has at least one demand as shown in Fig. 4 (b). The number of outage components (transponders) is calculated using the supposed outage probability. For example, if the outage probability is 0.00588 (0.588%) and the number of working components is 9000 throughout the network, the number of outage components is 52 (round down to integer).

1) Get demands and the accommodated network: Prepare the demand accommodated network by the method discussed in Sec. III A.

2) Generate transponder outage: Randomly chosen components from entire network (only working ones) are changed into outage states. In other words, the links that has these failed components become down. Thus, the slots in these links will be lost (Fig. 4c). The number of loss determine the impacts on demands in the following process.

3) Check the impacts: Each demand has the value of tolerance against loss. The process counts the demand where the number of loss exceed their tolerance values.

4) Return IP: The outage components changes with each trial, so we have carried out 1000 simulations to get statistical mean of IP. By changing the outage probability, we evaluated IPs for three demand classes.

IV. RESULT AND DISCUSSION

Figure 5 shows the result of outage simulations. As we expected, class A demand has extremely high availability in comparison with other classes. Higher FEC redundancy and route diversity used in class A yielded higher availability than class B as shown in Fig. 5.

We have successfully confirmed our flexible design scheme in the numerical simulations. However, This is the first implementation of our proposed approach, so further improvement/optimization will be needed including extension of possible FEC list, optimization of accommodation algorithms in various demand types, and the criteria for evaluation including IPs. Needless to say, actual implementation into G.mtn will need further discussion in standard bodies.

V. CONCLUSION

We proposed novel programmable availability design scheme, enhancing the SCL of FlexEthernet with FEC. For the purpose, we proposed novel FEC selection algorithms to reduce FEC redundancy to requisite minimum. In numerical simulations in COST266 network, we have successfully confirmed flexible design performance of our proposed scheme in various demand classes including higher reliability and low latency.

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