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Design of Translucent Optical Network using Heterogeneous Modulation Formats

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Abstract--**We propose a cost-effective design to reduce the regeneration nodes in translucent optical networks by employing two different modulation formats to achieve two optical reaches in 40-Gb/s systems. Substantial cost saving is achieved.**

I. INTRODUCTION

In a translucent optical network [1], several regeneration capable nodes are strategically placed in the network, so as to assure the traffic requests can reach their respective destinations with accepted quality. Optical reach refers to the distance that an optical signal can travel before its quality degrades to a level that requires regeneration. It is often limited by the physical layer impairments in the optical transmission links. In view of optical transmission, the modulation format of the optical signal has significant impact on the achievable optical reach [2,3]. With intrinsic property of heterogeneous route distances in most optical networks, more than one modulation formats for the optical signals may be employed for different links, so as to optimize the optical reach requirement for different traffic requests, and thus reduces the number of required regenerator nodes and the number of hops required. In this paper, we propose a novel network planning architecture to reduce the network cost in a translucent optical network by employed non-return-to-zero (NRZ) and carrier-suppressed-return-to-zero (CS-RZ) formats for optical signals running on different routes. Our results show that it is a cost effective design for future backbone network planning.

II. NODE ARCHITECTURE AND NETWORK MODEL

A typical optical regeneration node comprises a core optical cross-connect (OXC) module, a number of optical transceivers and a 3R electronic regeneration cards [1,3,4]. NRZ node and CS-RZ node have similar architectures as the optical regeneration node, except that there is no regeneration card and are incorporated with different type of transceivers. At each node, the wavelengths on the incoming fiber links are de-multiplexed and switched by the core OXC switching module, before being multiplexed onto the outgoing fiber links. For a NRZ or CS-RZ node, there are *N* transceiver pairs. Moreover, we assume that *M* regenerator cards are equipped at each optical regeneration node in the 3R electronic regeneration module. The number of transceivers and regenerator cards in different types of network nodes is listed in Table I. Each regeneration node can receive and transmit both NRZ and CS-RZ signals. As the CS-RZ signals are generated by carving the pulses from the NRZ signals using an additional optical modulator and both of them use P-I-N photodiodes as the receiver, NRZ nodes and CS-RZ nodes can communicate with each other without any format conversion.

TABLE I NUMBER OF TRANSCEIVERS IN NRZ / CS-RZ / REGENERATION NODES

	NRZ Transceiver	CS-RZ Transceiver	Regenerator Card
NRZ node	*N*	-	-
CS-RZ node	-	*N*	-
Regeneration node	*N*	*N*	*M*

III. TRANSCEIVER AND REGENERATOR PLACEMENT

In this section, we describe the algorithm to place regeneration nodes, NRZ and CS-RZ nodes, in the network. To simplify the model, we use physical distance to represent the physical impairments accumulated along the route. More specific physical impairments evaluation model could be used like amplifier noise as the metrics. Note that the major constraint of our design is to make sure every node pair could establish at least one physical impairment feasible connection between them.

Input: **G(*V,E*)**, an undirected graph representing the network topology. Each link consists of a pair of fibers in opposite direction. R_{NRZ} and R_{CS} denote the optical reach of NRZ and CS-RZ modulation formats.

Step1: Use Dijkstra algorithm to get the shortest path between each node pair. Record the result in a matrix [L_{sd}]. This matrix will be used to justify whether a physical impairment feasible path exists between a node pair in the following steps.

Step2: If only NRZ modulation format (R_{NRZ}) is employed, find the minimum number of regeneration node required to make sure that at least one feasible path exists between each node pair, denoted as m. This step is to find the minimum connected dominating set of ***G(V,E)*** if the optical reach is R_{NRZ} [5].

Step3: If only CS-RZ modulation format (R_{CS}) is employed, find the minimum number of regeneration nodes, denoted as n , required to make sure that at least one physical impairment feasible path between each node pair This step is similar with step2. We assume that $R_{CS} > R_{NRZ}$ and the difference is large enough to make $n<m$.

Step4: Initialize $i=m-1$. If there are i regeneration nodes in the network, denoted as regeneration node set ***Set(R)***, where $n\le i\le m-1$, find all the possible combinations of ***Set(R)*** subject to the following constraints:

Constraint 1 For each node pair in ***Set(R)***, at least one feasible path exists with optical reach R_{CS}. As in our model, every regeneration node has CS-RZ transceivers.

Constraint 2 For nodes that are not in ***Set(R)***, denoted as ***Set(T)***, there is at least one feasible path within R_{CS} from each of them to at least one node in ***Set(R)***.

For each combination, pick out those nodes in ***Set(T)*** of which the physical distances to each node in ***Set(R)*** are greater than R_{NRZ}, denoted as ***P*** type node. Get the number of ***P*** type nodes for each combination and record those combinations with the least number of ***P*** type node. Note that a ***P*** type node will become CS-RZ node and the rest nodes are NRZ nodes. The aim of this step is to find the node planning map with minimum overall network cost comprises the costs of regeneration nodes, NRZ nodes and CS-RZ nodes if there are i regeneration nodes. i=i-1; if $i \geq n$, go to Step 4; else, go to Step5.

Step5: Given the cost of NRZ transceiver (C_{NRZ}), CS-RZ transceiver ($C_{CS\text{-}RZ}$) and regenerator card (C_{RE}), get the minimum normalized overall network cost of those placement maps from Step4 for each i.

Output: The regeneration node set ***Set(R)***, the NRZ node set ***Set(NRZ)***, the CS-RZ node set ***Set(CS-RZ)***.

IV. Results and Discussions

Our design is applied on two network topologies, namely NSFNET (see Fig. 1), and Pacific Bell Network (see Fig. 2), where all link lengths are in the unit of km. In our test, N=M=4. The values of M and N make no difference to the test conclusion. Since transmission of 40 DWDM channels over 1,700 km of SSMF using the CS-RZ format [2] has been demonstrated, considering that the sensitivity of CS-RZ has 1-2 dB improvement compared to NRZ, the optical reaches of CS-RZ and NRZ in 40-Gb/s are assumed to be 1700 km and 1140 km, respectively. The cost of the conventional NRZ transceiver is normalized to a value of 1, while the relative costs of a regenerator card and a CS-RZ transceiver are assumed to be 1.5 [3] and 1.2. Table II lists the network node map of the heterogeneous-format (or hybrid) design in the two topologies, using our proposed algorithm, as discuss in section III.

With this heterogeneous-format design, the relative network cost savings are estimated, as compared to the network designs with all NRZ nodes and with all CS-RZ nodes. Considering NSFNET, it is found that relative cost savings of 10% and 12.3% are achieved, as compared to the cases of all NRZ nodes and all CS-RZ nodes, respectively. Similarly, for Pacific Bell Network, the respective relative cost savings are 18.7% and 11.6%.

Besides, the difference in the optical reach of the two chosen modulation formats also has significant impact on the heterogeneous-format design. For example, if the assumed optical reach value of NRZ format is varied from 1140 km to 1500 km, while that of CS-RZ format remains unchanged (1700 km), the normalized network cost of Pacific Bell Network under different design varies, as depicted in Fig. 3. As the optical reach of NRZ format is getting closer to that of CS-RZ format, the advantage of using heterogeneous-format design starts to lose, due to the reduced optical reach difference and the relatively lower cost of the NRZ nodes. From Fig. 3, after the optical reach of NRZ format exceeds 1350 km, the network design with all NRZ nodes becomes more cost-effective than the heterogeneous-format design.

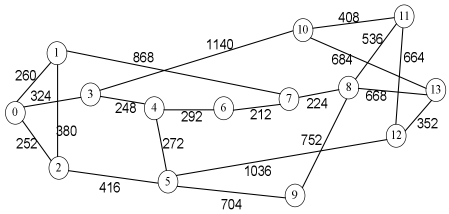

Fig. 1. 14-node 21-links NSFNET (Link lengths are in the unit of km)

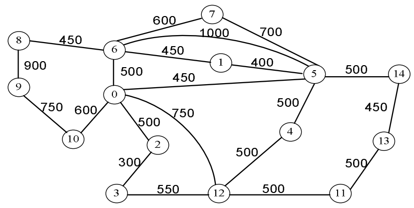

Fig. 2. 15-node 21-links Pacific Bell Network (Link lengths are in the unit of km)

TABLE II Node Map of Heterogeneous-format Design

	Regeneration node	CS-RZ node
NSFNET	8	0, 2
Pacific Bell Network	0	9, 11, 13

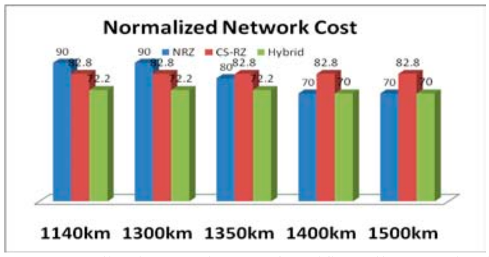

Fig. 3. Normalized network cost of Pacific Bell Network with different network designs, under different assumed optical reach values of the NRZ format, as shown in horizontal labels.

V. Conclusion

In summary, we have presented a novel translucent optical network planning design using heterogeneous modulation formats. Our results have show that such design can achieve substantial (>10%) cost savings. The heterogeneous modulation formats considered are not restricted to NRZ and CS-RZ. All other feasible advanced modulation formats can be taken into consideration at the network planning stage.

References

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