NPARC Specification Sheet V3

Network Path Analyzer for Regeneration and Conjugation

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1 Introduction and Scope

This *NPARC Specification Sheet* describes the final logic for:

- **Regenerator Placement** in long-distance optical paths, using a fixed threshold.
- **Optical Phase Conjugator (OPC) Placement** for dispersion mitigation.
- **Residual Distance** (uncompensated dispersion) calculation, consistent with practical constraints such as forbidden nodes (true source/destination, their immediate ROADMs).

NPARC reads input from a *Simon Simulator* output file, which provides a path (list of nodes) and link distances. This specification now includes a final, crucial detail: **we exclude the true source node and the true destination node from all distance-based calculations.** Only the sub-array from *source ROADM* to *destination ROADM* is analyzed for threshold checks, regenerator triggers, OPC placement, and residual distances.

2 Definitions and Path Exclusion

A path record from the simulator typically lists:

$$(\text{true\_source}) \rightarrow (\text{source\_ROADM}) \rightarrow \cdots \rightarrow (\text{destination\_ROADM}) \rightarrow (\text{true\_destination}).$$

Often, the distance from *true source* to *source ROADM* is a very small number (e.g., 0.01 km), and similarly from *destination ROADM* to *true destination* is also very small. We denote:

- **Node** 0: True source node (excluded from threshold calculations).
- **Node** 1: Source ROADM (start of the sub-array for analysis).
- **Node** $(n-2)$: Destination ROADM (end of the sub-array).
- **Node** $(n-1)$: True destination node (excluded from threshold calculations).

Exclusion Rule:

> All threshold-based distance accumulations, regenerator triggers, and OPC computations occur only between *node 1* (the source ROADM) and *node* $(n-2)$ (the destination ROADM). Links $(0 \rightarrow 1)$ and $(n-2 \rightarrow n-1)$, typically the short 0.01 km segments, are *ignored*.

3 Regenerator Placement Logic

We assume a globally defined **regenerator threshold**, denoted as T (e.g., 1500 km). The sub-array for analysis is $[1 \dots n-2]$ of the node list. Let $D(i,j)$ be the distance accumulated from node i to node j *within that sub-array.*

3.1 Trigger Condition and Forbidden Nodes

(a) **Trigger Condition:** If the cumulative distance from the last regenerator (or from sub-array start if no reg yet) exceeds T, a new regenerator is required.

(b) **Forbidden Nodes for Regenerators:**

- Node 1 (source ROADM) and node $(n-2)$ (destination ROADM) are *never allowed* for regenerators.
- Thus, in the sub-array indexing, index 0 and index (sub_n $-$ 1), which correspond to these ROADMs, are skipped for reg placement.
- If we need to place a regenerator but the preceding node is forbidden, the path is **unreachable**.

(c) **Direct Links Exceeding Threshold:** If a single link in the sub-array surpasses T and no valid intermediate node exists, the path is unreachable.

3.2 No Regenerators Needed

If the entire sub-array distance $\leq T$, then no regenerator is placed.

4 OPC (Optical Phase Conjugator) Placement Logic

After placing regenerators, we apply the OPC rules.

4.1 Case 1: No Regenerators in Sub-Array

1. If the *sub-array* total distance $\leq T$ (thus no reg needed),
2. And if the sub-array has **3 or more nodes** in $[1 \dots n-2]$,
3. Then place **exactly one** OPC at the node in the interior (i.e., excluding sub-array index 0 and index (sub_n $-$ 1)) *closest to the midpoint distance* of the entire sub-array.

If fewer than 3 sub-array nodes exist, we skip OPC entirely.

4.2 Case 2: Regenerators Placed

When the sub-array *does* contain one or more regenerators:

1. Partition the sub-array into *sections*:

$$[\text{source\_ROADM} \to \text{R1}], [\text{R1} \to \text{R2}], \dots, [\text{Rk} \to \text{destination\_ROADM}].$$

2. In each section, if there are **3 or more nodes** (counting the section's start and end),
3. Place **one** OPC at the interior node (excluding section endpoints) nearest that section's midpoint in distance.

4.3 OPC Forbidden Nodes

Similarly to regenerators, the node that is exactly the source ROADM (*sub-array index 0*) or the destination ROADM (*sub-array index (sub_n-1)*) is forbidden for OPC placement.

5 Residual Distance Calculation

We define **Scenario 1** (no OPC) and **Scenario 2** (OPC present). Distances are always measured in the sub-array only.

5.1 Scenario 1: No OPC

- If no regenerators exist, the *entire sub-array distance* is considered the residual distance.
- If one or more regenerators exist, the **residual distance** is the distance from the *last regenerator* in the sub-array to the sub-array's end (*destination ROADM*).

5.2 Scenario 2: One or More OPCs

When at least one OPC is placed, we:

(i) **Compute** for each OPC:

$$|(\text{distance from section start to OPC}) - (\text{distance from OPC to section end})|.$$

(ii) **Sum** all such absolute differences over all OPCs.

(iii) **Add** the *last leftover segment distance* from the final regenerator to the end of the sub-array (i.e., from R_{last} to destination ROADM).

(iv) The **final residual distance** is the sum of step (i) and step (iii).

6 Unreachable Paths

A path is declared **UNREACHABLE** if:

- Any single link in the sub-array is $> T$ and no intermediate node can accommodate a regenerator, or
- The logic attempts to place a regenerator at a forbidden node (source/destination ROADM) and thus fails threshold compliance.

7 Summary of Key Changes

This final version of the specification **excludes** the true source (nodeIDs[0]) and the true destination (nodeIDs[$n-1$]) from every threshold check and from the residual distance calculations. Only the sub-array [1..($n-2$)] is relevant. Nodes at the extremes of this sub-array (i.e. index 1 and index ($n-2$) in the *original full path*) are likewise *disqualified* from receiving regenerators or OPCs.

In addition:

- If *no* regenerator is needed but the path has at least 3 intermediate ROADM nodes, we place a single OPC (Case 1).
- If regenerators are present, an OPC can appear in each section with 3+ nodes (Case 2).
- The residual distance in the presence of OPC(s) always incorporates the leftover from the last regenerator to the sub-array's end.

8 Conclusion

By following this final specification, the NPARC tool ensures:

- **Correct Regenerator Placement** without ever placing them at the true source, destination, or their immediate ROADMs.
- **OPC Placement** is consistent with either "no-regens" or "with-regens" scenarios, using midpoint-based selection for each sub-section.
- **Accurate Residual Distance** reflecting either a full sub-array or last-segment leftover, plus absolute differences for each OPC segment.

This concludes the final revision of the NPARC specification sheet with all updates included.