Detecting Spatially-Close Fiber Segments in Optical Networks

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Our Contributions

I. Fast polynomial-time algorithms for detecting all spatially-close fiber segments.

II. Fast polynomial-time algorithm for detecting the intervals of a fiber that are spatially-close to another fiber (or to a set of fibers).

III. Fast exact algorithm for grouping spatially-close fibers using a minimum number of risk groups.

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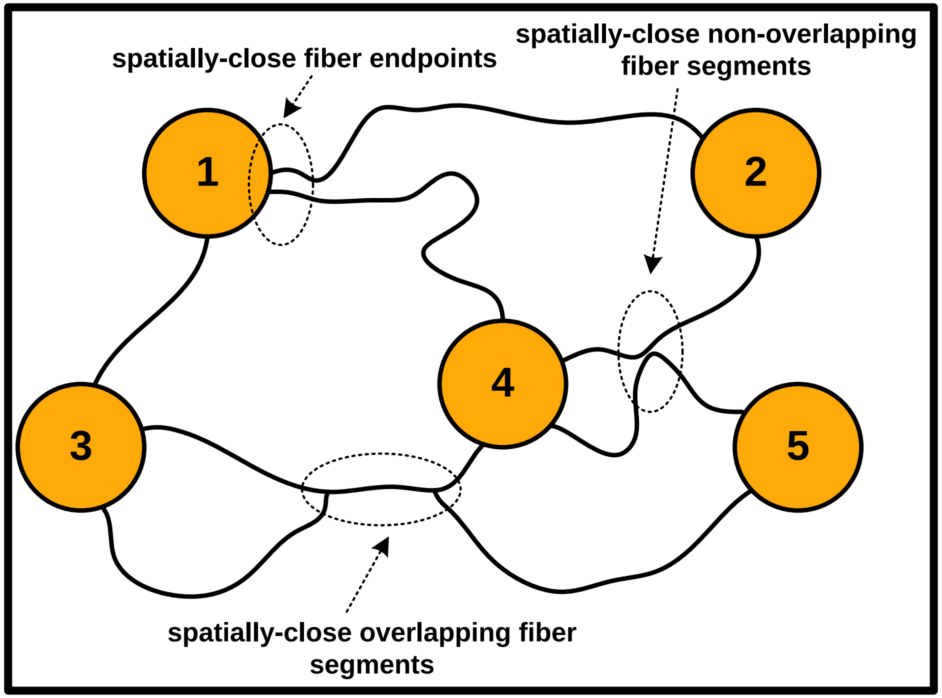
Problem I

Detection of
Spatially-Close Fiber Segments:

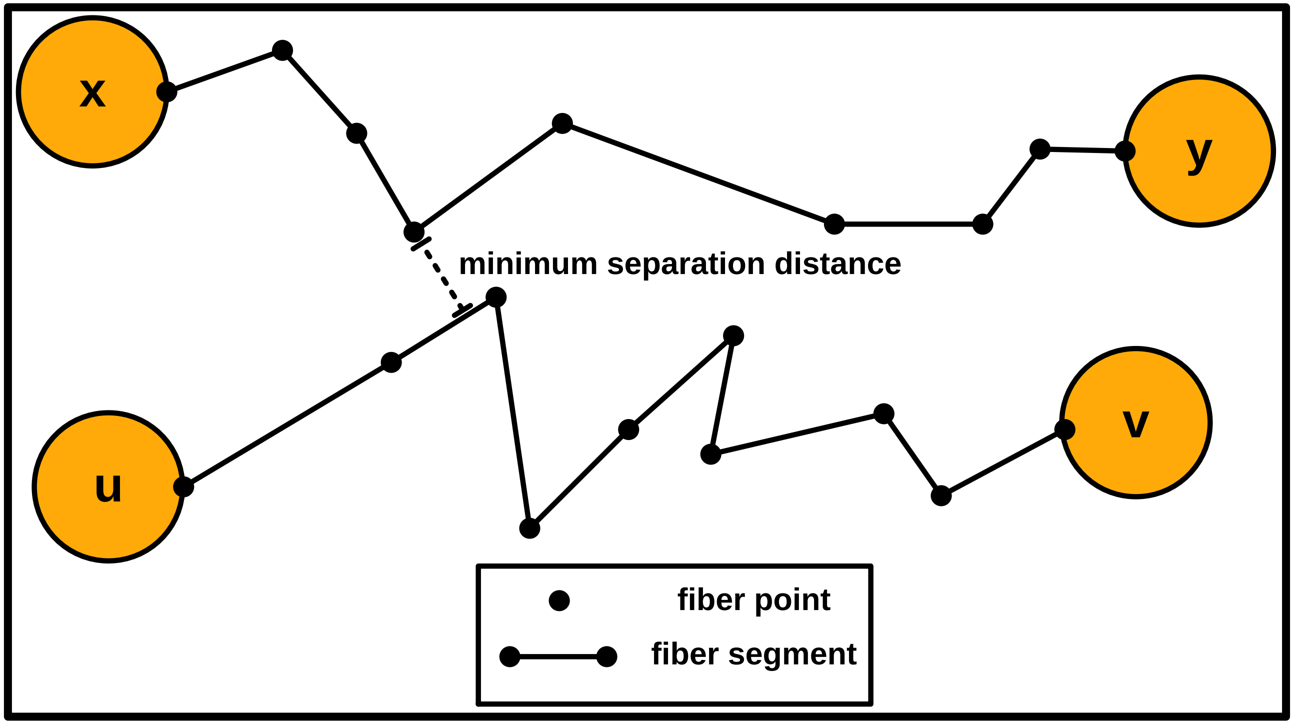
Given a set of fibers, find all the fiber segment pairs that have a minimum distance of less than Δ.

Motivation



- Spatially-close fiber segments have a high chance of failing simultaneously in the event of disasters.
- Yet, previous network resilience research often disregarded the geography of the fiber segments and considered all links to be straight.

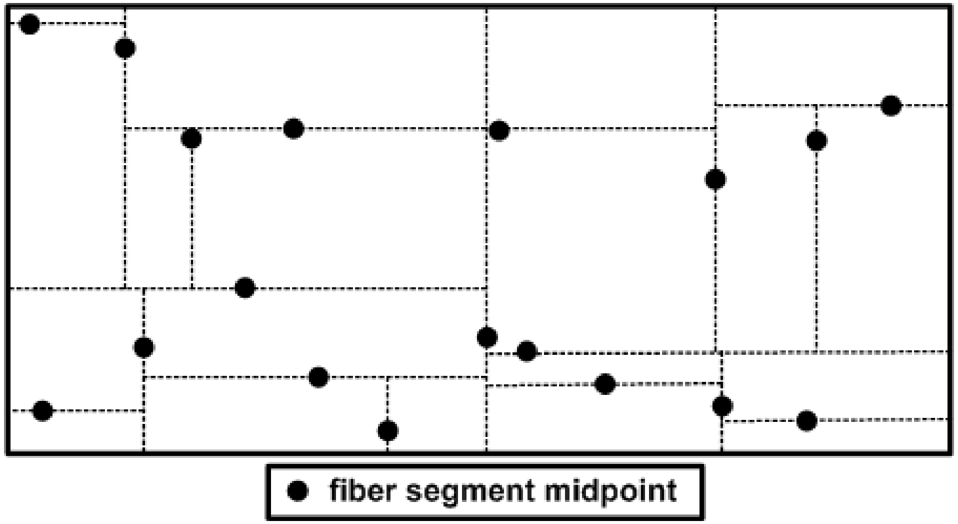
Fiber Representation



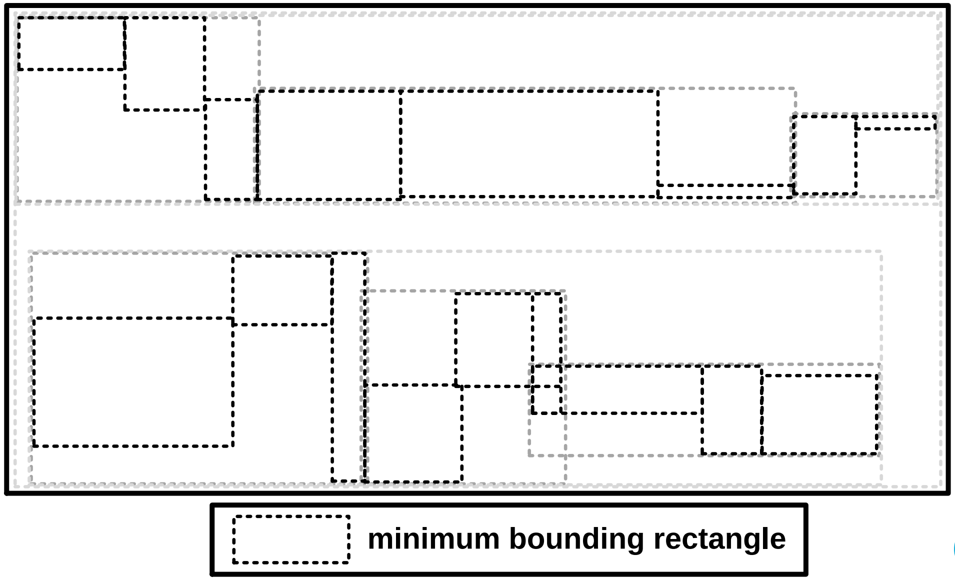
- Non-straight concatenation of multiple fiber segments with irregular lengths.
- Each fiber segment is a straight line connecting two fiber points of known geodetic location.

Proposed Algorithms

1. k-d tree based



2. R tree based



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Proof-of-Concept

Network	Algorithm	Minimum separation distance (α)						
		5 m	**50 m**	**500 m**	**5 km**	**50 km**	**500 km**	**5000 km**
Angola Telecom	Naive approach	20.16 s	20.16 s	20.16 s	20.16 s	20.16 s	20.16 s	20.16 s
	Algorithm 1	1.12 s	1.13 s	1.15 s	1.15 s	1.66 s	11.90 s	19.81 s
	Algorithm 2	0.21 s	0.22 s	0.23 s	0.23 s	0.34 s	9.17 s	21.20 s
Ethiopia Telecom	Naive approach	2.98 min	2.98 min	2.98 min	2.98 min	2.98 min	2.98 min	2.98 min
	Algorithm 1	7.12 s	7.37 s	7.55 s	7.80 s	14.79 s	2.12 min	3.05 min
	Algorithm 2	0.75 s	0.75 s	0.75 s	0.76 s	2.50 s	2.01 min	3.22 min
Telkom South Africa	Naive approach	8.60 min	8.60 min	8.60 min	8.60 min	8.60 min	8.60 min	8.60 min
	Algorithm 1	30.89 s	31.17 s	31.90 s	31.97 s	50.51 s	5.20 min	8.97 min
	Algorithm 2	1.28 s	1.30 s	1.31 s	1.45 s	8.23 s	4.53 min	9.00 min

- Tested on three real-world topologies.
- Coordinates projected onto 2D Cartesian plane.
- Significant time-savings can be achieved by our proposed algorithms, particularly when Δ is low.

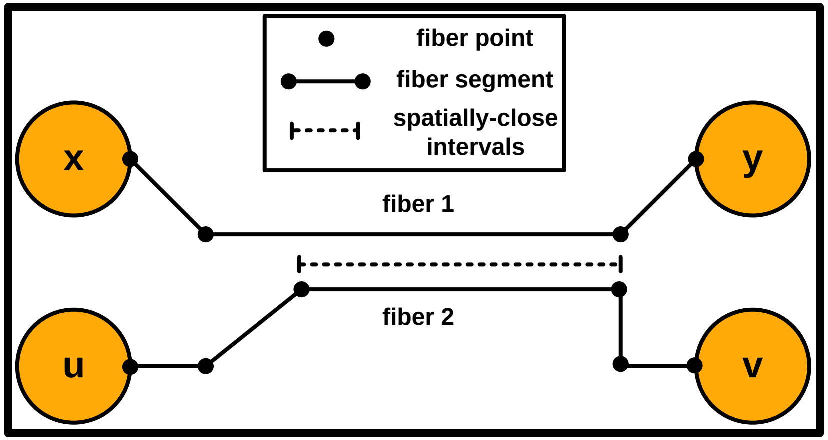
Problem II

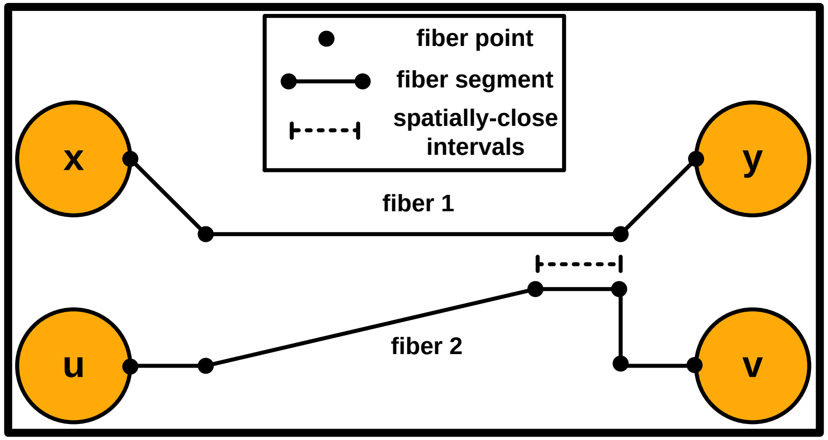
Spatially-Close Intervals:

Given a fiber and a set of other fibers,

find the intervals of the fiber that are spatially close to any fiber in the fiber set.

Motivation





Fibers with longer spatially-close intervals have higher risk of failing simultaneously.

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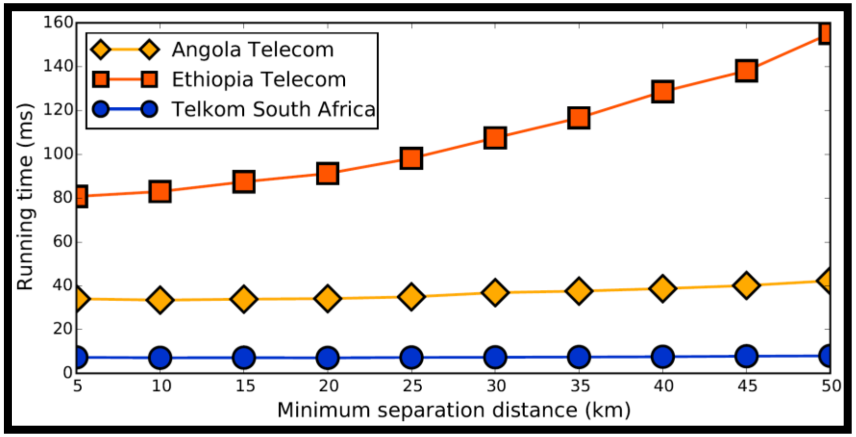
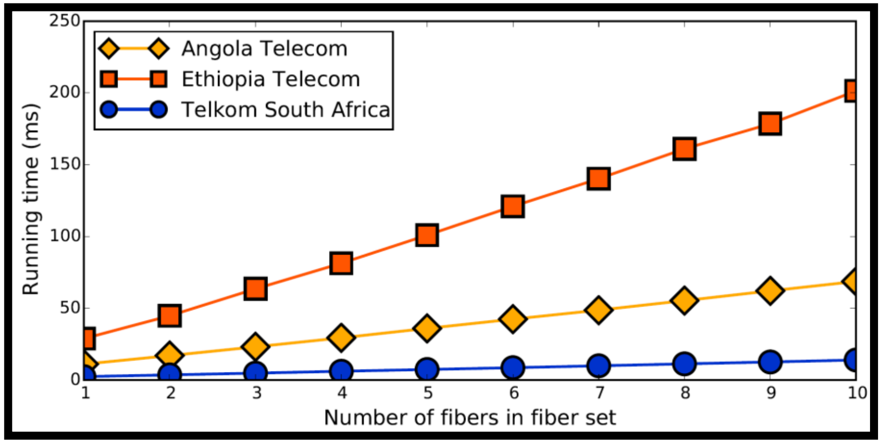
Proof-of-Concept





- We propose an algorithm based on the use of line equations and union function to compute the spatially-close interval.
- Can further be fasten by combining fiber segments with collinear fiber points.
- Combining short non-collinear fiber segments saves running time at the expense of inaccurate results.

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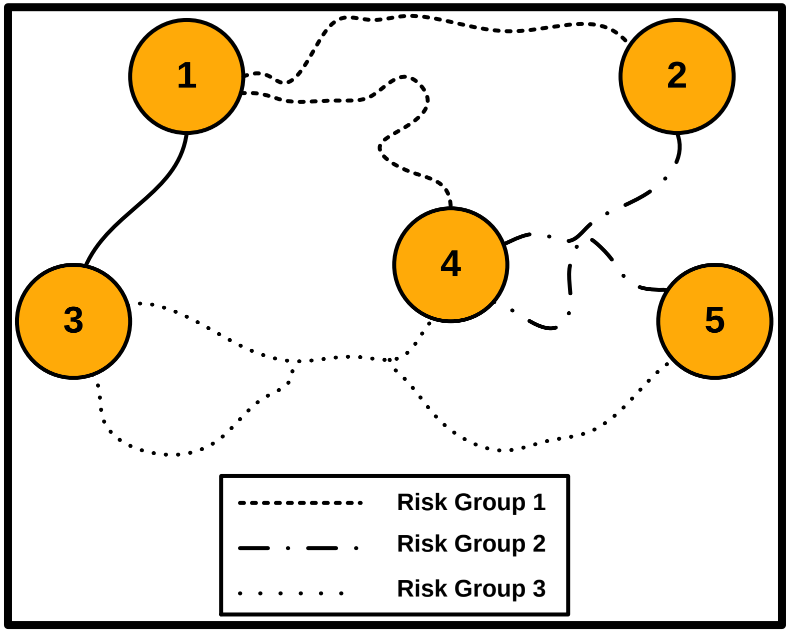
Problem III

Risk Group Assignment:

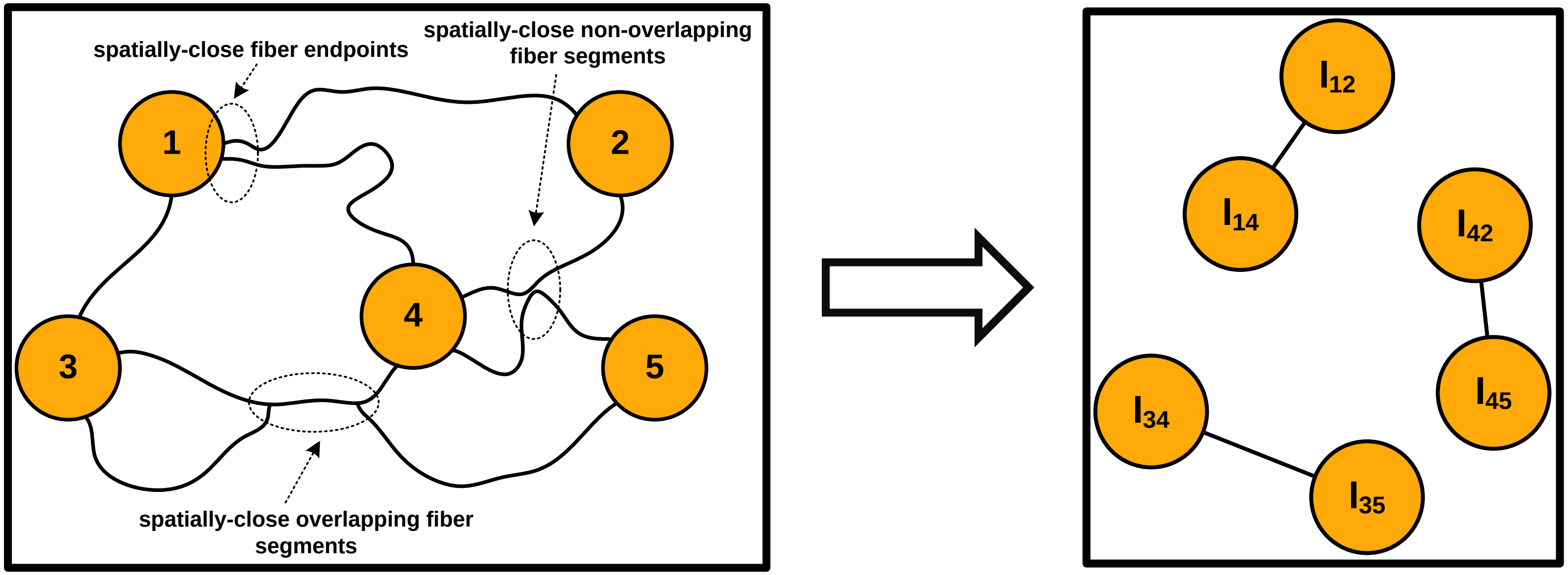
Given a set of spatially-close fiber pairs,
assign fibers that are spatially close
to each other in the same risk group,
using the minimum number of groups.

Motivation



- A risk group is a set of fibers that are spatially close to every other fiber in the same set.
- Focus on maximal risk groups, such that the number of risk groups used is reduced.

Proposed Algorithm



- An auxiliary graph for representing spatially-close fibers, with each auxiliary node representing a fiber.
- If any two fibers have a distance of less than Δ, connect their corresponding nodes with a link.
- Each maximal clique in the auxiliary graph then represents a maximal risk group.

Proof-of-Concept

Network	Property	Minimum separation distance (α)						
		5 m	50 m	500 m	5 km	50 km	500 km	5000 km
Angola Telecom	Total number of maximal risk groups	9	13	16	15	12	9	1
	Average number of fibers per maximal risk groups	2.22	2.15	2.25	2.60	3.00	8.11	16
	Maximum number of fibers per maximal risk groups	3	3	3	3	4	9	16
	Minimum number of fibers per maximal risk groups	2	2	2	2	2	7	16
Ethiopia Telecom	Total number of maximal risk groups	12	16	17	17	15	11	1
	Average number of fibers per maximal risk groups	2.08	2.25	2.41	2.41	2.67	11	21
	Maximum number of fibers per maximal risk groups	3	3	3	3	4	14	21
	Minimum number of fibers per maximal risk groups	2	2	2	2	2	10	21
Telkom South Africa	Total number of maximal risk groups	210	230	311	271	281	3659	1
	Average number of fibers per maximal risk groups	2.03	2.05	2.47	2.82	4.97	80.31	343
	Maximum number of fibers per maximal risk groups	3	3	5	8	9	108	343
	Minimum number of fibers per maximal risk groups	2	2	2	2	2	19	343

Higher Δ increases the number of spatially-close fibers and risk groups. However, as the size of risk groups increases, the possibility of a maximal risk group being a superset of another smaller risk group increases, thus reducing the number of maximal risk groups.

Conclusions

- Our proposed algorithms far outperforms the intuitive naive approach in finding all spatially-close fiber segments.
- Spatially-close intervals can be used to differentiate spatially-close fibers.
- Our risk group assignment also enables ample knowledge of existing risk-group-disjoint paths to find disaster-disjoint paths.

Thank You!
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