Diversity Requirements for Selecting Candidate Paths for Alternative-Path Routing

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Outline

- Overview of Routing Strategies
- Alternative-Path Routing – Diversity Requirements
  - Candidate Paths with Complete Diversity
  - Candidate Paths with Diversity only with respect to the Most Heavily Loaded Links
- Results of a Network Study that Compares the Two 'Diversity' Schemes
  - Unprotected Traffic
  - Protected Traffic
- Algorithms to Find a Set of Candidate Paths
- Conclusions

Routing Strategies

Goal: Given a call request from Node A to Node Z, determine the path over which the call should be routed

Desirable features for the Routing Strategy:

- Low probability of call requests being blocked
- Cost effective
- Low complexity (depending on the application)

Several well-known Routing Strategies:

- **Fixed-Path Routing**: Pre-calculate a single path between Nodes A and Z, and always use that path for all such call requests
  - Simple & fast, but typically leads to very unbalanced link load and unnecessary blocking
- **Alternative-Path Routing**: Pre-calculate *K* different candidate paths between Nodes A and Z. When a call request arrives, select one of the *K* paths to use based on the current network state. The call remains on this path for its duration (under no failures).
  - *K* of about 3 works well
- **Dynamic-Path Routing**: When a call request arrives, dynamically search for a path.
  - Somewhat slower; may not be suitable for highly dynamic network applications
  - In an optical-bypass based network, potentially results in wavelength contention issues

Alternative-Path Routing has been shown to be effective.

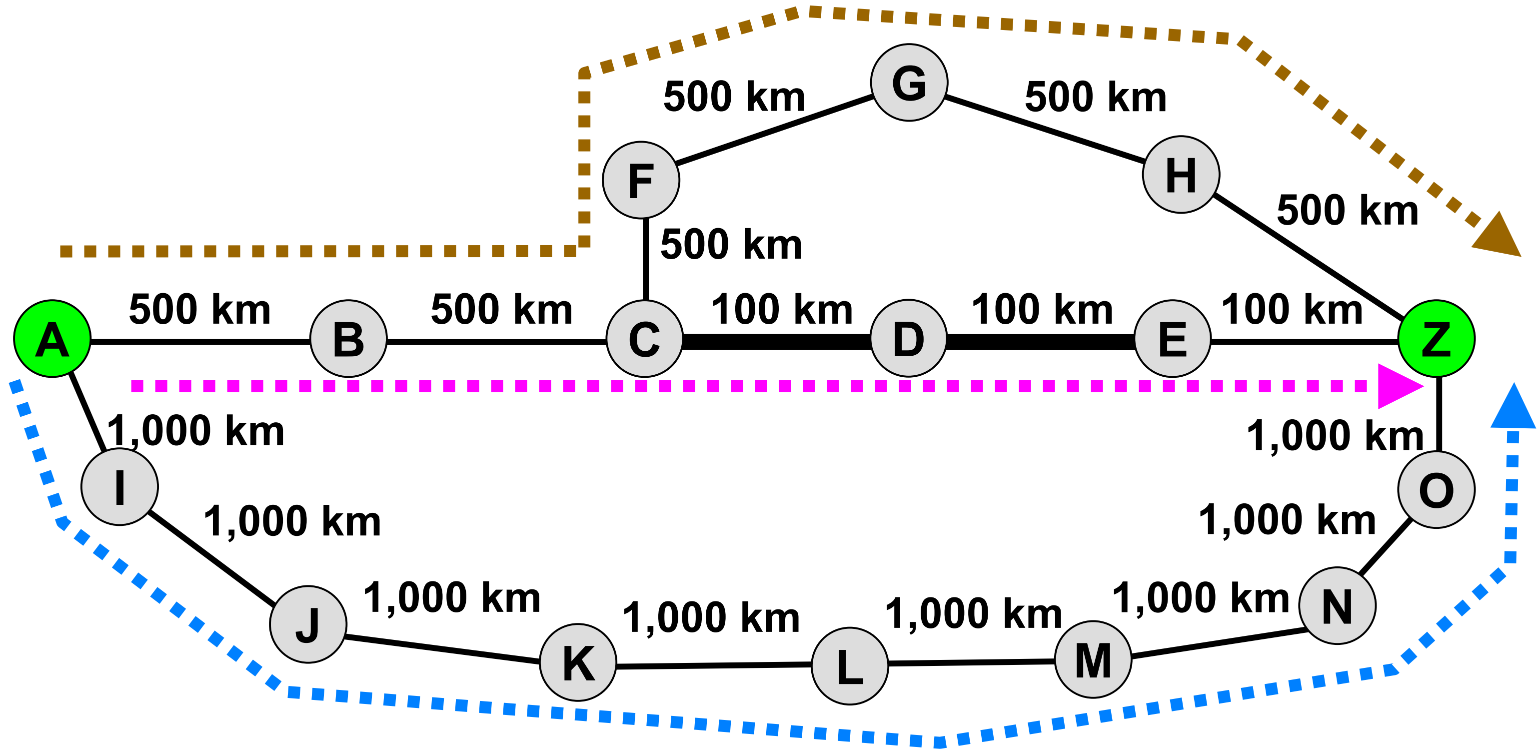
The question is how to select the *K* candidate paths.

Optical-Bypass Assumption

- In what follows, it is assumed that the network supports optical bypass, with an optical reach of 2,500 km
  - After traveling 2,500 km, the signal needs to be regenerated
  - In such networks, the cost of a path is dominated by the number of regenerations along the path

- The same general principles that will be discussed hold for O-E-O networks as well, where the signal is regenerated at every node along the path

Simple Network Example



Assume Links CD and DE are heavily congested (i.e., the <u>bottleneck</u> links)

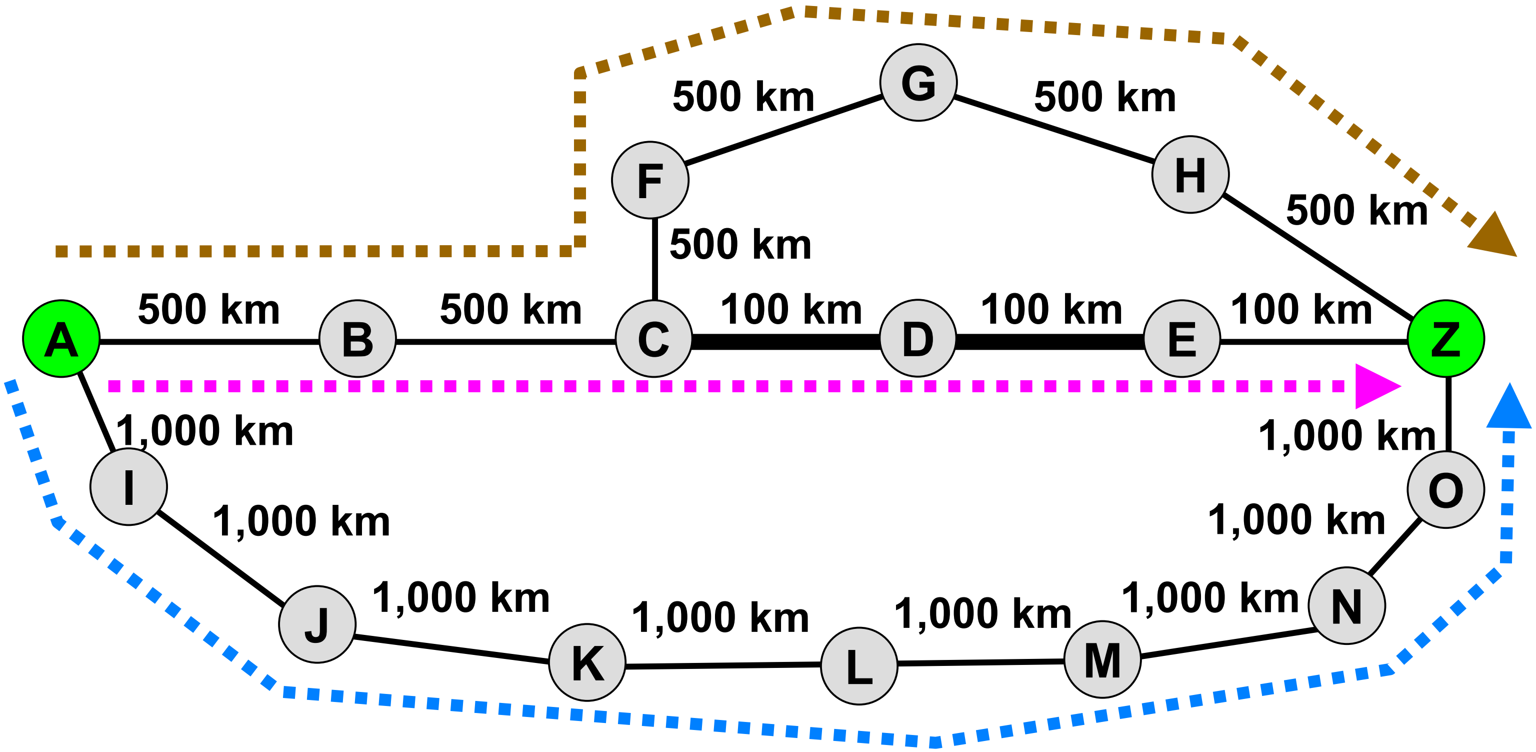
3 Possible Paths between Node A and Node Z

A-B-C-D-E-Z: 1,300 km; no regenerations

A-B-C-F-G-H-Z: 3,000 km; 1 regeneration

A-I-J-K-L-M-N-O-Z: 8,000 km; 3 regenerations

Completely Diverse Candidate Paths



Assume using alternative-path routing, and want 2 candidate paths (unprotected)

If require completely diverse candidate paths, then the options are:

Candidate Paths: **A-B-C-D-E-Z** and **A-I-J-K-L-M-N-O-Z**

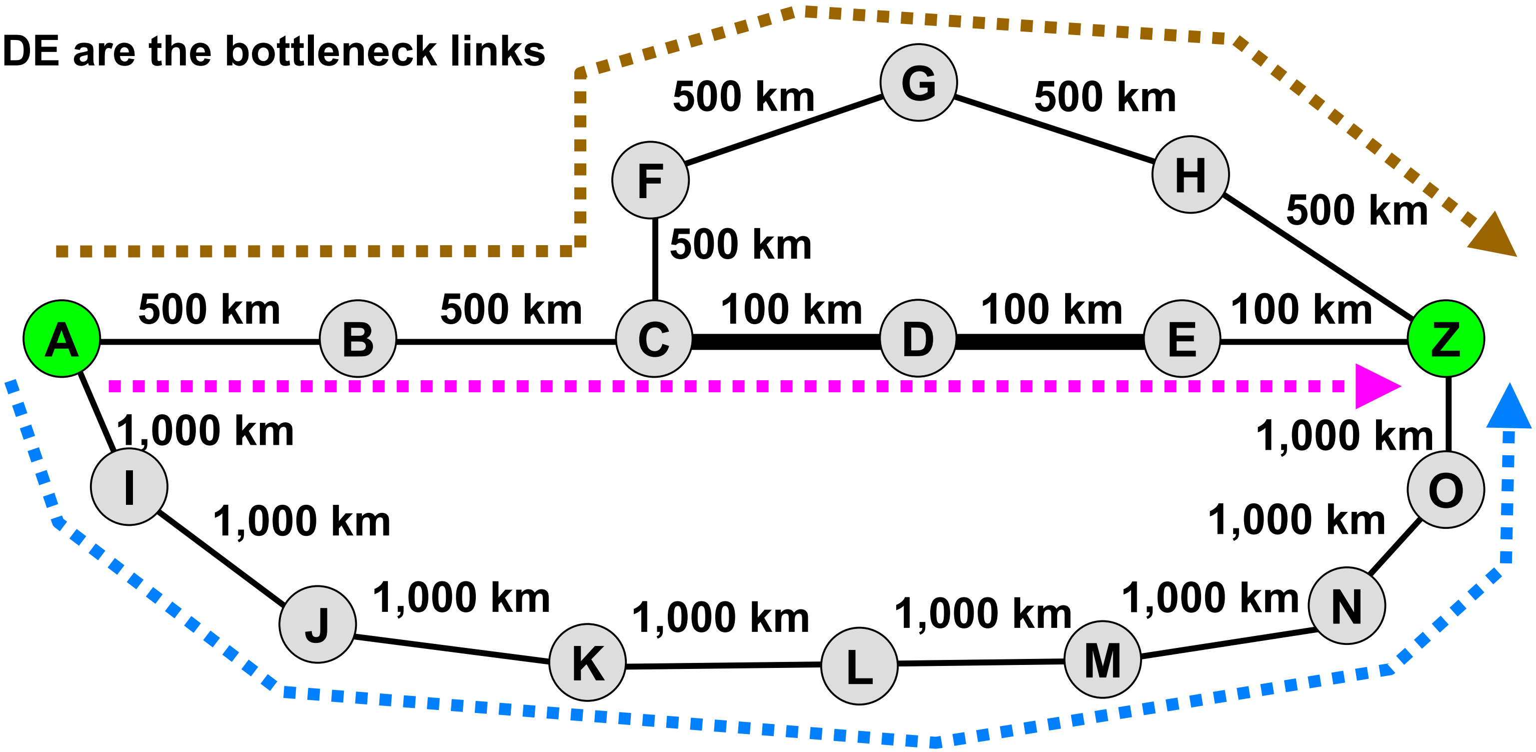
or

Candidate Paths: **A-B-C-F-G-H-Z** and **A-I-J-K-L-M-N-O-Z**

Most research papers require completely diverse candidate paths

Candidate Paths with 'Bottleneck' Diversity

CD and DE are the bottleneck links

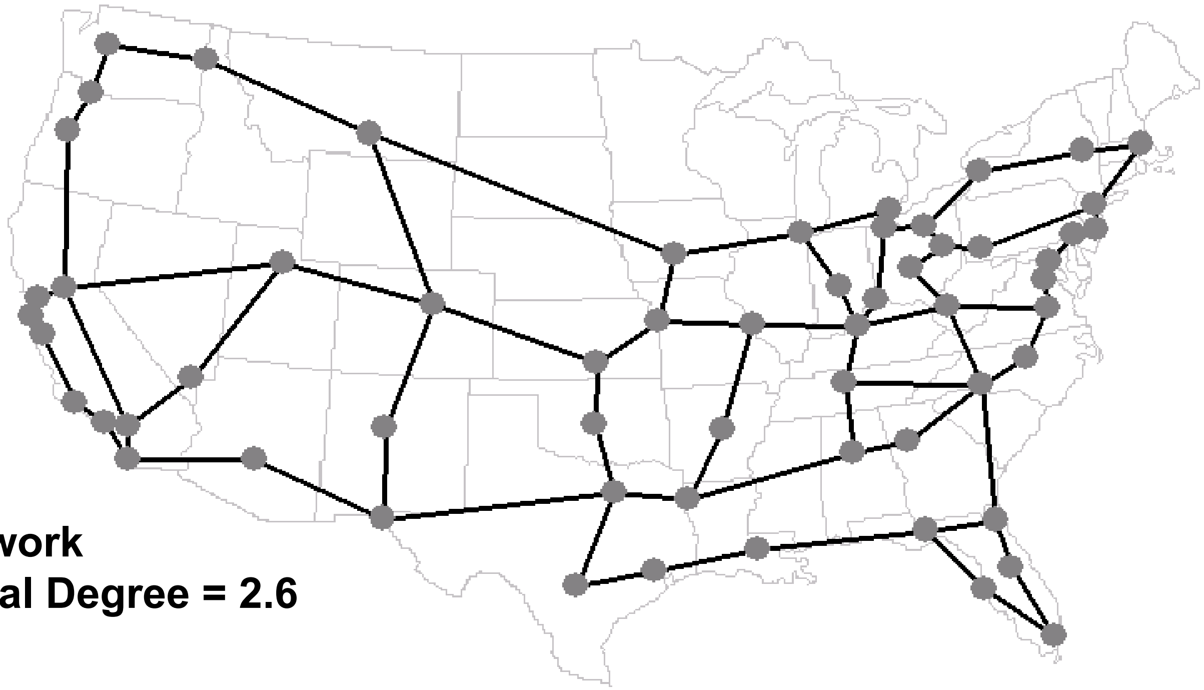


The bottleneck (i.e., most heavily congested) links are CD and DE.
Select candidate paths that allow these links to be avoided when routing calls.

Candidate Paths: **A-B-C-D-E-Z** and **A-B-C-F-G-H-Z**

No need to include the **A-I-J-K-L-M-N-O-Z** path as one of the candidate paths. This path is costly (3 regens), burns more bandwidth, is less reliable, and has greater end-to-end latency.

Network Study



60-Node Network
Average Nodal Degree = 2.6

- Poisson call arrivals; exponential holding times
- Alternative-path routing with *K* = 3 (i.e., three candidate paths)
- For each call, select the lowest-cost candidate path that results in the least loading. If none of the lowest cost paths are available, then consider candidate paths with one extra regeneration (if any). If none of these paths are available, then consider candidate paths with two extra regenerations (if any).
- Maximum of 80 wavelengths per fiber
- First-Fit wavelength assignment. Allowed to add an extra regeneration to mitigate wavelength contention issues (not needed very often).

Results for Unprotected Traffic

(95% Confidence Intervals are shown in the Paper)

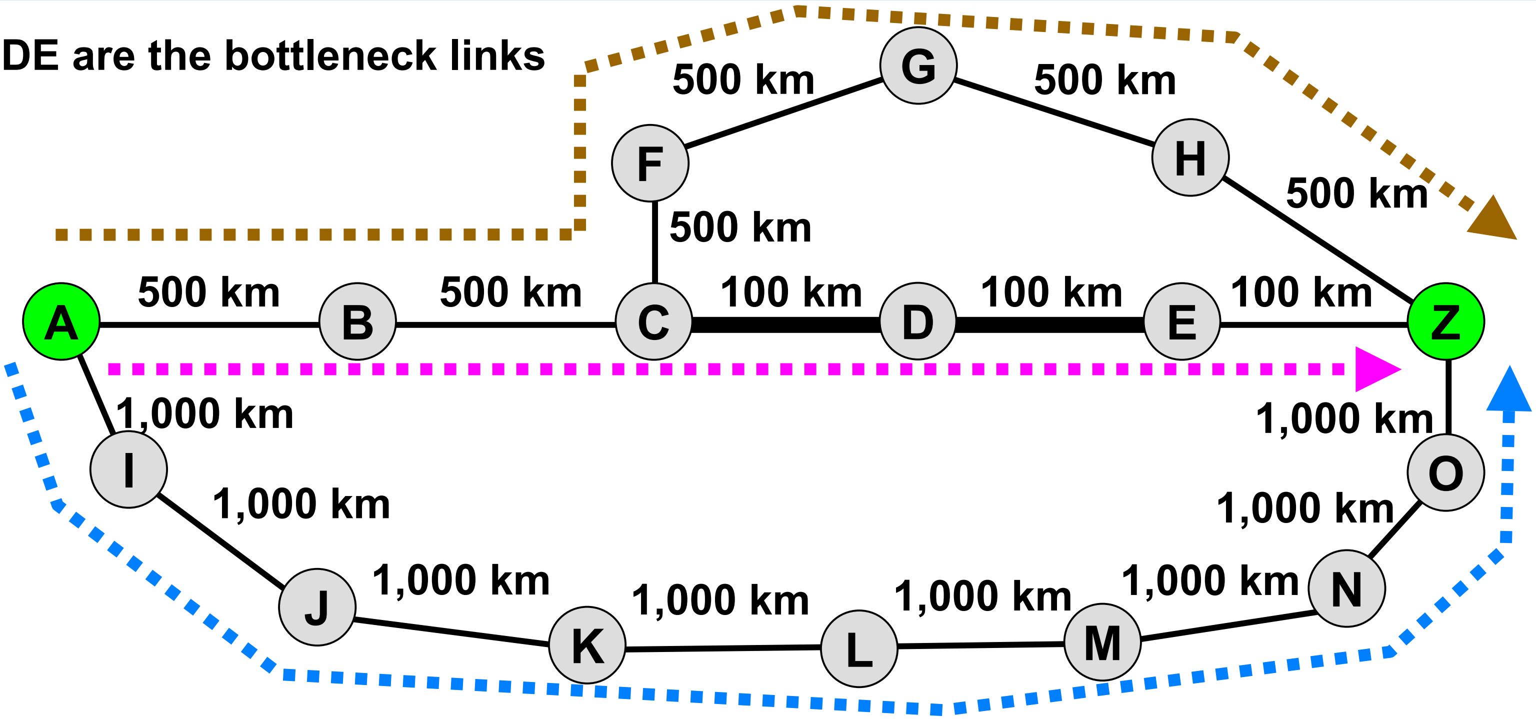
	Completely Diverse Candidate Paths	Bottleneck Diverse Candidate Paths
Avg. # of Candidate Paths per source/dest.	2.2	2.6
Avg. Routed Path Length	1,895 km	1,814 km
Avg. Routed Hops	4.8	4.5
Avg. # of Regenerations per Routed Demand	0.35	0.29
Avg. Blocking Probability	3.7×10^{-4}	1.6×10^{-4}

Bottleneck diversity results in a lower blocking probability and lower cost.

Likely results in somewhat greater call availability also (shorter paths, fewer hops)

Candidate Paths for 1+1 Protection

CD and DE are the bottleneck links



Need to Pick Two Completely Diverse Paths for 1+1 Routing ("Path-Pair")
i.e., *The Working and Protect Paths Must be Completely Diverse*

But, How Diverse do the Candidate Path-Pairs Need to be from Each Other?

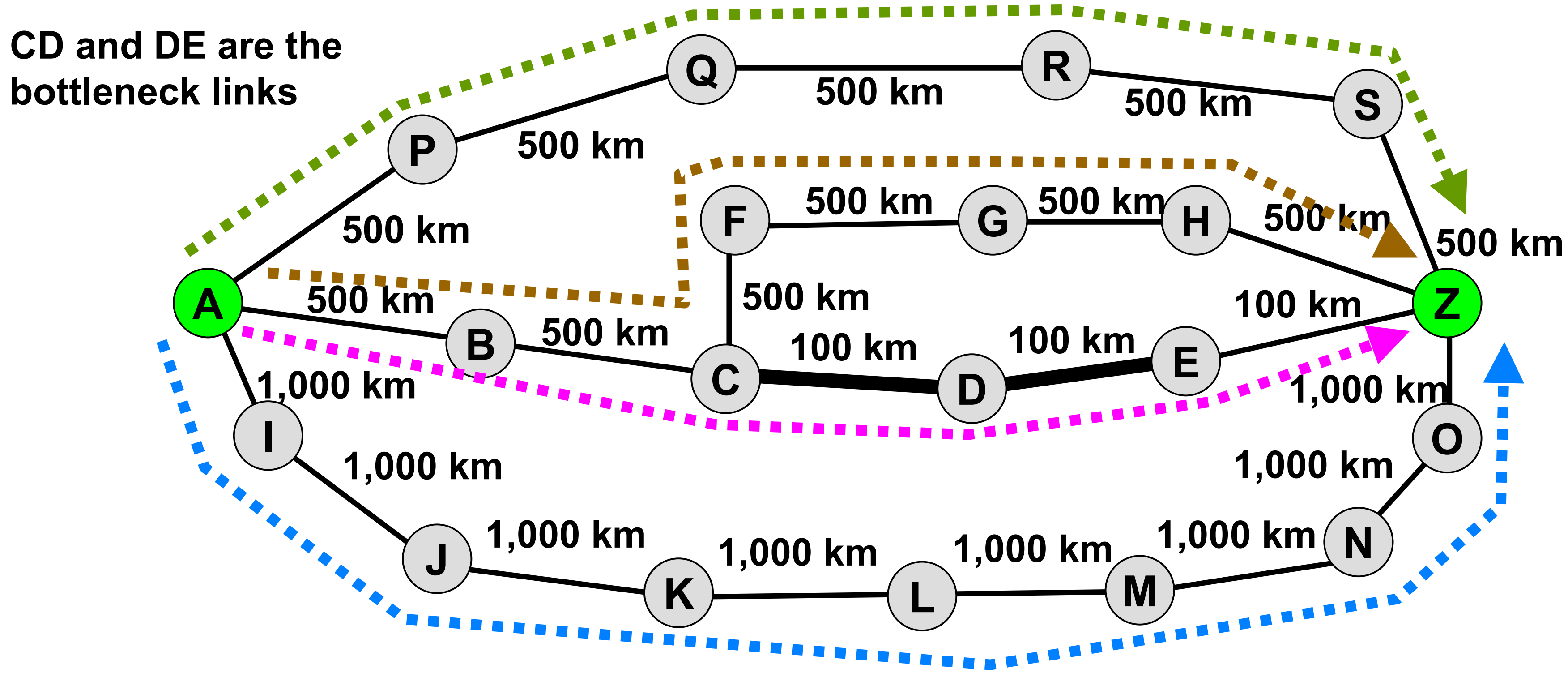
If require that Candidate Path-Pairs be completely diverse from each other, then:

Candidate Path-Pair 1 (W+P): **A-B-C-D-E-Z** + **A-I-J-K-L-M-N-O-Z** (can't find 2nd Candidate pair)

If require that Candidate Path-Pairs be diverse only with respect to the Bottleneck Links, then:

Candidate Path-Pair 1 (W+P): **A-B-C-D-E-Z** + **A-I-J-K-L-M-N-O-Z**
Candidate Path-Pair 2 (W+P): **A-B-C-F-G-H-Z** + **A-I-J-K-L-M-N-O-Z**

Candidate Paths for 1+1 Protection (2nd Example)



Candidate Path-Pairs Using Completely Diverse Paths:

Candidate Path-Pair 1 (W+P): A-B-C-D-E-Z + A-P-Q-R-S-Z

Candidate Path-Pair 2 (W+P): A-B-C-D-E-Z + A-I-J-K-L-M-N-O-Z

Candidate Path-Pairs that are Diverse with Respect to the Bottleneck Links:

Candidate Path-Pair 1 (W+P): A-B-C-D-E-Z + A-P-Q-R-S-Z

Candidate Path-Pair 2 (W+P): A-B-C-F-G-H-Z + A-P-Q-R-S-Z

Results for 1+1 Protected Traffic

(95% Confidence Intervals are shown in the Paper)

	Completely Diverse Candidate Path-Pairs	Bottleneck Diverse Candidate Path-Pairs
Avg. # of Candidate Path-Pairs per source/dest.	1.4	2.7
Avg. Routed Path Length	4,748 km	4,863 km
Avg. Routed Hops	11.6	11.8
Avg. # of Regenerations per Routed Demand	1.02	1.00
Avg. Blocking Probability	107×10^{-4}	3.7×10^{-4}

Bottleneck diversity results in ~30 times lower blocking probability

Difficult to compare other parameters because of the large difference in blocking

Determining Candidate Paths

- Completely Diverse Candidate Paths
  - Suurballe or Bhandari algorithms to find *K* diverse paths

- Candidate Paths with Bottleneck Diversity
  - Route expected traffic pattern using shortest-path routing to determine the likely bottleneck links (or use a max-flow technique)
  - Once determine bottleneck links, then:

    Eliminate a single bottleneck link (or a sequence of consecutive bottleneck links) and run a shortest-path algorithm on the reduced topology to find a candidate path. Repeat this procedure for *N* bottleneck links, for some *N.*

    (Not good to eliminate all bottleneck links at once – new bottlenecks arise)

    (Other strategies are possible; e.g., running an *M*-shortest path algorithm)
  - Narrow down the set of generated paths to *K* candidate paths
    - Typically take the shortest path
    - Select *K*-1 other paths based on cost (i.e., number of regenerations)

Conclusions

- Complete Diversity is Required for Providing Protection
  - The Work and Protect Paths *of a given Path-Pair* should be Diverse
- Complete Diversity is Not Required for Purposes of Load Balancing
  - The Candidate Paths (or Candidate Work/Protect Path-Pairs) do not Need to be Diverse *from One Another*
- Selecting Candidate Paths with Bottleneck Diversity rather than Complete Diversity results in:
  - Lower Blocking Probability
  - Lower Cost Network
  - More Reliable Network
- Requiring just bottleneck diversity is also advantageous for shared mesh protection
  - With shared mesh protection, increasing the number of candidate paths (i.e., larger *K*) typically affords more opportunities for sharing the protection capacity
  - With bottleneck diversity, more candidate paths can be found