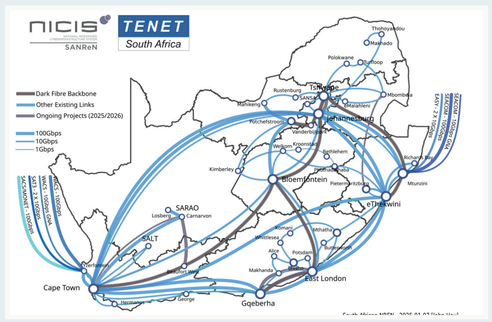
A Performance and Resilience Analysis of SANReN

BACKGROUND

- SANReN is South Africa's high-speed research backbone.
- SANReN faces rising demand, congestion and critical node vulnerabilities.



OBJECTIVES

- Identify resilience weak points using centrality, spectral, and core metrics.
- Validate resilience with NS-3 simulations and reinforcement strategies.
- Compare models & develop a framework for resilient SANReN topologies.

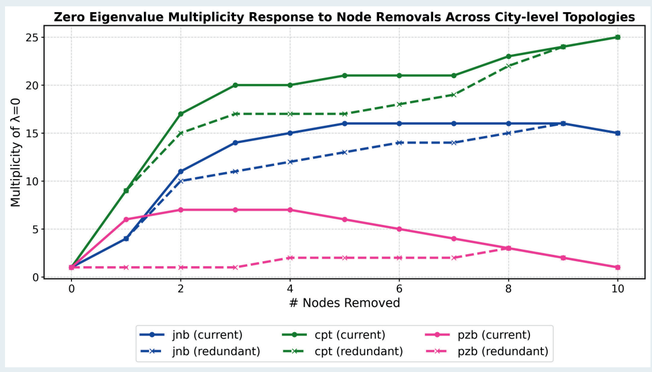
METHODOLOGY

1. **Identify Critical Nodes** – ranked these nodes using composite centrality (degree, closeness & betweenness)
2. **Add Redundancy** – Added edges to top-ranked nodes.
3. **Evaluate Resilience** – Measured algebraic connectivity, zero-eigenvalue multiplicity, and core metrics.
4. **Test Failures & Validate** – Ran node/edge removal experiments and validated with NS-3 simulation.
5. **Compare Models** – Compared spectral and core resilience to highlight complementary strengths.

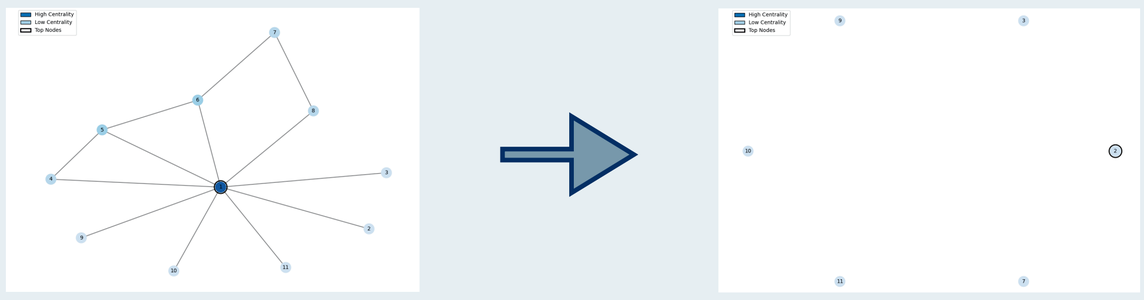
RESULTS

Node failures:

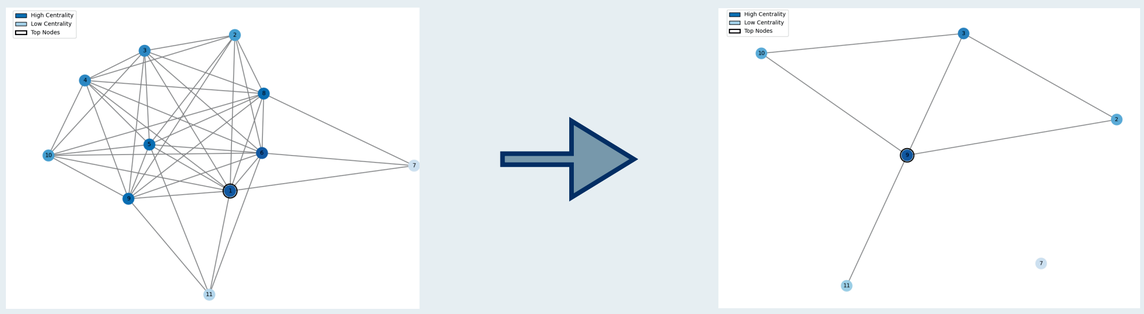
- Redundancy improved resilience in small topologies.
- In larger cities, benefits only appeared after several node removals.



Pietermaritzburg current topology before and after 5 critical node removals



Pietermaritzburg redundant topology before and after 5 critical node removals



Edge Failures:

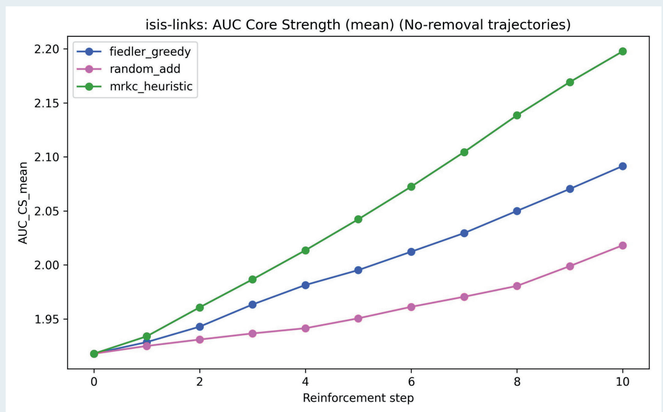
- Minimal resilience improvement from redundancy.
- Resilience gains only visible under larger edge removal increments.

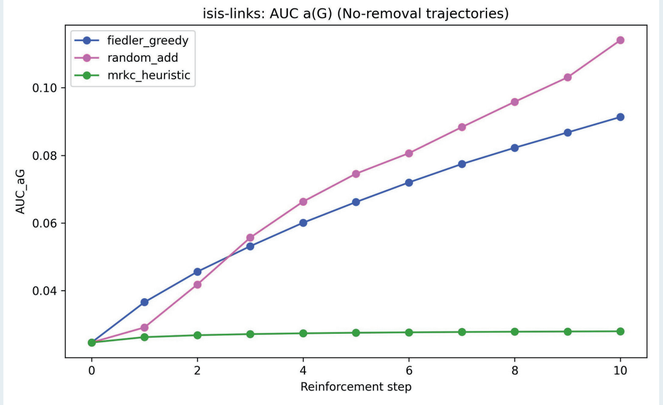
NS-3 Simulations

- Johannesburg's redundant topology was more resilient than the current one after 4 – 7 node failures.
- However, redundant topology collapsed under extreme failures (8+ removals).

Reinforcement Strategies:

- **Fiedler-Greedy:** best for increasing connectivity.
- **K-Core:** boosted local redundancy but risked "super-hubs."
- **Random:** competitive baseline.





Model Comparison

- **Spectral Graph Model:** faster drop in connectivity and a sharper rise in fragmentation under random failures, descending targeted removals, and direct core node removals ($p < 0.001$) → greater fragmentation risk.
- **Core Resilience Model:** larger changes in resilience metrics under ascending targeted removals from the periphery ($p < 0.01$) → layered embedding risk.
- **Bottom 10% removals:** No significant difference between the two models ($p > 0.4$).
- **Outcome:** Models are complementary, each highlighting different resilience risks.

CONCLUSIONS

- Centrality metrics identified critical nodes
- Spectral and core resilience metrics revealed resilience shifts under failures.
- NS-3 simulations and reinforcement strategies confirmed resilience improvements, but only when redundancy was distributed throughout the topology.
- Spectral vs core models captured different risks - providing a framework for resilient SANReN topologies.

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