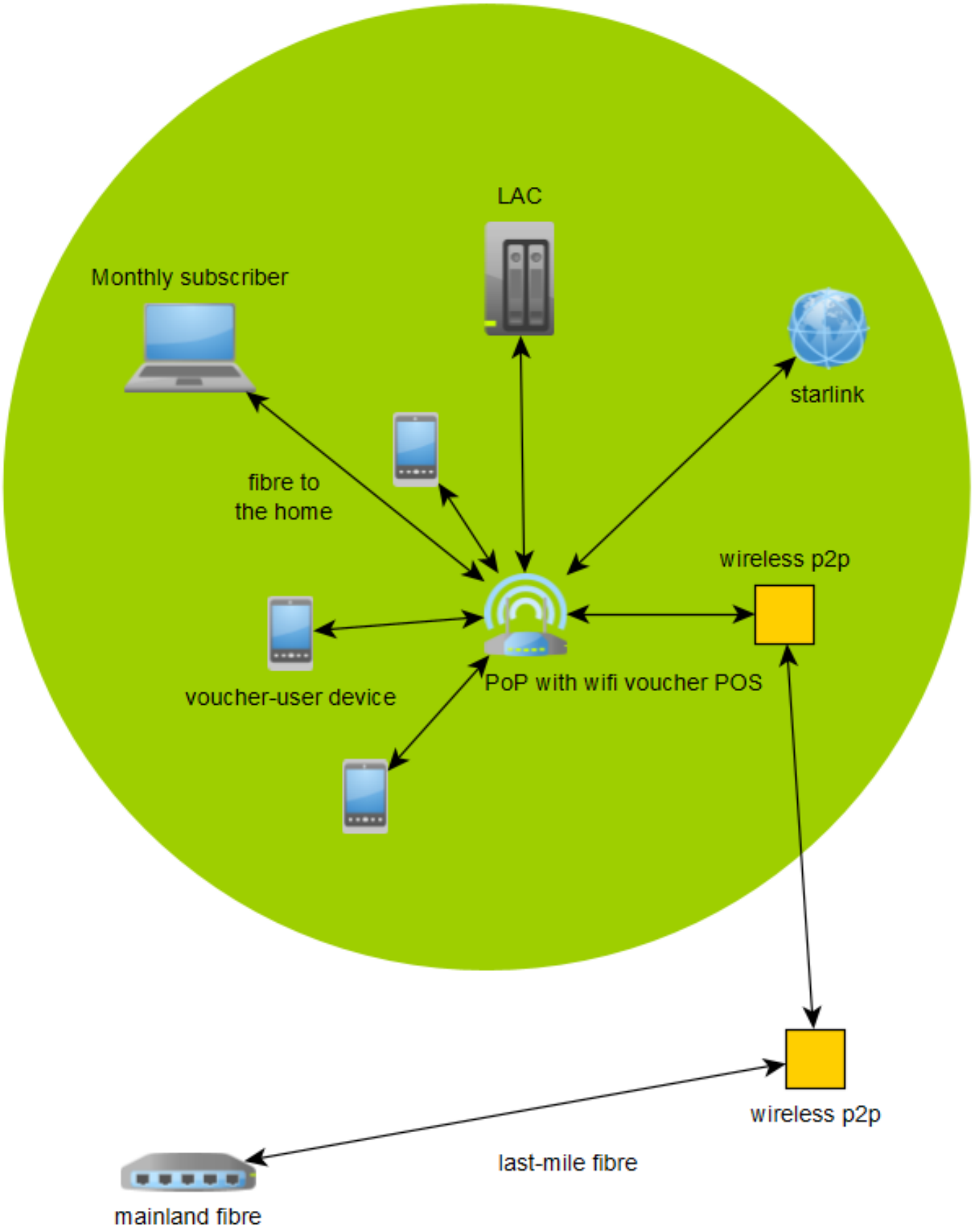


Measuring resilience in alternative network deployments

Anastasia Beasley, 2026

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This report was written on Boonwurrung land.
The fibres of this Internet are made from Yuuru people's white sand, the remnants of long-gone volcanos that are melted once more and drawn out in long strings to trace corridors of knowledge across the country.

Many thanks to the generous people who took the time to speak to me about their networks or proof-read this report.

Introduction

In an increasingly unpredictable operating environment, Australia's internet has plenty to learn from disaster-affected or resource-constrained networks. This report seeks a flexible framework for measuring resilience in alternative or community-centred networks, with the hope that it can eventually be used to compare the contribution of different factors to overall resilience.

The first section discusses the types of threats that affect community-centred networks in different contexts. The second section proposes using dynamic Bayesian networks as a flexible method for modelling resilience in those contexts.

Terminology

Alternative networks refers broadly to networks that *aren't* provided by a company whose main goal is to provide connectivity for profit. They could be operated by purpose-driven organisations who aim to close the digital divide, hobbyists, academics, or a users' co-operative.

Community networks are a subset of alternative networks, providing community-centred connectivity solutions by actively involving their members in operational decisions.



Installing school connection to the Local Access Cloud System (LACS) at Gilutongan Island (CVISNET 2022)

Goals

1. Map the operational factors contributing to resilience in alternative networks.

2. Determine whether the utility of including operational and contextual pressures in modelling resilience for alternative network deployments.

Method

This is a mixed-methods approach combining a literature review, interviews, and network simulation. The literature review includes academic articles, conference papers, blog posts from organisations like the Internet Society that support community networks, and RFCs.

Interviews included community network stakeholders from a range of contexts, largely not-for-profit organisations that have supported alternative network operators in many communities across their region. Network operators themselves have many competing demands on their time, so information about technical and operational challenges were sourced from Network Operator Group conference presentations and project reports.

The network simulation is an experiment in extending a common network modelling method to include contextual pressures that alter the capacities of a network's components. Contextual pressures for alternative network operators can include unreliable power or extreme weather, which makes equipment failure more likely.

Designing networks for meaningful connectivity

A **resilient** Internet is one that can continue providing meaningful connectivity despite the full range of challenges and difficult conditions its networks are experiencing.

Meaningful connectivity is achieved when users have affordable, consistent access to Internet services that meet their needs. The diversity of needs the Internet serves makes it impossible to measure resilience against one universal benchmark. Some users only need VoIP, which can be achieved with a 3G connection and a mobile phone, but studying online requires high-speed broadband and a computer with a keyboard (Aguiar 2025).

The following examples illustrate why factors like government policy, climate, and social capital should be included in network resilience modelling.

1. Community licenses

Kenya has an Internet Service Provider (ISP) license tier that's accessible for locally operated networks serving under-connected communities. They are able to engage with local leaders, set up infrastructure and develop a market for internet services where larger ISPs couldn't justify the cost.

Being locally owned and operated gives networks a competitive edge, because they can tailor their services to the needs of local industries. Aherinet's products accommodate inconsistent cash flow, as cheap as 2 hours on a public wi-fi hotspot for 20 shillings (about 22 Australian cents at the time of writing). They also offer packages of internet connection and software for landlords, medical clinics, sole traders, and students. Some packages include web hosting, domains, device setup and troubleshooting, and training opportunities (Aherinet 2026).

Community ISPs occasionally outgrow their licenses and become tier 3 or 2 ISPs – a more heavily regulated class of business. Larger ISPs may also enter the local market after a few years once the user base has been established. The goal of a community ISP is simply to provide internet access to more people. It's still considered successful if it exits when market competition grows or it's purchased by a larger ISP: the overall connectivity has still been resilient to changes in ownership and business structure without disrupting service.

2. Local content networks

Caching frequently-accessed content close to its users makes Internet access more affordable, faster, and less dependent on international connections. Some island communities can't rely on their mainland connection, let alone international ones, so anything important must be hosted on the island.

The Phillipines
Local Access Cloud (LAC) is a large-area wifi station attached to storage with some basic communication and bulletin board functions. In Gilutongan, this system hosts a Moodle instance for the local school to access learning materials online, even when connectivity to the global Internet isn't available.



Locally Accessible Cloud System for Disaster Resilience (Sakano, 2019)

Indonesia

The Internet of Things is sometimes more important than the World Wide Web. In Aceh, microclimate sensors send data to a local cloud processor that generates a dashboard. Weather in an archipelago is extremely localised and volatile, so having access to a national weather site would do nothing for climate resilience. For fishing and farming, locals need accurate real-time predictions based on local data to make strategic decisions.

Common Room Foundation, which deploys these networks with island communities, is committed to creating and sharing illustrated network operator handbooks in Indonesian. They provide in-depth training at deployment, so the people using the weather stations or smart reticulation are able to repair or reconfigure them as needed.



Installing a seawater monitor (Common Rooms 2025)

3. Mesh

Mesh networks are flexible and quick to deploy, though unpopular as long-term infrastructure. They're a decentralised form of network where users route traffic through each other to retrieve content from the Internet or communicate locally.

South Africa's Council for Scientific and Industrial Research (CSIR) and Canada's International Development Research Centre funded the First Mile First Inch (FMFI) program to set up intranets within communities that could be used to share the cost of backhaul. The FMFI program was geared towards lowest-cost infrastructure, so relied on cantennas (wi-fi antennas made from found materials like coffee tins) which were easy to build and could reach up to 5km (Wireless Africa 2007).

Although mesh is cheap and quick to set up, this type of network only works if nodes are always on. Power and backhaul were not cheap or reliable in the areas FMFI was implemented. There was a lack of education in the community about how mesh works, so it would often stop working when equipment was powered off. For example, the local school turned off the entire computer lab every night, which made a critical node of the mesh unavailable. The more often it stopped working, the more people gave up on using the internet and unplugged their nodes. By 2010, CSIR was describing its wireless mesh deployments in Pretoria, Mamelodi and Mpumalanga as experiments for research rather than community-owned connectivity solutions, but maintained that the community-owned mesh model was a solution to expensive internet (CSIR, 2010).

Community networks often fail at the end of the grant period that deployed them, so the Internet Society (ISOC) and OpenCellular sponsored iNethi to try a new economic model for a network in Ocean View. It locally hosts a marketplace with blockchain “vouchers” that can be used to exchange goods and services or buy more time on the network. It was noted in the initial community workshop that 80% of money earned in Ocean View is spent outside it, because there's a lack of food producers in the area. This was framed as a reason to deploy this network rather than a threat to its sustainability – a community currency won't circulate if there is nothing of value to trade. People in Ocean View do make valuable things like bags and jewellery, but it's an extremely impoverished area, so their buyers are outside the community (Imhoff Farm 2026). The voucher system was deployed in September 2023 and lasted until January 2024.

4. Entrepreneurship

A common model for community-centred connectivity solutions is to run an entrepreneurship program that trains someone in the community to operate a network as a small business.

In Kenya, Aherinet's experience shows that building local technical capacity is challenging because people often leave the village to pursue better opportunities once they have in-demand skills.

In India, the Digital Empowerment Foundation (DEF) has used a similar model to deploy hundreds of Community Information Resource Centres (CIRCs) as one-stop shops for everything that might require a device or internet connection.



Map of CIRC deployments in India (DEF 2024)

The key difference is that DEF runs targeted programs for older women (especially widows) or People With Disabilities. The layered discrimination that these groups face in regional India means they have limited mobility, and are extremely unlikely to move once they've set up a small business that provides financial independence and a meaningful role in the community.

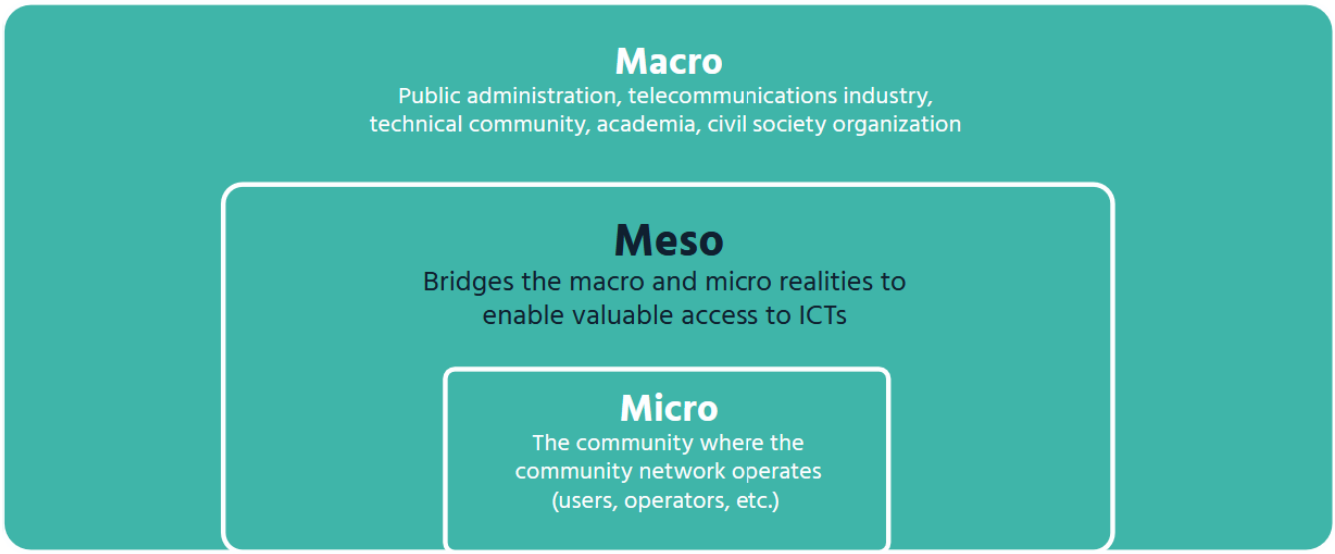
Established ways to measure resilience

The Internet Resilience Index is a composite indicator; the process of calculating it was developed by a panel of experts over many years.

Some of the metrics used by ISOC easily translate to small-scale alternative network deployments. For example, the percentage of the 1000 most frequently accessed websites that are cached locally could be calculated on a network level rather than a country level with access to outgoing request data. Upstream redundancy in the Index is the average number of providers a smaller network would be able to buy bandwidth from in the country, so on a network level, the actual number of available upstream providers can be used instead.

ISOC's Community Network Readiness Assessment Handbook was developed in collaboration with community network experts in Africa. It provides a comprehensive framework for calculating the social, political, legal, economic and technical viability of a proposed network, taking three “layers” of stakeholders into account.

ISOC's distinction between macro, meso and micro stakeholders speaks to the unique risks community network operators need to model in the planning stage. Networks funded by international aid and economic development programs are vulnerable to conflicting priorities between funding bodies and users. The companies selling internet to Australians would exist in the macro level of this framework, and the sustainability of the business is analysed in a different team from the network's resilience to disruption.



Three layers of stakeholders in community networks (De Tena et al. 2024)

In community-centred connectivity, deployment decisions are inseparable from product design, education, financial modelling, and weather. The techno-economic assessment in the Handbook creates a 2-year business plan, but doesn't provide a method for quantifying the valuable information about operational risks that is gathered in the community mapping phase.

A resilience study on the Wray Wireless Mesh Network in England mapped dependencies across layers of the Internet owned inside and outside the community, then used a classic operational risk matrix method to rank potential failures by their likely impact (Schöller et al. 2011). A cybersecurity study on power plants in the Republic of Korea (Shin et al. 2013) combined this approach with Bayesian network analysis to model how changes in the failure probability of one node alter the failure probabilities of its neighbours. These methods for measuring resilience are able to model interactions between physical risks (e.g. obstructed line-of-sight connection) and operational risks (e.g. lack of ongoing training for staff) by using a risk matrix to quantify the operational risks.

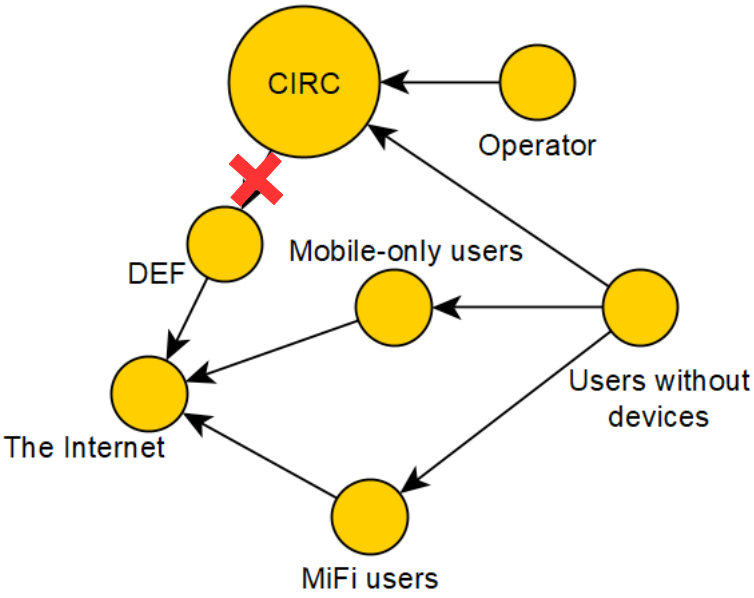
Modelling resilience in alternative networks

Bayesian networks offer a way to integrate qualitative risk assessments into the same model as hardware risks and dependencies (Shin et al. 2015). Unlike the country-level Resilience Index, this isn't optimised for comparison and ranking of large-scale networks. Instead, it ranks risks and their impacts against each other within a network, and operators use their domain expertise to choose which metrics need to be included in that calculation.

Value	Mitigation	Likelihood	Consequence
0.9	Very good	Very unlikely	Negligible
0.7	Good	Unlikely	Mild
0.5	Average	Possible	Significant
0.3	Bad	Likely	Grave
0.1	Very bad	Very likely	Catastrophic

A classic operational risk matrix showing lightening risk for a wireless network (own work)

The networks in this report are mostly connected by wireless towers, so they're often taken offline by lightning. Quantifying the impact of lightning damage on resilience using this matrix provides a structured way to estimate how often downtime will occur, for how long, and what the impact will be for this specific community of users.



Network graph of a disconnected CIRC (own work)

Simulating a lightning strike in a wireless network

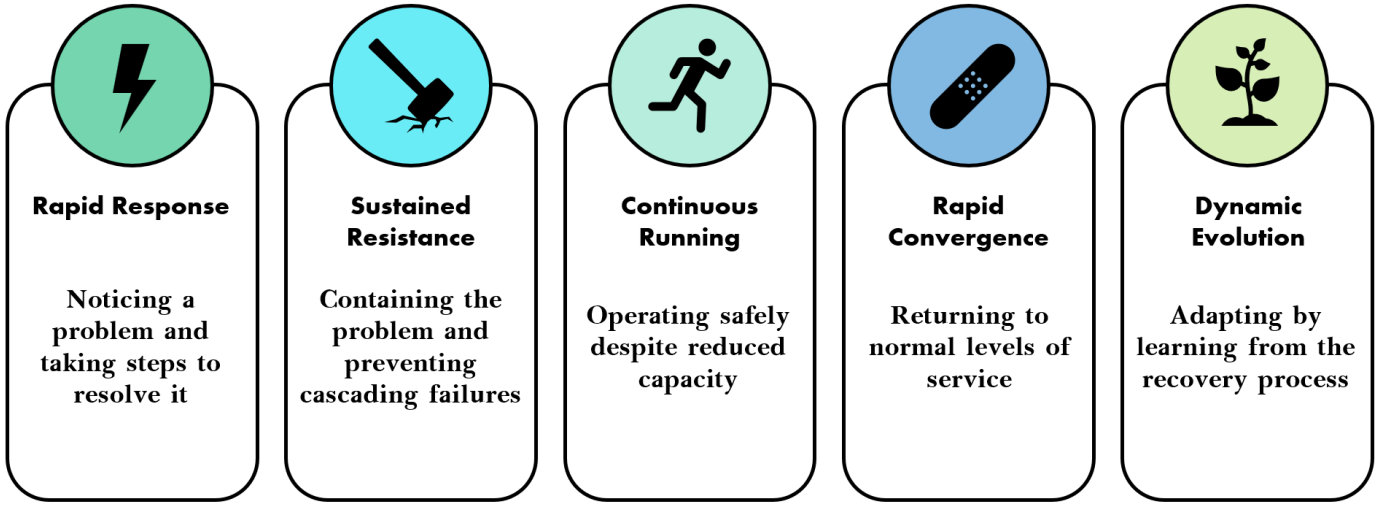
This example uses a simplified model of a CIRC, where the edge affected by lightning is marked in red.

Some users have ways to access the Internet without a CIRC. This is the only way to get equipment replaced, so it's important to assess the operator's capacity to effectively use those other links that provide backup when the main network is unavailable.

Jiang et. al (2021) created four capacities for each node that change over the network's recovery period. These can be expressed as values between 0 and 1 using the risk matrix.

- **Control**: ability to manage resources or routing across the whole network, not just immediate neighbours
- **Action**: ability to execute commands on its neighbours e.g. enforcing access authentication requirements or removing a node
- **Observation**: collecting timely and accurate data
- **Decision:** interpreting what the data means

Mapping these capabilities to each node produces a graph that can be used to simulate the network's behaviour under adverse conditions and evaluate its response against five criteria. In the Dynamic Bayesian model, the network will perform these capabilities sequentially from left to right, starting at the time of destruction (the lightning strike).



The five resilience performances of a network in recovery (own work, adapted from Jiang et al. 2021)

If a point-to-point antenna is destroyed, the CIRC modem would be the first to "notice" (high observation capacity), but it would be up to the operator to realise the cause was lightening and coordinate a response (decision and action). Purchasing and installing network equipment requires Internet connection, and the CIRC is offline, but the operator may be able to hotspot from 3G, make a phone call, or use a friend's MiFi (mobile wifi router).

Nodes' capacities also alter the behaviour of their neighbours. At the beginning, the operator node has high control capacity – the ability to effectively coordinate a recovery response across the network. When the lightning strikes, the operator's control capacity is diminished and distributed between the mobile-only and MiFi nodes.

Mobile connection requires a monthly subscription (top-up credit isn't easy to find in rural hamlets), whereas bandwidth from DEF is billed as it's consumed, making it much more accessible to low-income users. As a result, women's Internet connectivity in rural India is less resilient than men's because without a CIRC, they need to borrow devices or subscriber lines from male family members who may restrict their usage to “protect” them (Ashraf 2025).

Understanding this context, we might expect a CIRC's dynamic evolution capability to be high. The operator develops stronger processes for recovery after each outage, which may increase rapid convergence capability. The sustained resistance and continuous running capabilities could be expected to remain low unless she diversifies her upstream suppliers, for example, by forming agreements with MiFi owners to temporarily connect the CIRC for a one-off fee in emergencies.

Conclusion and recommendations

Australia's urban internet is only beginning to feel the effects of climate change and inconsistent power supply. There is much to learn from the network operators on the front line of these issues, so it's important to have a flexible method for modelling network resilience which can take in different types of data.

Some of the research that went into this report will be shared with two Internet Research Task Force working groups. Global Access to Internet for All (GAIA) has an informational RFC from 2016 about the types of alternative network deployments, which can be updated with these new case studies.

Adaptive Resilience & Measurement for Operational Robustness (ARMOR) is in the process of refining their charter and scope to encourage the development of “human-centric” metrics while drawing the line at policy or human rights discussions. This research is a starting point for the group to discuss quantitative methods for modelling material constraints or political interference mechanisms (e.g compelled assistance) in their resilience measurement techniques.

Including operational factors in network simulation and resilience measurement creates a more complete picture. It highlights dependency loops, like power and internet, and invisible infrastructure, like the inverse relationship between social mobility and network resilience in entrepreneurship programs. Trust and collaboration in a community (social capital) is now included in Australia's resilience framework as the biggest single predictor of disaster recovery (Hanvin et al. 2025), and it may be useful to include it in network resilience frameworks as well.

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