Making networks resilient to climate change

White paper

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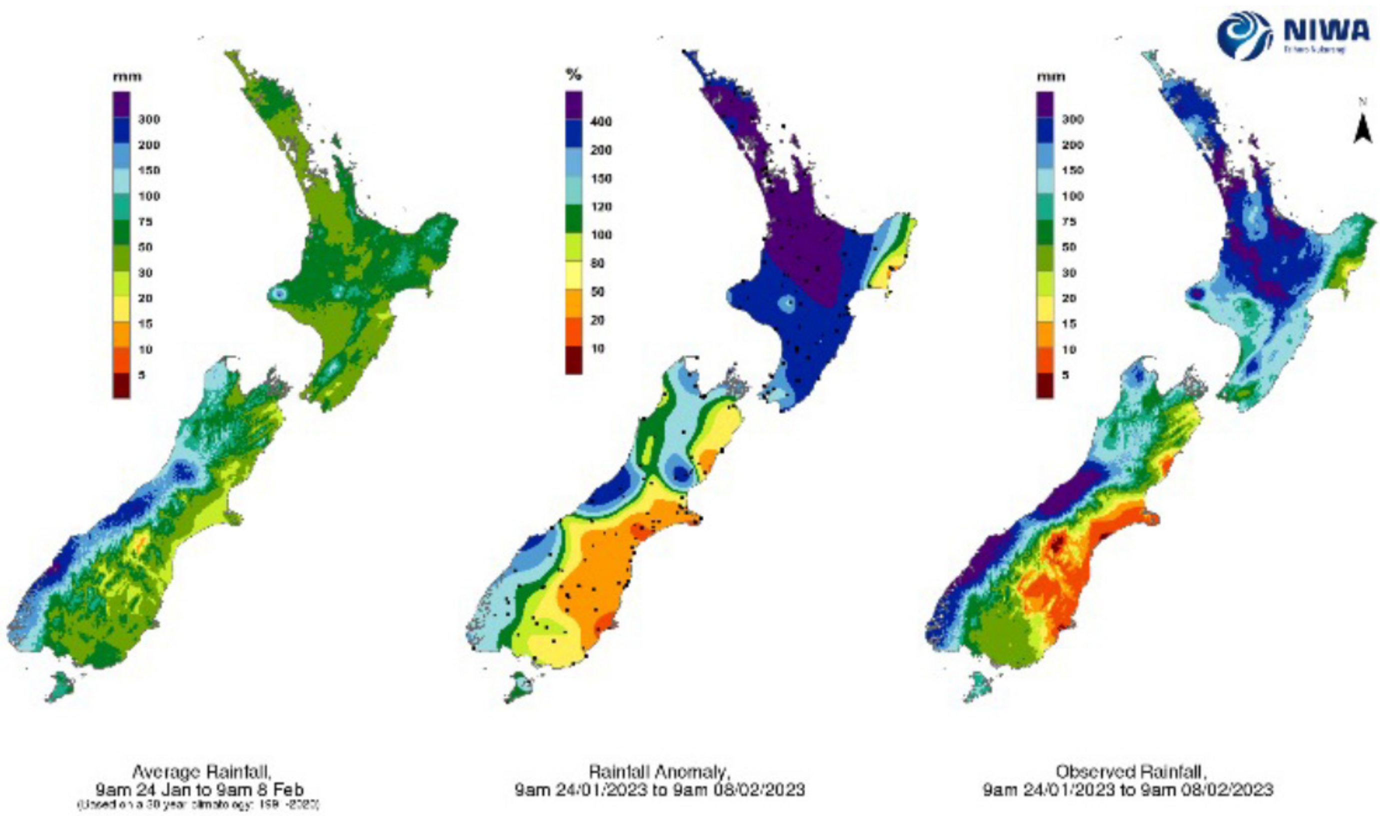
Climate change is presenting network operators with unprecedented physical network risks. Many networks were planned years ago based on climate data that had been relatively stable since measurements began. In the last decades, weather events have escalated to the point that those old standards are no longer valid. Network resiliency has become an issue as a result. Looking at recent events, including the New Zealand 2023 summer storms, we describe the kinds of issues that operators now face in these extreme events. As a way to learn from these experiences, we look at new approaches to network resilience in terms of design, engineering and restoration. To improve resilience we also examine existing and emerging technologies that can help in powering the network, providing alternatives for backhaul and transport networks, and upgrading network planning and risk modeling.

Introduction

Climate change is predicted to result in three specific kinds of events that impact on network availability: extreme weather, wildfire incidence, and extreme heat (and sometimes cold!) events.

On January 27th 2023, Auckland and much of northern New Zealand received more rainfall in a shorter period than had occurred in all of recorded history, causing severe flooding.

Figure 1. End of January 2023 rainfall event in New Zealand (Image: International Institute of Water and Atmospheric Research) [1].



This was followed only two weeks later by Severe Tropical Cyclone Gabrielle, which hammered the upper North Island, causing landslides and widespread flooding especially in the Hawke's Bay region. People died in the floods, and communities were cut off with no communications or road access for extended periods.

The loss of communication capability, especially to emergency services was the most visible issue, but there were many other less obvious impacts such as ATM and point of sale terminals not able to communicate and purchases by electronic means disabled including purchases at gas pumps.

Figure 2. Feb 2023 Flooding In Wairoa District, NZ (Image: Wairoa Civil Defense) [2].

These extreme weather events were worsened by climate change, with the warmer atmosphere accumulating more water and increasing the frequency and intensity of downpours [3]. Effectively, historical records on expected climate events such as rain intensity, flood risk and windspeeds are now much less useful for anticipating the future.

A further effect observed in the Northern Hemisphere is the impact of climate change on the jetstream, with slowing of the usual west to east weather transitions, or even stationary weather systems, resulting in one area receiving unusually heavy rainfall while an adjacent area is in drought.

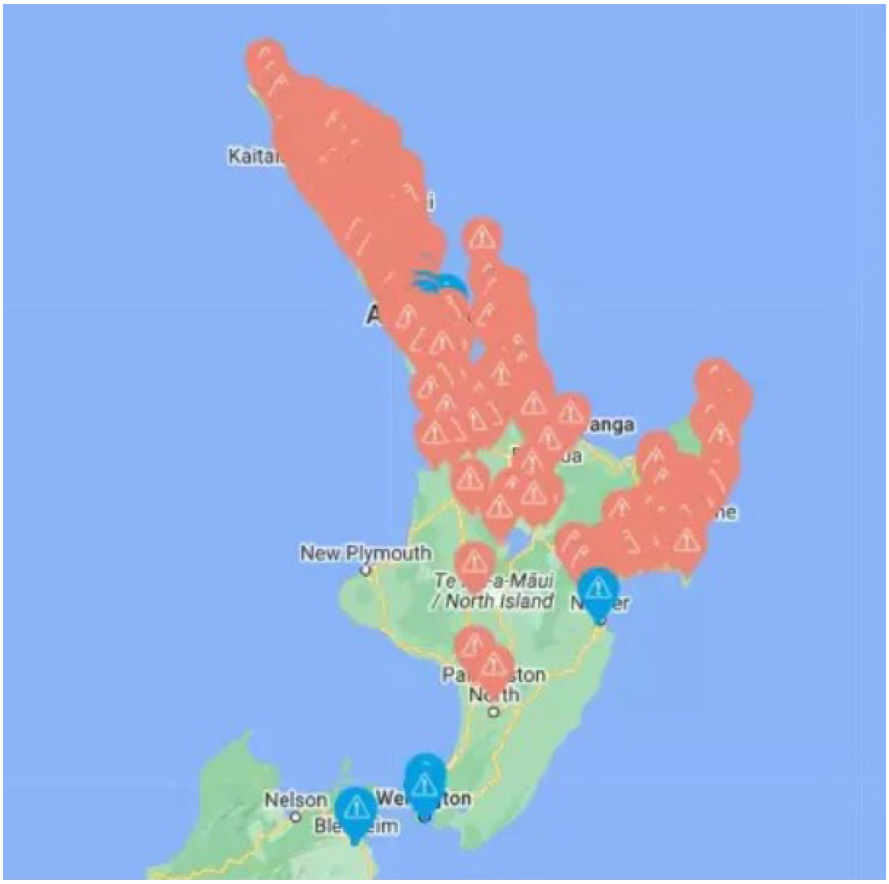
Impacts on telecommunications

There are significant impacts from these weather events on the telecommunication system, which is especially problematic as it is most needed for critical emergency rescue response during these events. For the Jan/Feb 2023 weather in New Zealand, three types of failure were most significant in their impact: power infrastructure, backhaul infrastructure and long-haul infrastructure.

Figure 3. Access to helicopters for repair and generator refueling competes with rescue activities

The power infrastructure, including substations in Hawke's Bay, was flooded and poles went down leading to loss of power for cell sites. The power outages lasted far longer than the available battery backup, so diesel generators were used to provide power for the most critical sites. In some cases, however, the diesel generators were stolen by locals desperate to get access to power, and in all cases, the generators had to be refueled. Due to many landslides and bridge outages, some of the cell sites were inaccessible by road, and helicopters had to be used to bring in fuel. A small generator needs refueling, sometimes as often as every seven hours. About 80% of cell site outages were due to power issues [4]. Only a few cell towers were blown over by the high winds. Power outages also impacted end-users, who, being without power had no way to recharge their cellphones. This was also true for backup low-earth orbit (LEO) satellite access equipment, which consumes on the order of 80W for a Starlink terminal.

Figure 4. Chorus provides the wholesale fiber infrastructure for much of New Zealand. The Chorus fiber outage map for 14 Feb 2023 is a sea of red outage markers (Image: Chorus screenshot as captured by Ben Moore, Businessdesk NZ) [5].



Backhaul fiber from cell sites was badly damaged by landslides, accounting for about 20% of cell site outages. In urban areas a cell out of commission can have its area covered by adjacent cells, but in rural areas the loss of a cell cannot be compensated for by other towers because they are too widely separated.

Long haul transport fiber was badly affected by landslides, with one major route being cut in 15 places, and another in 35 places. Fortunately, geographically diverse routes meant that these transport network outages had minor service impacts, but a very long restoration time during which the remaining infrastructure was vulnerable. Particularly at risk are bridges over major rivers, as these large bridges are often one of only a few crossing points. A bridge washout can take out multiple theoretically diverse fiber routes that all traverse that same bridge.

So, what happened in those areas that lost traditional networks? Some were simply unable to communicate. Some had partial communication service capability for a community via either very old technology, such as Ham radio operators! [6], or very new technology such as Starlink LEO satellite. Even with very low take-up rates, Starlink ran more slowly than usual as individual household Starlink terminals suddenly became the communications hub for an entire community, although performance could also have been adversely affected by the heavy rains, which obstruct the millimeter wave satellite signals. It is common in disaster events for there to be exceptionally heavy communications traffic, as everybody wants to check in with family and friends; if the network is disrupted, that heavy traffic will persist and grow as repeat attempts add to the new load. By contrast, if at least minimal communications is retained, this surge quickly passes.

Although Cyclone Gabrielle caused huge ocean swells, this did not damage the international cable landing points, which nonetheless, have been identified as points of vulnerability for global network connectivity due to storm surges, rising seas and erosion [7]. The cables themselves can also be damaged, for example, by wave/current force sediment scouring or burying of cables (flooded rivers carrying sediment to the coast), and coastal erosion can be a risk to cable and transport regeneration sites.

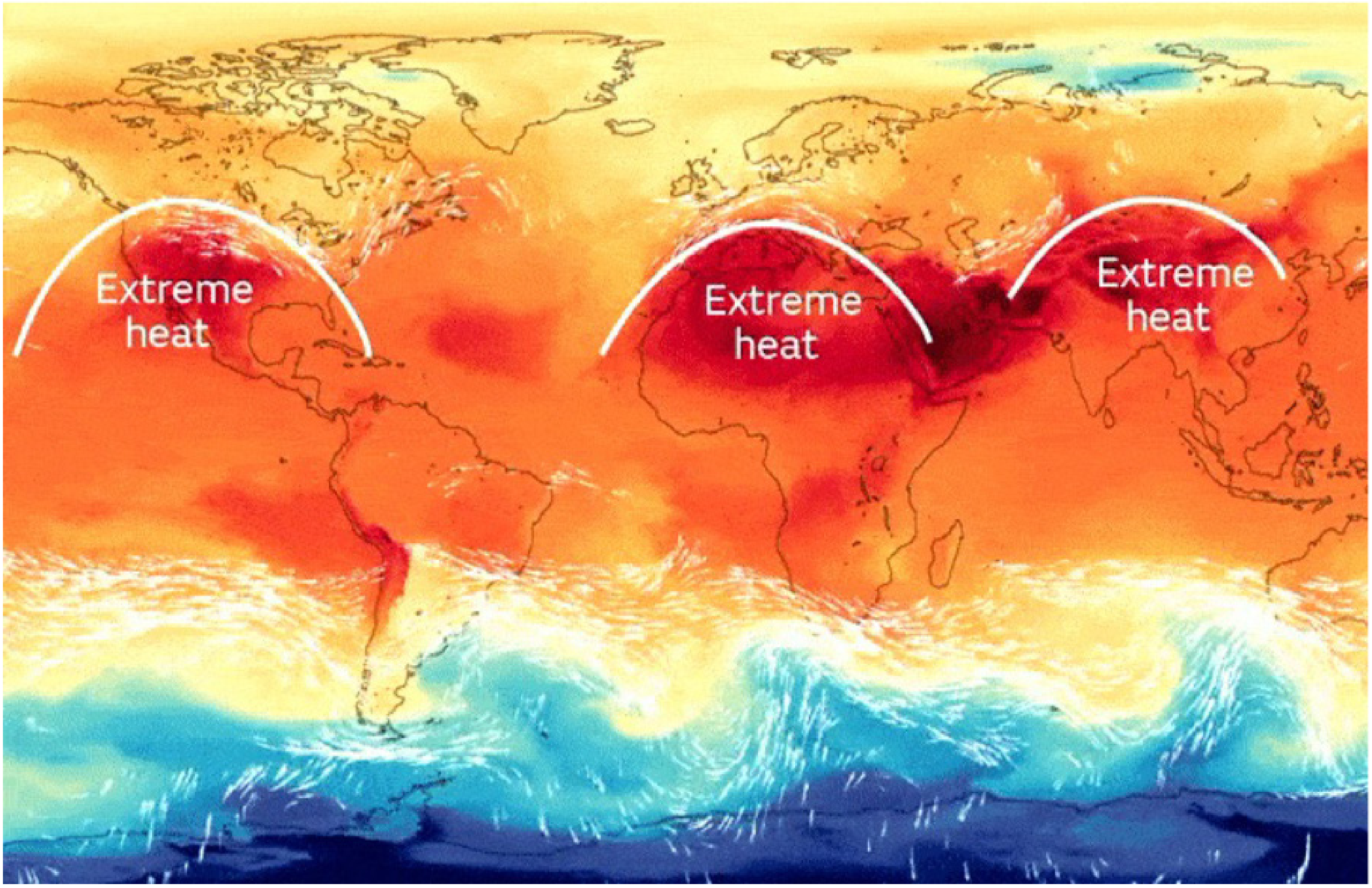
Of course many other global weather events have had far worse impact. When Hurricane Maria hit Puerto Rico in September 2017, it “destroyed 95.2% of cell sites and damaged internet and underwater cables so badly that many Puerto Ricans were left without cable or wireline service for more than a year after.”[8]

Figure 5. Aftermath of Hurricane Maria, Puerto Rico (Image: Roosevelt Skerrit, PDM 1.0 DEE)

Figure 6. Base Telecom employee assesses fiber optic cable damage after wildfire at Camp Pendleton, CA (Image: Sft. Luis Vega, Wikimedia Commons)

Meanwhile in other areas, it is the impact of climate change on increasing wildfires that is more of a concern. In British Columbia, Canada, 2023 was the most expensive and destructive year ever, with 2,217 fires burning 25,000 square kilometers, 84% more than the previous record set in 2018 [9]. Wildfires impact the telecommunications infrastructure in several different ways by destroying the power grid feeding cell sites by burning the wooden power poles, by burning the power and communication cables, and by burning the base station site infrastructure. Extreme heat can fuel wildfires but is also a more general issue, as power grid draw for air-conditioning causes brownouts and blackouts as well as equipment failure.

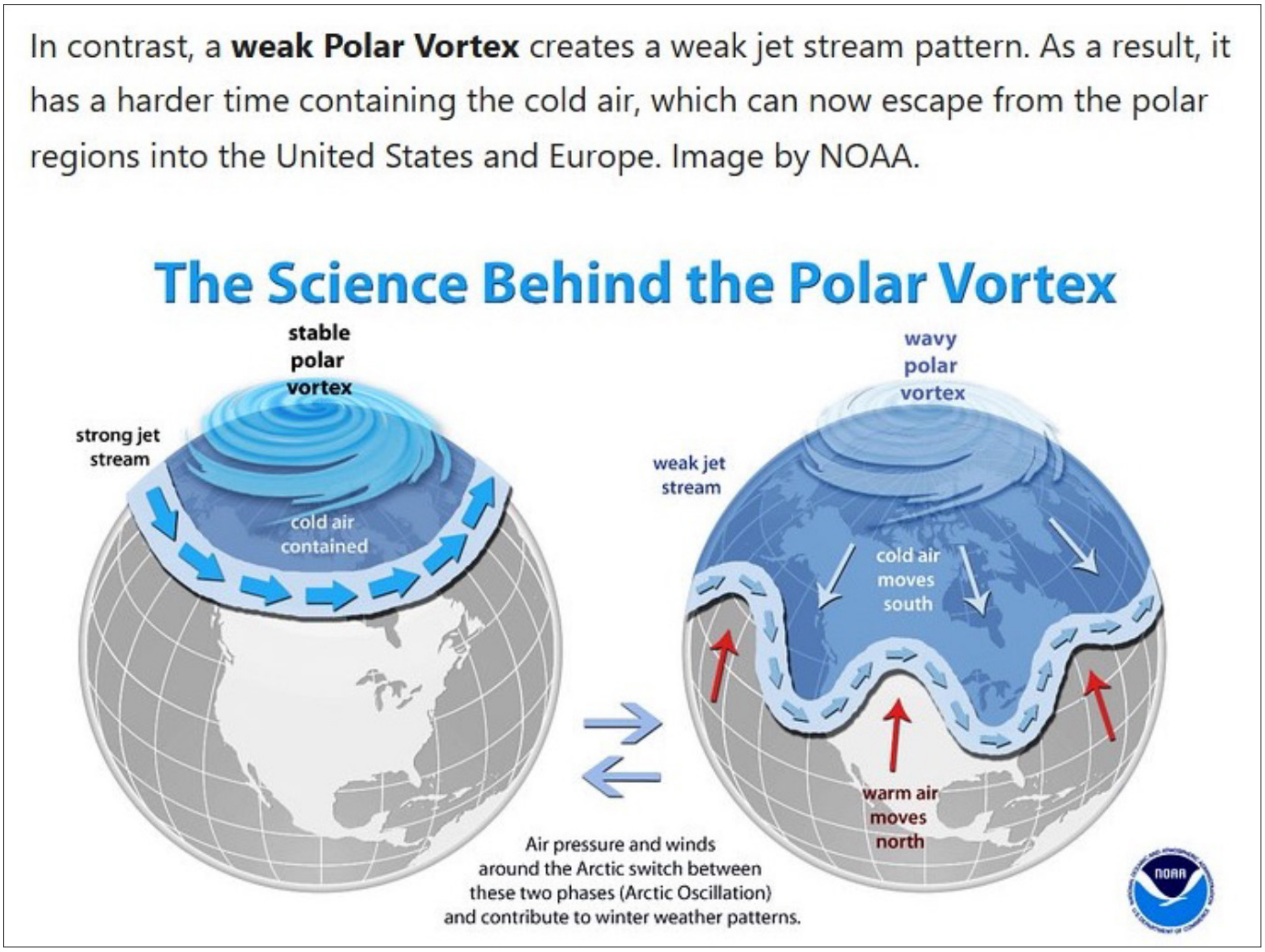
Figure 7. A stagnant polar jet stream on July 2023 trapped heat over parts of North America, Europe and Asia (Image: World map image with permission of the UK Met Office, cited in E360 Digest) [10].



In Sept 2022, Twitter lost a key data center in California due to an extreme heat wave that broke a 100-year temperature record [11], and Starlink satellite users lost service as their receiver dishes overheated [12]. Radio access network (RAN) equipment can also fail in extreme heat conditions, and the summer of 2023 was the hottest since records began in 1880 [13].

The opposite season can also be a problem. Climate change is making winter storms more intense, as a warmer atmosphere holds more moisture and this moisture eventually falls as rain, snow or, in the worst case, freezing rain, which is the most likely to knock out power lines [14]. Also as the northern Arctic warms, the temperature difference between the polar regions and the tropical regions decreases, which slows the polar jet stream and causes it to go further north and south. A southerly dip can cause extreme cold events (including blizzards) in areas that are unprepared [15].

Figure 8. How climate change creates unusual cold events
(Image: U.S. National Oceanic and Atmospheric Administration) [16].



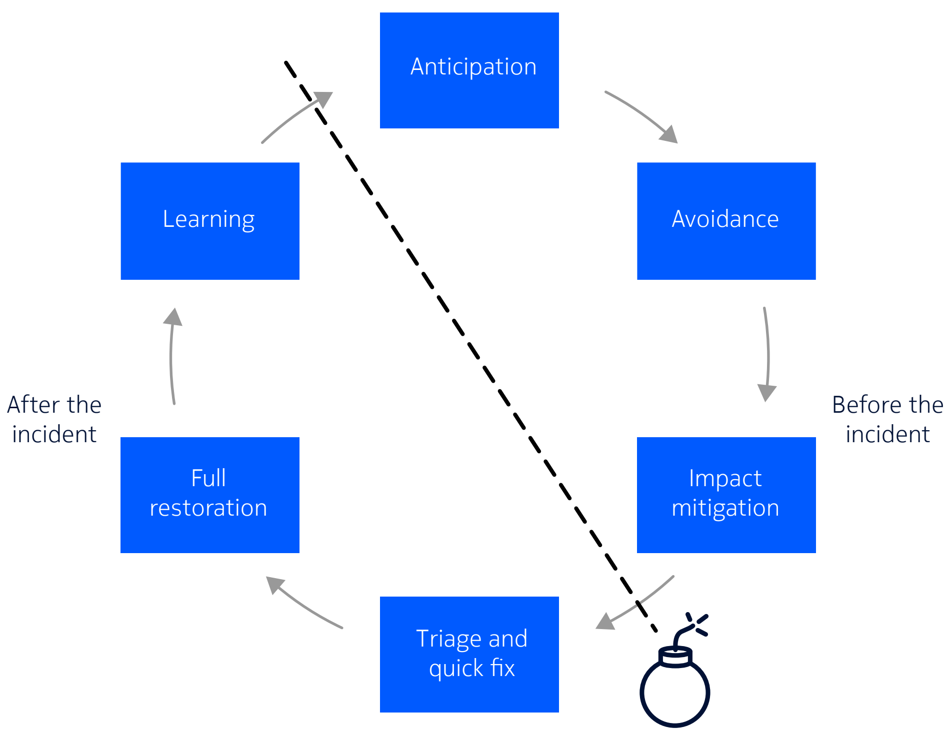
Climate-related failures are especially difficult to recover from because they tend to hit relatively wide regions resulting in many simultaneous failure events. Traditional models for planning network availability such as reliability block diagrams and Markov models generally assume failure event independence, which is far from the truth for many climate events. So, while the network and operational processes may have been designed to be resilient if, for instance, a single farmer plows through a fiber cable, are they resilient to hundreds of power and connectivity failure events occurring at the same time? How do you get the required number of staff on site across broken roads with failed gas pumps? How do you communicate with those staff when the networks are down? How do you coordinate across the many different companies involved in restoration (e.g., power, civil defense, network management centers, tower companies, and field work)?

The impact on operators from failure events can be substantial and includes loss of customers, damage to reputation and customer satisfaction, loss of revenue, cost to repair, and compensation to affected customers. Conversely, if you are the provider whose network kept going while others failed, customers will remember that.

What can be done to improve network resiliency?

Resiliency starts at the network architecture and organizational process stage. Mitigation of climate related risks is of course a part of a wider resiliency risk context which includes risks from earthquakes, volcanoes, tsunamis, and of course the non-physical threats such as cyber-security, network software and hosting reliablity, and risks from loss of GNSS satellite timing and sync signals. There is always a limited amount of money and an almost unlimited set of potential resiliency investments. The critical thing is to identify those changes and investments that provide the greatest gains for the least cost, and to invest to the level that the company is willing and able to support. Planning for resiliency and disaster recovery can seem overwhelming and hard to financially justify when you are mitigating risk from rare events. Many of Bell Labs Consulting engagements deal with identifying and prioritizing the potential resiliency actions that could be taken by a service provider. Many resiliency enhancing actions just involve change to past methods, procedures, and architecture choices at relatively low cost. There are six phases of resiliency planning and actions.

Figure 9. The six phases of resiliency planning and actions



1. **Anticipation.** While it is possible to learn from past events, given that the historical climate metrics are now obsolete, it is even better to use resiliency audits and simulations to anticipate the full spectrum of possible failure modes and their consequences. In the case of climate risks, many specific weather events such as cyclones can be predicted days in advance. Of course many resiliency risks will be tied to specific geographical circumstances and different operators will have different sets of risks and priorities such as tornadoes inland and tsunamis on the coasts.

2. **Avoidance.** Avoid the event ending up being service impacting if that is possible, typically by making the basic network design and architecture as robust as can be afforded. The International Telecommunication Union provides some useful design-for-resiliency guidelines including Supplement 35 to L Series [16]. For example, if there are land-based failure modes, construct an undersea cable around the problematic area. Also at a design level, plan for rapid restoration. For example, does your cell site have a place to plug in a generator and disconnect from the mains power? If not, you will need an electrician to switch to generator-based power backup. Can the cell site router be simply and locally reconfigured to use a temporary microwave backhaul link?
3. **Impact mitigation.** Mitigate the impact on customers at a design level so that failure events may damage full-service capability, but some minimal service capability is retained for as many customers as possible. Focusing on public safety, Cell Broadcast Distribution can get emergency messages out extremely quickly and reliably. In Alberta, Canada, in 2023, for example, there were 304 emergency alert messages including 150 wildfires, 20 flash floods, 15 thunderstorms and 109 tornados. Removing people from perilous situations through advance warning reduces public safety risks. A simple resiliency mechanism that is sometimes overlooked is simply to have a national roaming agreement in place in place, so that if one one operator's network is down, users may roam onto another operator.
4. **Triage and quick fix.** When a significant climate event occurs, the situation will be confused and dynamic. Expert skills are required to determine what actions can and should be taken in what order to restore the most critical services to the largest number of people. Next, restore as quickly as possible, typically with a 'quick fix' solution. This could be a LEO satellite or microwave radio backhaul deployed to a cell site, or even fiber optic cable strung quickly over treetops by helicopter. A quite dated set of guidelines that nevertheless still describes good principles is provided by ITU-T recommendation L.392 [17].
5. **Full Restoration.** Finally do the 'slow fix' permanent restoration.
6. **Learning.** The final phase is dissecting the experience to learn what worked and what didn't – what should be changed in engineering and design, and how event responses can be improved. Each of these phases is supported by design and analysis that balances the positive impact of a resiliency enhancing initiative (especially on public safety and welfare) against its cost.

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Before the storm: standard practices in engineering and design for resilience

The starting point for engineering is to attempt to avoid outage events altogether through such actions as:

- Building redundancy in physical infrastructure: geo-diverse fiber routes, diverse site power feeding, geo-diverse central sites, ladder or mesh routing with automated rerouting, and no single points of failure
- Increasing the environmental hardening requirement specifications of outdoor equipment such as allowable environment temperatures
- Design of cell towers for higher maximum wind load and regular inspection
- Relocation of equipment away from flood zones, shorelines and landslide risk areas.

The engineering for restoration must be done in advance. For example, if you want to use LEO backhaul to temporarily replace a lost fiber link, this must be tested and configured in advance.

Engineering should also use site-specific resiliency planning, identifying critical sites that are at higher risk, have a higher impact from an outage or are more difficult to restore. These should be designed to achieve a higher standard of robustness and resiliency. Standards of resiliency must also be maintained over time, for example, as 5G radios are added to a cell site, it will increase the energy draw, and therefore reduce the backup energy period unless additional batteries are added.

Engineering for resiliency should be a continual learning process that begins long before events by assessing network resiliency through audits and follow-ups post-event with post-mortems to identify opportunities for improvement.

Emergency response plans should be coordinated with government agencies and local communities and cooperation/infrastructure sharing agreements with other operators (e.g., roaming) in the event of an operator-specific outage event

Other engineering aspects of design for resilience include:

- Hardening of physical premises against flooding, high winds, and fires
- Removal of vegetation surrounding sites and maintenance of access roads.

During and after the storm: standard processes for rapid service restoration

As part of the "before storm" preparation process, it is critical that you design "during and after the storm" standard restoration processes that have been planned in advance and tested. It should cover even the smallest details, such as whether or not the cell-on-pallet you plan to take to a downed cell site has a size and weight that allows it to be carried by the available helicopters? Here is a starting list of the restoration processes you need to consider:

- A process for management of the restoration process including keeping senior management in the loop but not in the way of those doing the restoration. Typically, all key staff concerned both in the field and at management level need satellite phones/data links. Roles and responsibilities need to be clearly defined, with backup personnel if the primary are unavailable.
- Make sure that you have the right staff with the right skills within reach of the places you may need to restore. And those skills must be maintained over time as you change personnel and equipment providers. Or can you simplify the restoration process sufficiently that specialized skills are not required?[1]
- Have all equipment and spares and materials that are required for the restoration readily accessible, preconfigured into working packages, and ready to deploy at decentralized sites within easy reach of the areas that may be affected.
- Periodically practice restoration practices, with live 'fire drills'.
- Pre-position generators, batteries, and fuel at sites that are either at risk or are especially critical. Preplacement of generators and fuel is determined by a combination of risk (e.g., hurricane prevalence) and impact (criticality of the site).
- Cells-on-wheels (COWs, truck pulled) and cells-on-pallet (COPs, helicopter or truck delivered) can be used to provide fast temporary service where a cell site has been badly damaged and will take some time to restore. These can be pre-positioned to areas where risk is forecasted depending on site criticality.
- Centralized buildings may have 1+1 generator sets, tested weekly, with warmed oil supply, and oil tankers may be parked on site when supply is at risk.
- Have some means of getting to sites, or at least a plan to quickly secure access to such vehicles. This may be 4WD vehicles, helicopters and boats, for example.

1 In New Zealand, restoration processes were assisted by people in the local rural communities such as farmers. People in the community have a strong vested interest in assisting with service restoration, but for them to safely assist restoration processes must be 'plug and play'.

Going beyond standard resiliency

These traditional resiliency solutions may not prove sufficient for the challenges of climate change, in large part because the current engineering design rules were based on environmental assumptions that are no longer true, and we don't know yet what the new conditions will be. The backup batteries on cell sites were designed for short duration outages such as those caused by a single point power failure, for example, due to a brownout or fallen tree. Cyclone Gabrielle took out 470 cell sites in less than 24 hours [19].

Widespread weather events can take days to restore power to the most critical sites and weeks to fully repair. When a derecho (widespread, long-lived, straight-line wind storm) hit Ontario, Canada, on 21 May 2022, it knocked down 1,900 power poles in nine hours [20]. Full power restoration took weeks.

Powering cell sites during grid power failure

Providing long duration, permanently in place, backup power to cell sites is an extremely expensive proposition. Costs can be mitigated by being selective in both which sites are backed up and how they are backed up. In urban areas, it is possible to plan which sites will have long-duration power backup and which will not be backed up but get coverage from nearby long-duration backed-up sites. This process usually starts with planning for long-duration backup for cell sites that cover hospital, civil defense shelters, police, and ambulance sites. This prioritization allows a longer duration of backup power availability for any given level of investment. This does not generally occur today and, for optimal effect, requires that the antenna tilt angle be adjusted during the failure event (tilt up) to extend the coverage area of sites that will remain in service due to their extended backup power.

One option to improve the cost vs. protection capability of the battery backups is to leverage time-of-day power pricing. This would work as follows: when the forecast is for no or low risk of a weather event, battery capacity at cell sites is used to decrease the site power load drawn from the grid during high power price periods of the day, or even sell power back to the grid. Many utilities are building BESS's (Battery Energy Storage Systems) for exactly this supply/load balancing reason – why not put them next to cell sites where they can do double duty, increasing resiliency to failures of grid power? However, when the forecast is for a risk of a weather event, the batteries are topped up and held at maximum.

It is also possible to have a fleet of backup generators and fuel on wheels that can be trucked into cell sites when an extreme weather event is forecast and shuffled around regionally in response to weather forecasts.

Figure 10. Local solar and wind production can be used to charge batteries for base stations

Local solar or wind generation can be used to charge the batteries with a more desirable environmental footprint, but the cost effectiveness of this is location dependent and frequently unattractive. Solar powering can be ineffective in higher latitudes during winter due to reduced insolation and snow cover, and the viability of wind powering is location specific. Many types of wind power generators must shut down during high winds, limiting their utility during extreme weather events. In general, local generation also requires increasing the size (and cost) of battery reserves and is most appropriate to protect against very long duration outage events. Nonetheless, the economics and efficiency of solar, wind and battery power are constantly improving, and for new cell site construction in remote areas where the costs of running power to the sites are considerable, off-grid local generation should be actively considered where wind and/or isolation can be relied on — as long as the risks posed by intermittency (excessive cloud cover, too little or too much wind) can be mitigated.

Pruning the power consumption of the site allows longer running with a given quantity of backup power, for instance, turning off the high-band TDD 5G carriers whose mMIMO radios consume the most power and leaving on the low band FDD carriers that have the best reach. This can be tuned by the operator based on the nature of the outage and the expected time to repair: for outages expected to be repaired quickly, leave all the carriers turned on; for long duration events, move quickly into power saving mode. Such power load pruning techniques may require changes at the cell site to enable remote management and cell hibernation on loss of backhaul, as well as the ability to continuously monitor battery condition and charging. It is also possible to configure the RAN to conserve power at the user end. Bell Labs Consulting has been engaged to assist in the construction of the complex strategy required both for pre-incident planning (e.g., how much backup for which site) and incident-in-progress management (e.g., constraining RAN energy use).

Selective site backup and power pruning measures suddenly change the normal load/capacity balance of the network. Turning off intermediate sites puts more load on the remaining sites, and turning off carriers removes network capacity. This creates a secondary problem: how to prevent severe performance issues due to overloading. Plain old telephone systems know how to give priority to emergency voice calls over other call types, but as communications transition to IP there is no simple way to tell the difference between a tweet signaling a user trapped on a roof by flooding and someone sharing a picture of their cat. The edges of the network are not typically smart enough to do anything like deep packet inspection to distinguish traffic types, and encryption makes it impossible to know the content of traffic. So, what to do when disaster strikes?

- Give priority to voice and messaging traffic. Where 3G still exists, this can be made the restoration priority, but in LTE and 5G, priority and resource reservation can be used to assure voice and messaging priority, e.g., wireless priority services (WPS) in the US.
- Block traffic at network ingress points[2] for capacity limited areas to all streaming entertainment video and all online gaming traffic (cat videos and Fortnite can wait[3]).
- As 5G network slicing is introduced with the 5G SA core network, it is possible to prioritize traffic from different applications to better optimize resources. Assuming that there are one or more lowband 5G carriers, the URSP protocol can be used to map specific applications into specific slices with different priority settings, reserved capacity, guaranteed performance, and differential drop priorities. For example, emergency voice calls could be handled by a first priority slice, messaging traffic[4] in a second priority slice — making sure that emergency response is messaging capable! A third priority slice could be dedicated to NB-IoT traffic to keep ATM machines, POS terminals, fuel pumps, and fire alarms working. Everything else could be assigned to a best-effort fourth priority slice. Remember, however, that resiliency may be best served by conserving site energy reserves by turning off higher band 5G access. Also resiliency measures which only exist in 5G will not be accessible from some devices, and in some cases 5G coverage may be less than that of LTE. The bottom line, build resiliency into both LTE and 5G. And be sure to consult with partners and stakeholders, especially civil defense and emergency services, on the planned traffic prioritization.

2 This requires filtering at the mobile packet core (LTE PGW or 5G UPF) of packets with source/destination addresses ranges of the video/gaming servers, ideally only for the GTP tunnels that terminate at capacity limited cells. This may require coordination with the providers of these services to ensure that requests do not simply revert to a more distant server.

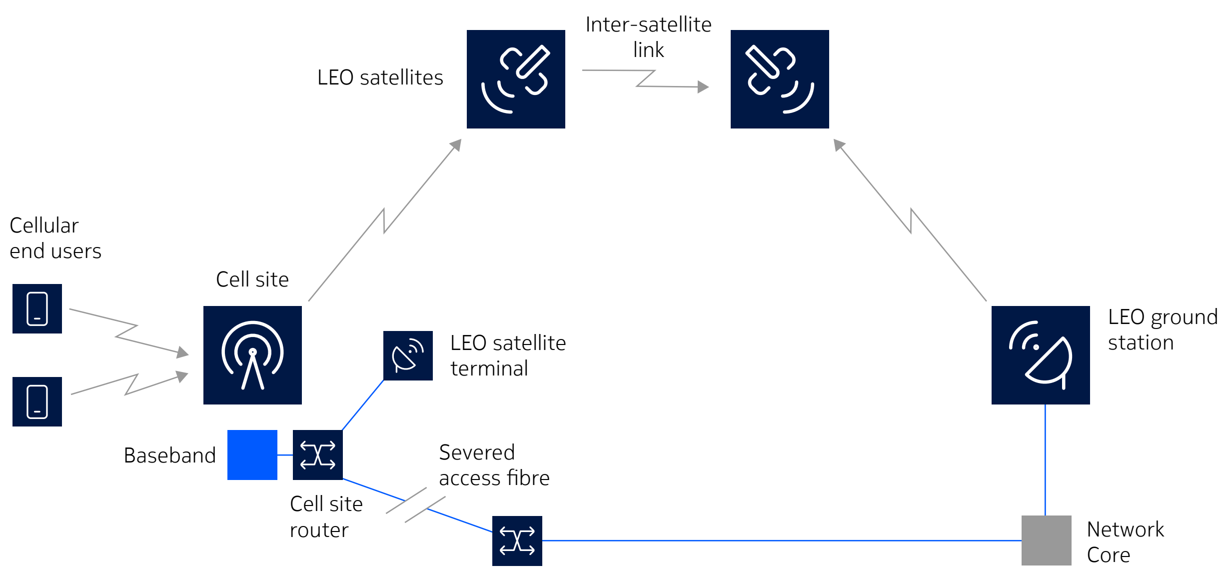
3 Note that it is very important during the restoration process to bring sites and traffic types back on line gradually, so as to avoid signaling storms from overwhelming the core network. Light up a new area and give it a few hours for the traffic surge to pass before lighting up the next area.

4 Even small amounts of cellular capacity are sufficient to carry large amounts of messaging traffic.

New approaches to protection of backhaul and transport

After power management the next most important issue is backhaul/transport fiber availability. Microwave is the traditional backup mechanism for fiber backhaul. Microwave is increasingly out of favor as capacity and performance favor fiber, but under reduced capacity conditions at the air interface (as we contemplate pruned power load), a relatively low-capacity microwave link may still be good enough. Operators who are bringing fiber to a cell site previously served by microwave may want to leave the microwave in place as a backup. However, this isn't a foolproof backup solution; intermediate microwave relay points may not have power. Microwave is also possible as a quick temporary fix solution.

Figure 11. LEO Satellite as a backup to terrestrial backhaul



An emerging option is low earth orbit satellites (LEO), which have been popularized in the consumer space by Starlink. In this context, however, we are thinking of LEO as a backup backhaul technology from a cell site to the core network. A LEO service overcomes many of the traditional weaknesses of GEO satellites, which were low capacity, low throughput, and created long latencies. However, they still have the traditional microwave issue of reduced performance or failure during heavy rain or snow due to signal blockage. This means that they may be less useful during an extreme rain/snow events but can help in the post event recovery. For network providers with LEO satellite ground units at critical cell sites, it would be optimal if the LEO provider offers an emergency capacity option, which only charges the network provider for usage. Under normal conditions a small trickle of traffic could be used to verify that everything is alive, but under backhaul failure conditions, the LEO link picks up the priority-only traffic.

This requires some architectural adjustments, as the core network must be ready to receive LEO satellite-based backhaul and you must assure that LEO ground stations are connected to the core network. Give the reduced capacity of the LEO relative to normal fiber backhaul, you may also need to implement priority traffic management schemes such as the slicing solution discussed above. Spark NZ announced in November 2023 that they have started the rollout of temporary satellite backhaul terminals for deployment to cell sites that have lost fiber connectivity.

Alternatively, a bargain basement rural backup solution disjoint from the public network would be a Starlink or similar service with a public Wifi access point and a backup battery/generator automatically enabled in the event of public cellular network outage. It could be located at key rural community gathering points such as a civil defense post, community center, grocery store, or gas station.

Figure 12. A Starlink terminal being used as a community communications hub in Kupiansk after the Russian Occupation in 2022 (Image: Віталій Носач / РБК-Україна from Wikimedia Commons)

Ultimately end users can also use LEO links, either from a fixed terminal like Starlink, or with new phones that can send and receive direct emergency messaging. The new iPhones support direct to satellite SoS messaging, and other phone and LEO satellite providers such as SpaceX, Lynk and Kuiper will soon follow suit. This will establish a growing population of users with direct emergency messaging capability independent of the terrestrial network, provided that satellite earth stations are still operational and connected to emergency response staff. Many LEO providers also plan to expand beyond emergency only messaging to more general purpose messaging direct to device, and even voice.

LEO satellite equipped phones are also an asset for communication service providers' operational staff as they conduct repairs in areas where the network is out of service. LEOs could also, with more difficulty from a network engineering perspective, be used to backup critical fiber transport routes that may be at risk from landslides or bridge failures.

Figure 13. AT&T contractors carry a "Cell on Wings" Drone
(Image: SSgt Charlye Alonso, Defense Visual Information Service)

Drone technology can also be used to improve service restoration time and service outage impact mitigation. This takes three forms:

1. The use of drones to survey and assess damage and therefore triage and determine the best restoration plan
2. Delivery of lightweight critical supplies into cut off areas, which could include batteries to power end user communications equipment or satellite phones
3. The use of tethered drones as temporary cell towers, carrying an RRH/RU and antenna up at height, with power and communications coming from a cable down to a ground-based unit. This would typically be to provide less than three kilometers of coverage. AT&T used such 'Flying COWs" (Cell On Wheels/Wings) to provide fast recovery from hurricanes Maria, Michael and Ida [21].

Simulation-based anticipation of failure mode

Network resiliency begins far before the outage event with planning. A new tool in that planning is constructing digital twins of the network. The digital twin is an analog to the real network that has fidelity to how the real network will perform. Because it is a simulation, it allows failure scenarios to be tested and planned for that have never been seen in the live network or can never be tested in the live network.

The digital twin can help map the usually physical network-driven outages resulting from climate risks into secondary failure modes. For example, a particularly common failure mode is cascading control plane overload. This usually starts with a physical or logical transport failure, which interrupts traffic on some significant route. When the transport is restored, there is a sudden flood of connection or session initiation requests. In some cases, this flood overwhelms the capacity of the control plane and many requests are denied, which results in retransmission events that increase the flood volume, sometimes resulting in catastrophic outages.

In other cases, mechanisms built into the control plane to detect and mitigate denial of service (DoS) attacks interpret the flood as DoS and discard the traffic, thereby denying legitimate service requests. This is the kind of thing that the digital twin can test for. The simulation can try a ‘rupture and restore’ on simulated fiber connectivity to see whether the resultant control plane load exceeds the capacity of the systems hosting those control planes.

Digital twins can also help build the business case for resiliency enhancing measures. By quantifying the significance of potential failure events, they can help value avoidance or impact mitigation measures.

Summary

Network operators are facing unprecedented physical network risks due to climate change. The design rules with which networks were planned years ago are no longer valid. However, in addition to revising network planning and operational practices to match the new reality, there are emerging technologies that also present new means of meeting these challenges, including smart planning and management of the network, power management technologies, LEO satellites, and drones.

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About the author

Jonathan Segel is a Partner with Bell Labs Consulting, located in Ottawa, Canada. His main areas of interest are wireless networks, technologies, and new services. He leads mobile service provider consulting engagements around the globe, balancing the business, customer, and technological dimensions of change. Before joining the Bell Labs Global Consulting practice in 2018 his experience included 16 years designing and delivering telecommunication services with Telecom New Zealand and 15 years developing new telecommunication products within Alcatel/Lucent/Nokia. Recent work in addition to resiliency includes developing strategy for emerging 5G B2B services and network slicing, establishing vRAN/cRAN/O-RAN plans and prospect assessments, Fixed wireless and mmWave strategies, and technoeconomic modelling/simulation of future RAN networks. Jonathan is an MBA graduate of Queen’s University (Summa Cum Laude), and P.Eng. (Electrical). He holds 15 patents, and has won a Nokia product innovation award, an Award of Excellence, and was a Distinguished Member of the former Alcatel-Lucent Technical Academy.

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Abbreviations

COW	Cell on wheels/wings
DoS	Denial of service
FDD	Frequency division duplex
LEO	Low-earth orbit (satellite)
mMIMO	Massive multiple-input, multiple-output
RAN	Radio access network
RRH	Remote radio head
RU	Radio unit
TDD	Time division duplex
WPS	Wireless priority services

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