IOWN GLOBAL FORUM

From Redundancy to Agility: A New Paradigm of Network Resilience

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Contents

1. Introduction **4**
2. Conventional Approaches and Gaps **5**
2.1 Conventional Approaches to Achieving Resilience 5
2.2 Environmental Change 5
2.3 Examples of Potential Risks 5
2.3.1 Simultaneous Multi-Location Attack on Paris Olympic Network 5
2.3.2 Submarine Cable Failure and Communication Resilience in Taiwan's Outlying Islands 6
2.3.3 Submarine Cables Face Increasing Threats 6
3. Requirements for Enhanced Resilience **7**
3.1 Multi-Route / Redundant Architecture 7
3.2 Rapid Detection and Switching Capability 7
3.3 Multi-Operator Coordination and Rapid Service Restoration 7
3.4 Multistakeholder Dialogues and Collaborations for Resilient Submarine Cable Systems 7
3.5 Geographic and Supply Chain Diversification 8
3.6 Alternative Channels and Technical Contingency Plans 8
3.7 Disaster and Risk Planning 8
4. Enhanced Resilience for Open APN **9**
4.1 Support of Open APN 9
4.1.1 Multi-Route / Redundant Architecture 9
4.1.2 Rapid Detection and Switching Capability 9
4.1.3 Multi-Operator Coordination and Rapid Service Restoration 10
4.1.4 Supply Chain Diversification 10
4.1.5 Alternative Channels and Technical Contingency Plans 10
4.1.6 Disaster and Risk Planning 10
4.2 Examples of technical challenges 10
4.2.1 Agile Resilience in Optical Networks to Overcome Unpredictable Disasters 10
4.2.2 Submarine Cable Deep-Ocean Observation of Mega-Thrust Earthquake and Tsunami 11
4.2.3 Flexible Spectrum Sharing Services 12
5. Further Study **13**
6. Conclusion **14**
References **15**
History **17**

1. Introduction

In the modern digital economy, network operators – including ISPs, international transmission service providers, and content delivery networks - face increasing requirements for network resilience. Network resilience is defined here as the ability to maintain continuity and quality, and to recover rapidly from failures, human interference, or natural disasters. Historically, conventional transmission networks were designed to withstand predictable disasters from historical data and failures caused by operational errors. These approaches implicitly assume that traffic demand, facility location and disaster scenarios can be predicted with reasonable accuracy.

However, in recent years, the dominant type of service, climatic conditions, and geopolitical risks have undergone significant change, undermining the validity of the conventional assumptions of predictable traffic demand, facility locations and natural disaster effects. Climate change due to global warming has led to unprecedented events, including floods and wildfires that cannot be explained by historical data [Grant]. In parallel, growing global awareness of potential risks facing infrastructure, including those related to military activities, which can co-occur in multiple locations [Blooming], necessitates considering human-induced disruptions in addition to natural disasters. These emerging factors highlight the necessity of rethinking resilience approaches that rely on assumptions of predictability. Under such changes, it is frequently required to emergently respond to unpredictable events like large-scale natural disasters and human interferences – purposeful or accidental. Therefore, new concepts for improving reliability are required, including not only pre-disaster design for comprehensive redundancy, but also dynamic agility of post-disaster recovery with cooperation among operators. It is essential to aggregate available resources that remain unaffected by the disaster and dynamically interconnect them to restore services quickly. Moreover, as the scale of disasters grows, there is no guarantee that a single operator can secure the necessary resources for rapid recovery.

Conventional architectures address these challenges through pre-provisioned redundancy and predefined restoration protocols – mechanisms that assume bounded failure scenarios and single-operator control. The Open APN offers a capability that goes beyond this: the ability to dynamically establish authenticated optical paths across infrastructure borrowed from other operators, without prior bilateral configuration, using open and standardized control interfaces. This enables post-disaster recovery at a speed and scale that single-operator, pre-configured protection schemes cannot achieve. The current Open APN Functional Architecture document version 3 [APN FA] does not explicitly address resilience in this context. This white paper establishes that the Open APN can meet enhanced resilience requirements, and identifies how this should be reflected in the architecture.
This white paper describes the following items:

- Examples of events requiring enhanced network resilience and shows that current methods are inadequate
- Requirements of enhanced network resilience and how the Open APN can implement them
- Additions and deeper topics for the Open APN architecture documents as further study items

2. Conventional Approaches and Gaps

2.1 Conventional Approaches to Achieving Resilience

Typical approaches to achieving resilience include:

- Enhancing reliability through redundancy.
- Securing critical communications via congestion control and prioritized routing.
- Enabling rapid restoration of services in accordance with predefined protocols.

These approaches typically rely on estimating the impact of disasters and operational errors using service demand from demographic and facility locations. The importance of each facility is identified along with resource availability as key inputs for network design and disaster response. Network designers and operators have implicitly assumed that traffic demand, facility location, and scenarios of disaster and operational error can be predicted with reasonable accuracy. For example, it is assumed that traffic demand is largely driven by human-to-human communication and it has historically been inferred from demographic data, which is relatively stable and predictable. Network facility locations also tend to remain unchanged over decades of operation, while natural disasters have been predictable to some extent based on historical records. Under such conditions, these approaches were regarded as valid. However, machine-to-machine traffic does not necessarily fit into this traditional mindset.

2.2 Environmental Change

In recent years, however, the dominant type of service, climatic conditions, and geopolitical risks have undergone significant change, undermining the validity of the conventional assumptions of predictable traffic demand, facility locations, and disaster effects. Climate change associated with global warming has produced unprecedented events, such as floods and wildfires that are not fully captured by historical records [Grant]. In parallel, growing global awareness of potential risks facing critical infrastructure, including those related to military activities, which can co-occur in multiple locations, necessitates considering human-induced disruptions in addition to natural disasters.

Therefore, to address more uncertain failures, new approaches are required not only in proactive (pre-disaster) approaches, such as network design or predefined recovery protocols, but also in reactive rapid recovery measures during and after incidents.

2.3 Examples of Potential Risks

In this section, some reference cases of the new risks are described.

2.3.1 Simultaneous Multi-Location Attack on Paris Olympic Network

Bloomberg reported simultaneous attacks on the Paris Olympic network at multiple locations, in which fiber cables carrying broadband services were cut [Bloomberg]. This example suggests that failures can occur at unforeseen locations and on an unanticipated scale.

2.3.2 Submarine Cable Failure and Communication Resilience in Taiwan's Outlying Islands

In 2023, submarine cables in waters near Taiwan were damaged in quick succession within a single week, resulting in a prolonged network outage that lasted for several weeks. The disruption severely affected daily socioeconomic activities in the islands, highlighting the critical importance of network resilience.

2.3.3 Submarine Cables Face Increasing Threats

Insikt Group reported that the vulnerability of submarine cables has worsened amid rising geopolitical tensions [Insikt]. The report shows some cases of disruptions to services resulting from damage to multiple submarine cables at once. An analysis of cable damage incidents in 2024-2025 finds that three factors - lack of network redundancy, lack of route diversity, and limited global repair capacity - significantly increase the risk of major outages. An aging maintenance fleet of ships will further exacerbate the impact of submarine cable faults.

3. Requirements for Enhanced Resilience

From the perspective of optical communication using submarine cables and terrestrial fiber cables, typical resilience requirements include the following:

3.1 Multi-Route / Redundant Architecture

Submarine and terrestrial cables can be disrupted by natural disasters (e.g., earthquakes, typhoons, tsunamis, underwater landslides), ship anchors or fishing nets accidentally damaging cables, human interference, or security vulnerabilities. Operators must design multiple independent cable routes and landing stations, alongside redundancy mechanisms, to ensure that if any route fails, traffic can quickly switch to alternative routes and/or landing stations, minimizing service interruptions for end users.

3.2 Rapid Detection and Switching Capability

Operators must monitor cable and node status (e.g., physical damage, disconnections, sudden routing delays) and implement automatic or semi-automatic failover mechanisms to enable rapid rerouting when inevitable faults occur. When a submarine or terrestrial cable is damaged, the system should reroute traffic to alternative paths quickly to maintain connectivity quality and availability.

3.3 Multi-Operator Coordination and Rapid Service Restoration

During large-scale disasters, damage often occurs across multiple locations and critical infrastructure (including power systems) can become unstable. As a result, a single operator alone is unlikely to achieve rapid restoration. Therefore, it is essential to establish pre-agreed cooperative frameworks among operators, including shared priority routing, mutual use of repair resources, and coordinated operational procedures. In December 2024, eight Japanese operators launched a cooperative framework to enable rapid restoration of communication networks[docomo]. And under the framework, Japanese operators conducted joint on-site training in March 2025 [NTT]. Four mobile operators installed base-station equipment on the cable-laying vessel of a Japanese operator to provide wireless coverage from the sea. This exercise served as a concrete proof-of-concept of cross-carrier coordination and asset sharing for emergency network restoration. Similarly, in Australia, Telstra has collaborated with the government and other carriers to simulate temporary roaming on its network for users affected by outages [Telstra]. Such kind of multi-operator collaboration should be achieved and expanded in the optical network area.

3.4 Multistakeholder Dialogues and Collaborations for Resilient Submarine Cable Systems

Given the inherently global and cross-jurisdictional nature of submarine telecommunication cables, multistakeholder dialogue, including among governments, international organizations, reg-

ulatory authorities, submarine cable experts, vendors, operators, marine industries, and scientific community is vital for enhancing the resilience of this critical global infrastructure in order to safeguard our digital future and economic stability.
The International Cable Protection Committee (ICPC) was founded in 1958 and is the world's leading organization promoting submarine cable protection and resilience. With over 235 members from more than 75 nations, the ICPC operates as a Non-Governmental Organization. Its comprehensive mission includes mitigating risks of natural and human damage to cables, developing recommendations and best practices for industries and governments throughout the cable project life cycle [ICPC], promoting scientific research on cables in the marine environment, and advocating for the rule of law for the oceans.
And the International Advisory Body for Submarine Cable Resilience was established by the International Telecommunication Union (ITU) in partnership with ICPC in November 2024, with the aim of promoting dialogue and collaboration on potential ways and means to improve the resilience of the critical infrastructure. The Open APN's open control interfaces and common operator models provide a technical foundation through which IOWN GF members can participate in and operationalize such inter-operator coordination frameworks.

3.5 Geographic and Supply Chain Diversification

To reduce the impact of a single cable route or station failure, operators should deploy routes in diverse geographic locations (e.g., east-west, north-south submarine cables, multiple landing points in different countries/regions) and avoid over-reliance on a single vendor, maintenance, repair fleet, or path. This reduces the risks from natural disasters, human interference, and surveillance vulnerabilities. Routing cable to and from geographically and geopolitically stable routes and regions will help to improve overall availability.

3.6 Alternative Channels and Technical Contingency Plans

For long-term downtime risks caused by cable damage, operators should consider alternative transmission channels (e.g., satellite links, microwave transmission, terrestrial fiber detours, backup power generation facilities) and rapid repair capabilities. When cable repair is complex and time-consuming, these alternative channels can temporarily carry traffic until the main cable is restored.

3.7 Disaster and Risk Planning

Operators must include physical infrastructure (such as submarine cable landing stations, cable repair vessels, underwater monitoring equipment) in risk management processes, conduct regular drills, disaster simulations, and supply chain assessments, and cooperate with government, maritime, and telecom regulatory authorities. When sudden events occur (e.g., submarine cable cut by anchors and fishing nets, disconnection, undersea earthquakes), they can quickly activate backup routes and repair mechanisms.

4. Enhanced Resilience for Open APN

4.1 Support of Open APN

4.1.1 Multi-Route / Redundant Architecture

Like the conventional transport network, Open APN can also support network design with multi-route, such as ring and mesh topologies. Resilience in traditional transmission networks is considered with redundant links between two points. For example, resilience in typical submarine transmission is considered as redundancy of links between landing-stations (i.e. beach-to-beach). When considering mixture of terrestrial and submarine transmission, it can be designed as mesh topology along multiple diverse routes. The Open APN is based on such flexible design concept. And the Open APN architecture document introduces the new concept of GOIP (group of optically interconnectable ports), which clarifies the geographical coverage and the locations between optical connections can be established. The automated establishment of paths by APN-C simplifies operation in complex, multi-route and redundant topologies. Therefore, the Open APN topology is not limited to simple ring or linear-protection scheme.

In addition, with SDN (software defined network)-like feature of APN-C, the Open APN has capability to be integrated with upper layer controlling functions such as IP layer. Using open and standardized north-bound-interface (NBI) of APN-C, other controllers can cooperate with the Open APN. This also helps enhanced resilience [IPoOptical]. And automated features of APN-C will also time again produce consistent results and will reduce risks of human error in complex and repetitive tasks.

The Open APN architecture document does not clearly describe the redundant feature of the Open APN. However, the Open APN can support conventional technology such as path protection and restoration.

4.1.2 Rapid Detection and Switching Capability

The Open APN's support of streaming telemetry enables rapid failure detection and allows prediction of signal quality degradation. The automatic control feature of the APN-C can realize rapid recovery of the failed or degraded path after it detected.

The Open APN's ability to deliver a variety of services over optical paths enables multiple levels of switching capability; for example, it can employ fast OTN-based switching for rapid protection as well as packet-based switching for flexible and granular traffic handling. The packet-based route switching may be implemented in coordination with IP network controllers using the NBI of APN-C. OTN linear protection switching per ITU-T G.8031 targets restoration within 50 ms of fault detection; Open APN's APN-C automation supports this target while extending protection across multi-operator mesh topologies that G.8031 point-to-point and ring schemes do not address. For restoration scenarios involving borrowed inter-operator infrastructure – where pre-provisioned protection paths are unavailable – the field demonstration referenced in Section 4.2.1 achieved full optical path provisioning within six hours [Mano], establishing a practical benchmark for post-disaster agile recovery.

For rapid detection of failure, maintaining the control and management network (Data Communication Network) is essential; APN-C continuously monitors the network state and supports rapid problem analysis for both routine troubleshooting and major disaster recovery. The Open APN architecture can support these monitoring and analyzing features.

The Open APN can also support fiber-sensing technologies [FS]. Using these technologies, the operator can find failure points rapidly.

4.1.3 Multi-Operator Coordination and Rapid Service Restoration

By the Open APN's feature of supporting open interfaces on U/C/M (User/Control/Management)-plane, an operator can operate borrowed facilities not only fibers but also Open APN equipment through the interfaces.

In the case of large-scale disaster, an operator can connect its surviving equipment with the borrowed ones and can establish new paths with new route of the borrowed facilities. The common models of the facilities can also help to design the temporary network for restoration.

4.1.4 Supply Chain Diversification

To achieve supply chain diversification, Open APN network should support open interfaces, common models and interoperable equipment. The open and standardized interfaces and models achieve vendor-independent operation. And the user-plane interoperability achieves multi-vendor coexistence in one network. These reduce risks from supply chain dependency.

4.1.5 Alternative Channels and Technical Contingency Plans

Open APN should support coordination with other transport systems to provide alternative transmission channels. Through standardized interfaces and unified control, traffic can be rerouted to heterogeneous networks when primary optical paths are unavailable, ensuring service continuity under failure conditions.

4.1.6 Disaster and Risk Planning

Open APN enables coordinated operation across multiple operators, overland and undersea, through open interfaces and common models. During incidents such as submarine cable cuts, link failures, or earthquakes, operators can rapidly activate backup paths, initiate repairs, and utilize resources from other operators to accelerate service restoration.

4.2 Examples of technical challenges

There show some examples of technical challenges, which is consistent with Open APN's concept and will be discussed how these items apply to Open APN for further study.

4.2.1 Agile Resilience in Optical Networks to Overcome Unpredictable Disasters

This section is a summary of [Mano] [Xu] [Sahoo].

To address the unpredictability of disasters, this paper introduces the concept of agile resilience, which emphasizes dynamic adaptability across multiple operators and layers. It identifies key requirements and challenges as follows.

Key requirements

- Rapid establishment of optical wavelength paths across borrowed infrastructure
- Temporary sharing of partially idle network and computing resources
- Cooperative recovery planning among operators

Challenges

- Low-cost, rapid characterization of borrowed optical transmission facilities
- Transponder virtualization and/or delegated management of line ports
- Confidentiality-preserving cooperative recovery planning

The paper presents enabling technologies for the realization of agile resilience. The following three technologies are discussed. As for facilities characterization method, Digital Longitudinal Monitoring (DLM), optical line system (OLS) calibration, and transceiver noise estimation are discussed. With these technologies, an operator can rapidly estimate the features of borrowed fibers, amplifiers, OLSs, and transceivers and can design network and service paths.

For transponder virtualization, resource isolation, access control, and open control interfaces are discussed. With virtualization technologies, operators can rent out unused transponder resources without affecting their own operation.

Emergency situations require cooperative recovery planning to coordinate the location and scheduling of shared resources among operators. However, because operators are often reluctant to disclose sensitive data, such as network topologies or resource availability, a confidentiality-preserving approach is essential. This technology provides a swift, cost-effective solution for cooperative recovery while ensuring data privacy [Xu] [Sahoo].

In the paper, it also demonstrated rapid system characterization, optical path provisioning, and database migration within six hours using a field-deployed transmission systems. These results validate the effectiveness of the proposed enabling technologies and confirm the feasibility of agile resilience.

4.2.2 Submarine Cable Deep-Ocean Observation of Mega-Thrust Earthquake and Tsunami

This section is a summary of [Mazur][SPARKLE][MECOZZI1][MECOZZI2].

There are new optical sensing technologies available for sensing large scale natural disasters such as earthquakes and tsunamis, using active telecom submarine cables. Using a 4,400 km-long active telecom cable in the Pacific Ocean, the work detected the recent M8.8 mega-thrust earthquake in Eastern Russia with an unprecedented 100-meter spatial resolution — the highest ever for ocean-bottom sensing. These reports show transformative demonstrations of how telecom infrastructure can enable large-scale seismic and tsunami monitoring and report the largest number of deep-ocean sensors ever deployed and the first fiber-optic detection of a tsunami wave.

By applying such state-of-the-art fiber-sensing technologies to the Open APN, operators can rapidly obtain disaster-related information necessary for network operations and, at the same time, provide valuable information to society, such as improved tsunami warning systems.

4.2.3 Flexible Spectrum Sharing Services

This section is a summary of [Kaeval1][Kaeval2].

The report describes spectrum sharing service that logically partitions available optical spectrum on a fiber pair for different customers. It realizes “virtual” fiber pair with right-size capacity greater than a few wavelengths. This technology realizes new business models for optical network market but also can be used for operators’ cooperation in the event of major disaster.

5. Further Study

In the Open APN functional architecture document, there is no explicit mention of use cases or requirements related to resilience. This white paper presents the requirements for enhanced resilience and how they can be achieved within APN. However, for the important features related to the infrastructure sharing described below, this paper provides only conceptual ideas and some possible technical challenges. Therefore, further discussion is needed to develop them into concrete specifications.

- Technical aspect: Architecture for redundancy including optical network digital twins, Spectrum sharing, Automation technologies, on-demand optical path, privilege separation, etc.
- Institutional aspect: A framework for infrastructure sharing during emergencies, common metric/yardstick, Confidential information handling.

Regarding spectrum sharing leveraged by optical network digital twin architecture, it is considered one of the most promising technologies for enabling inter-operator infrastructure sharing during emergencies. While automation is a technology that can reduce operational costs not only in emergencies but also during normal operation. The extent to which processes can be automated in emergency situations is likely dependent on the scale of the disaster. Therefore, discussions on specific use cases and their categorization may be necessary.

Regarding the institutional aspects, it is undeniable that arrangements to facilitate cooperation among operators during emergencies are essential. To achieve this, it is necessary to discuss what information should be exchanged—both in advance and during emergencies—and through what method/interface such exchanges should be carried out. Information exchange among operators is required across planning, provisioning, monitoring and management of inter-operator services, but is challenged by the need to protect confidential resource information. Resource abstraction [RFC 7926] is an approach that enables confidentiality-preserving cooperation by providing limited visibility. It helps realize interconnection among operators' networks. Meanwhile its practical and detailed deployment remains challenging, especially for facility sharing during emergency situations. Therefore, both short-term relaxed approaches and long-term efficiency-oriented solutions are needed. Moreover, when abstracted information is shared among multiple operators, ensuring integrity and fairness is essential, motivating the need for open and fair information-sharing mechanisms.

6. Conclusion

This document has addressed the relationship between OpenAPN and network resilience, a topic not explicitly covered in the Open APN Functional Architecture document. It first highlighted that recent large-scale natural disasters and human-induced failures increasingly cause simultaneous disruptions across multiple domains, exposing the limitations of traditional resilience concepts in optical transport networks.

To meet these emerging challenges, this document outlined the resilience-related requirements for Open APN and explained how the Open APN architecture can potentially support them. It also identified several technical challenges that require further study.

Taken together, these considerations show the need to further specify and refine resilience-related aspects within the Open APN Architecture.

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History

Revision	Release Date	Summary of Changes
1	July 2026	Initial Release