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Establishing A Universal Telecom Network Seismic Resilience Performance - Can it be done

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Abstract

This paper provides a general idea of the complexity and difficulties of defining a single performance metric that fits all telecommunication networks/systems. The lightning speed of technology advances in telecommunication created demand, speed, and volume of data transmission. Most services and applications developed call for bandwidth and speed to satisfy performance and video streaming needs. The demand of services resulted in hardware upgrades as well as transmission media deployment increases, which create a more complex environment to nail down the network resilience performance.

When the deployment of transmission media is geographically dispersed, the network will be given a better opportunity to enhance performance of resilience. Also, when hardware upgrades are not concentrated to a few main locations, it will also help to improve resilience. The dispersed topography will not create blind spots when there is damage as a result of significant seismic event.

All telecommunication networks are designed to an optimum demand pattern. It will never be built to satisfy everyone calling or using the network services at the same time. However, in and right after a medium to large seismic event, the demand of 3 to 50 times the normal rate have been recorded.

This paper suggests a few options to reduce the stress on telecommunication network within this high demand period to enhance the network resilience performance. These options are attempts to establish a standard approach to substantiate telecommunication seismic resilience performance.

Keywords: telecommunication, resilience, network

1. Introduction

Telecommunication services can be grouped into three categories – voice, data, and media. Voice is the plain old telephones service (POTS) with a small twist with the technology changes; the addition of voice mails (or recordings), call back, conference call, call waiting, etc. Data is a collective term from text messaging to business and financial services (Internet). Media is television, videos (movies) streaming, and social platforms.

The physical elements that interconnect these services are globally and spatially distributed making telecommunication lifeline the only lifeline that interconnects the continents. This paper will not discuss the international links and their performance resilience. In order to simplify the discussions presented in this paper, a densely populated region with financial companies and banks, consumer and retails services, and industrial facilities will be used as a model. Government services will be an overlay of these functions within the discussions. Military network will not be included or discussed.

Using an ultra simplified network concept, the physical elements can be divided into nodes and links. In general the nodes provide and process services, while the links deliver the services to between nodes and the end customers. Both optical fiber transmission media and bandwidth are the factors of providing speed and volume to satisfy demand. Technology advancement also fuels the demand increase. Many applications depend on the bandwidth available to deliver its function.

It is not difficult to realize that telecommunication service is an inseparable part of our daily life. As saying goes - we just cannot leave home without it. When telecommunication service is interrupted due to a medium to large earthquake, what duration the telecommunication service return to normalcy is acceptable will be the question that needs to be answered. Also will the duration of returning to normalcy in one region acceptable to another region.

Resilience is defined in this paper as the duration of telecommunication services returning to normalcy. Duration means time in hours, days, or months. Understanding the configuration and topography of a network is one of the qualifications to develop a reliable resilience metric of a telecommunication network.

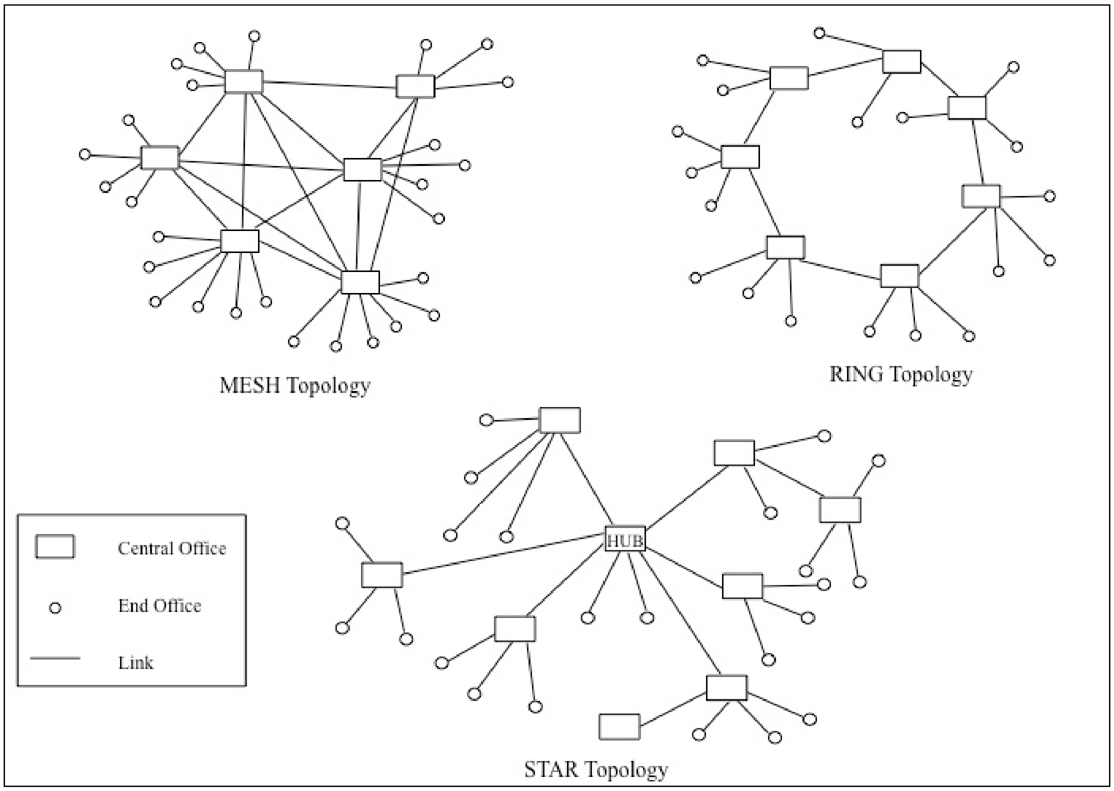

Fig. 1 - Simplified telecommunication network topology.

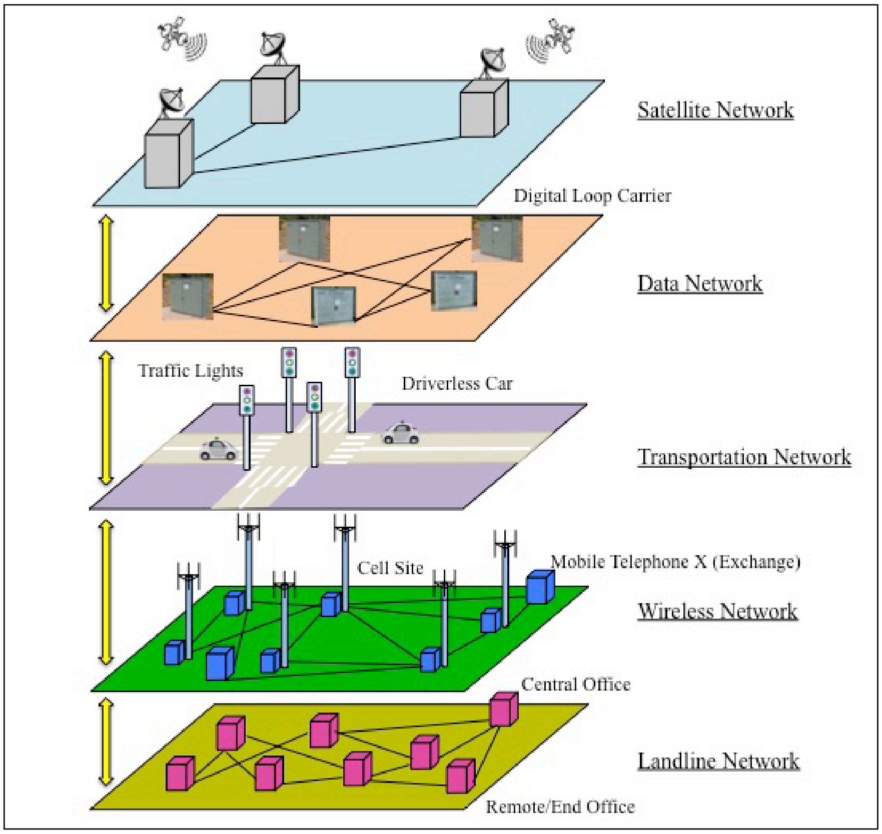

Fig. 2 - Simplified layers of telecommunication network.

2. Complexity and Vulnerability of Telecommunication Network

The simple configurations of the telecommunication network called Public Switched Telephone Network (PSTN) as shown in Figure 1 showing a two dimensional connections is now expanded into a three dimensional configuration, Figure 2. That does not mean that PSTN is not complex. As a matter of fact, not all end users (the small circle) are single terminal customers. It also represents an end user of a Private Automatic Branch eXchange (PABX). Such connection terminates at a large organization like a university, automobile manufacturer, etc., which handles internal calls and data, and external calls and data. That means it is a sub-network on its own with its own equipment processing voice calls and other functions specific to this network.

Figure 2 only presents a few layers of the telecommunication network; in fact each service is a layer on its own. These layers are now commonly called the Internet of Things (IoT), including such automated house appliance control, security, etc.. Electric power smart grid will soon become one of these layers. Unless it is absolutely necessary, new circuits will not be built. That is existing circuits will be use to share these new services. It is simply a good economics decision. All these layers are inter-connected and equipment specific to services rendered is located in the same facilities in many cases. This high degree of complexity is one of the difficulties to develop a model to accurately predict the performance of the network after a medium to high magnitude of earthquake. This is coupled with the fact that telecommunication networks are not design to handle every customer's demand at the same time. The demand recorded from past post earthquake events showing 3 to 50 times above normal traffic demand. It means that many calls to or from the impacted area are not completed.

The service contents of each network in different regions and countries add to the number of variables to the resilience equation. Each country definitely will have their own policy relating to telecommunication services and priority of emergency response. That is the complexity of the telecommunication network is more than just equipment, technology, services, and topology.

As a result of the Bell system requirements in North America, robustness of the Plan Old Telephone Service (POTS) network provided a reasonably good foundation for all the new services offered by the service providers today. The accelerated pace of services deployment and network implementations in this highly competitive industry resulted in hasty decisions without considering disaster impact in a more organized fashion to reduce the needless pain of service interruption to users. This includes designs (equipment and network), implementation, and operations/maintenance. One example is deploying cell sites in commercial building rooftops. There is no requirement, such as the requirements established for PSTN, for these new services except for interoperability. For example, there are many incidences that after an earthquake, the service provider cannot enter a red-tagged building to bring in temporary power to operate the site.

Internet is an excellent tool for all of us. In Tohoku earthquake, the Internet was compromised by some criminals setting up false help sites to take advantage of the victims' relatives. NTT was quick to close down these sites, but it was a good lesson for all service providers and users. With the proliferation of Wi-Fi sites, such as coffee shops, airports, etc. there are thousands of entry points to the telecommunication network. Therefore managing network security from a software point of view is a daily operation a service provider has to render. As a matter of fact, this is the most costly risk management the service providers have to render to secure the network operation.

Telecommunication networks are spatial; they cover a large geographic area. As a matter of fact, it is the only network that is global. There are hundreds of kilometers of submarine cable crossing all the oceans to connect continents. The interconnection media (copper or optical fiber) passes across trenches, faults, mountains, and rivers. Many cables are placed along railway line easement without burying, some are hung under a bridge without proper protection, and many buried along public right-of-way. Competition to capture a market share may be the cause. But the cables are exposed to a variety of hazards. In North America, backhoe digging, which occurs very often, is the most damaging hazard to buried cables.

In addition to complexity the network is vulnerable to all hazards, including man made hazards (including backhoe digging). Past earthquake performance records of telecommunication networks demonstrated that it performs reasonably well. Both equipment design and installation have been continuously improving against earthquake damage, cables (both copper and optical fiber) either bury or aerial are routed with good installation practices. Lesson learned from recent earthquake events indicates that cable (copper and optical fiber) requires better installation techniques to reduce cable faults. NTT has been continuously developing methods and materials to protect the optical fiber cables from water damage. Figure 3 shows a couple of the water prove technique and stretchable conduits designs to protect the cables.

Fig. 3 – NTT R&D Lab cable protection development samples

The ever-increasing capacity of optical fiber cable is creating concentration, which is becoming a problem. The base Optical Carrier (OC) rate is 51.84 Mb/s, which is designated as OC-1. OC-n is equal to n multiply 51.84 Mb/s. The most recent Optical Carrier deployed in North America is n equals to 768 – OC-768. That is 768 times the OC1 capacity. When one of these cables is damaged, the interruption will impact a wider area that is more users will be affected. There are two options to deal with this problem. One of the methods is to provide extra protection to this cable so it is fail save. The other method is to provide redundancy or spare circuit.

3. Dependency and Response

The term interdependency is generally mixed with dependency. From an operation point of view, lifelines do need one another to maintain smooth service. That does not mean lifelines rely on one another to function. For instance, wastewater plant requires power to function, but power does not need wastewater plant to operate. True interdependency means they depend on one another to perform their function.

Real interdependency between telecommunication and power is starting to happen with the concept of Smart Power Grid. When telecommunication fails, the Smart Power Grid will lose its smart. That is the Smart Grid will not function as intended.

There are many studies and researches relating to response after an earthquake. This paper will not discuss this topic except to emphasize its importance. The better the response plan the better resilience can be realized. Ultimately the quickness of response after an earthquake defines the performance of resilience.

3.1 Dependency

The original North America Bell system has established a standard of backup (reserve) power to deal with power outage. The power reaches each customer phone set so that when power outage occurs at the customer's premise, the phone set can be used to make calls. The normal power reserve is using batteries to store energy. The normal reserve power duration is 8 hours, while COs have reserve power up to 24 hours. However, when cellular phone service was implemented, there was no mandatory requirement to have power reserve at the cell sites. There are some service providers who provide very limited reserve power at their cell sites, usually a few hours of batteries.

From a recovery point of view, the speed to provide power to sites that do not have reserve power or long duration power supply is critical. Installation of quick connect on the exterior of the site will reduce the time to provide hook up genset power.

The trend is that both service providers and customers have to implement a second power supply source to ensure continuity of the service. Many customers who have optical fiber at their house find out that the rechargeable batteries used to power the optical signal conversion unit have limited service life. They need to be changed at intervals recommended by the manufacturer. When there is a power outage and the batteries may not work if the rechargeable batteries are at the end of their service life, these customers cannot use their in house equipment to make calls or to go on line. Therefore it is now a shared responsibility of the service provider and the customer to handle power dependency.

Large Central Offices also require continuous running water to operate the air condition unit. The electronic equipment produces a large amount of heat and it needs to be cooled to maintain a good service life. Unfortunately earthquake does not occur during cool weather when the air condition unit does not need to work hard. So in addition to power dependency, telecommunication networks also depend on water supply. Figure 4 shows a case when cooling fans are used to cool the telecommunication equipment in a Central Office to keep it from overheated after an earthquake. In this case the backup power luckily did not fail.

Fig. 4 –Fan was used to cool the electronics.

3.2 Capacity to Response

As the resource capacity of service providers in different regions and countries is different. The recovery response plan will also be very different. The resource capacity can be divided into two categories – human resources and material resources. The human resource is basically the technical service and spares management people. The material resource is essentially the spares and warehouses, tools and automobiles. The plan has to be a balance between severity of the event, and the resource capacity. That is the threshold of resources availability to recover from the event. Some service providers may not have the resource capacity to handle the repairs from an extreme event. When that happens, it does not mean the collapse of the network. Many services of the network will still function obviously with some limitation.

Many services providers have established mutual aid agreements to tackle resource capacity limitation. For example when a unit required by a service provide in the earthquake impacted area has to be ordered from manufacturer, and it happens that another service provider not in the impact area has one unit ready to be delivered, can be delivered to the service provider to recover. Sharing technical service personnel and service tools are usually a part of this agreement.

Needless to say, the response plan must be exercised annually and updated according to changes to the network. An outdated plan will be useless when it is needed.

Mitigation certainly is essential to reduce potential service interruption and maintain business continuity. Constant coordinating mitigation and response plan will enhance the network resiliency, which will prevent unnecessary service interruption.

The users (customers) can also help to reduce stress on the network after a damaging earthquake by restricting the use of telecommunication services for emergency only. In addition, the service provider can also use network management tools to redirect calls to reduce the traffic load on the network within the disaster area.

4. Opportunities

The opportunities discussed in this section by no means are exhaustive. Engineers and risk management of service providers, policy makers, regulatory agencies, and equipment manufacturers are encouraged to explore more opportunities to mitigate damage of this important service to the next level of resilience.

Redundancy and spare are not welcoming terms to network owners. These two terms have a negative economic sense that is not revenue generating asset. Therefore majority of the service providers have the wrong perception that resilience means costs, in fact it is a true investment in business continuity. Investing in resilience will definitely improve reliability of the services, which means building user confidence and satisfaction – a building block of customer loyalty. This investment will reduce needless hardship on the community in a post earthquake environment. The following topics are suggestions to service providers the opportunity to invest in resilience to reduce service interruption.

4.1 Network Expansion and New Service Implementation

Telecommunication network is ever changing and expanding to add new services and to reach the customers in new communities (individuals and organizations). It is an investment of the service provider to build a stronger business and capturing a bigger market share. It is also an opportunity to add strength to the network against earthquakes and other hazards that the network is exposed to. It is prudent to plan the expansion and service addition by adding a dispersed circuit to improve the survivability of the network. That is redundancy in both cable routing and central offices/remotes. This will allow the service provider to transfer services from a disaster area to the area that is not impacted by the earthquake.

Northridge earthquake 1994 when Pacific Bell Network Control Center at Sherman Oaks was impaired by power outage and building damage. The Network Control Service of the area was transferred to Oakland Network Control Center, which maintained the critical network management service in the post earthquake environment [Ref 7.1]. This was a result of preparedness and having redundancy to handle adverse situation.

So growing the network with mitigation as a part of implementation plan will help to improve resilience and reduce potential damage.

4.2 Micro-Grid Power Concept

During the Tohoku earthquake and tsunami, the telecommunication in Sendai did not go down with power outage. The Central Offices and cell sites do not need to have power brought in to keep them functioning. This was due to the Micro-grid Power [Ref 7.1] that NTT implemented, Figure 5. Power plant of the micro-grid has power reserve capability in case the generators fail. In addition, the power plant also uses solar power to augment power generation, Figure 6.

Fig. 5 – NTT experimental Micro-grid serving critical community functions in Sendai

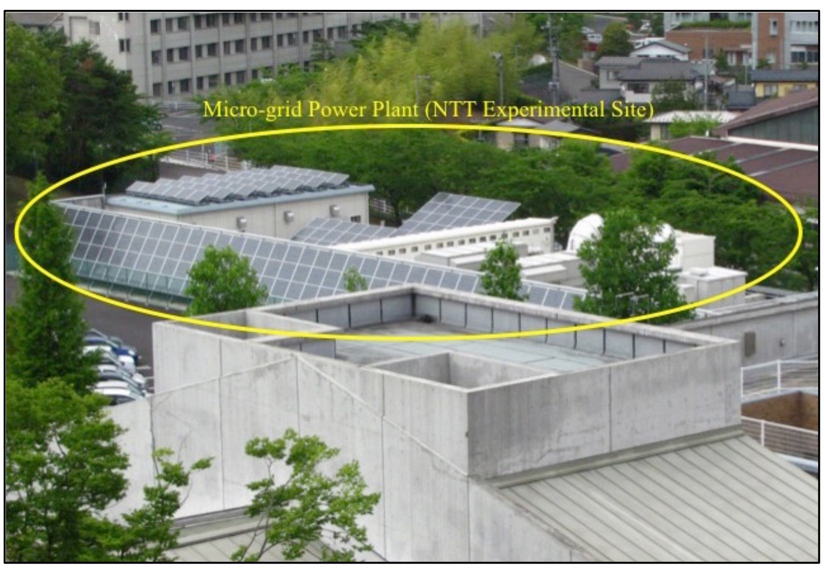

Fig. 6 – Aerial view of the NTT experimental Micro-grid Power Plant in Sendai

Most power outages after an earthquake are due to transformers shut down in substations. A Micro-grid does not need any substations since it covers a small area. The smaller transformer in the Micro-grid is less susceptible to earthquake impact.

The good performance has encouraged NTT to start implementing more Micro-grid Power Plants.

4.3 Digital Loop Carrier (DLC) power supply

There are many incidents observed in Concepcion Earthquake and Christchurch Earthquakes that roadside DLC cabinets and pole mounted cabinets failed due to power outage. As these units require power to operate and most of these cabinets do not have reserve power installed. This is an optical fiber network equipment to extend the data signal. Figure 5 shows the two different types of DLC cabinet installation.

Fig. 5 – Roadside cabinet on the left and pole mounted cabinet on the right

In the copper cable environment, DC power is fed through the copper cable to the repeaters. In the optical fiber circuit, the optical fiber cannot carry power (yet). The suggestion is to convert light into power to operate the DLC equipment. Research has demonstrated that this can be done. That is light can be converted to power as a power source for the equipment connected at the end of an optical fiber cable. However the current produced is not high enough to operate the equipment. The research effort needed is to develop a means to produce higher current to operate the equipment.

5. Network - Physical and Operational Differences

The differences between physical networks in the world are installation practices, design, and topology. Telecommunication networks, which are over a century old, many components, particularly the cables and their splice joints, in the network are subject to degradation. The term commonly used is aging. One has to recognize the fact that the equipment that are in service for a long time used old technology materials, which do not have a very long product life cycle. Unless there is problem with any aging components, there will be no incentive to replace or rebuild. The issue is earthquake becomes the means to identify aging problem. Indepth knowledge of isolating aging components and a systematic way to accurately predict a time to act before a problem occurs are needed. When network owners are fully capable of managing and mitigating aging problems and act on it, network resilience will definitely be advanced.

Opposite to aging, equipment is being replaced at a very fast pace – technology changes. Service providers that also offer advanced technology services can hardly keep up with the changes and the demand of new services. In many cases, hasty decisions are made to deploy the service to capture the market share without considering earthquake impact.

The equipment deployed by the network owner and service providers will not be the same in different regions or countries. Unless all manufacturers design, manufacture, and installed equipment for high seismic zones that the network owners and service providers can procure for the network, the performance of the equipment in an earthquake will be different.

In addition to equipment differences and factors of aging differences, circuit routing and cable splicing differences, spares components quantity and storage facilities differences, and installation practices differences are the attributes of the physical components of this network resilience equation.

Maintenance is one of the critical operations within a service provider's organization. A good maintenance program will definitely be able to isolate aging components, and keep the equipment always in top operating conditions. Good house keeping is also a key component of the maintenance program.

All service providers worldwide have one operational service that is the highest priority, it is the service for emergency response operators. Priorities of all other operational functions can be very different between service providers in different countries and regions within a country. The significance of establishing operational priority is to ensure order of recovery. That is to say, circuits within the network will have different priority of recovery. Therefore the lowest priority circuit will be recovered last, and the time to return to normalcy of this circuit will be the resilience of the network.

6. Conclusion

Resilience performance metric of a network is the performance metric of the weakest component (both hardware and software) in the network. Each network consists of its own set of specific components and operating software with different performances. The acceptable duration of interruption or recovery to normalcy will be different between different regions and countries. There is no benefit to establish a universal standard resilience metric. However, standard resilience metric can be set for essential services – emergency response services, hospitals and medical services, and community security protection. In order to establish this standard, critical criteria must be established and agreed upon by all service providers, or guidelines have to be created for all service providers to use.

Developing resilience metric of a network is a difficult task. Knowledge of component fragility and the time to restore are the basics to reaching a credible metric. The most vulnerable and the longest time to restore will be the resilience performance of that network. The severity of the event also plays an important role in restoration time and ability.

A good understanding of the vulnerability of the network will definitely help the service provider to protect their interests and to provide reliable service. Designs and state-of-the-art installation practices can also be developed to mitigate earthquake service interruption. This is the first major step towards a more resilience network. Again the person who is qualified to lead the task of developing a realistic resilience metric is a person who understands the network well. This person also needs a team of individuals who have good understanding of the components of the network. Software is part of the components, which delivers the services offered by the network.

The telecommunication network is a living entity it keeps on changing. This alone makes it more difficult to set a universal standard of resilience metric. Once a resilience metric is set for a network, keeping the metric in pace with the network growth and changes is an important engagement that must be carried out on an established schedule.

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