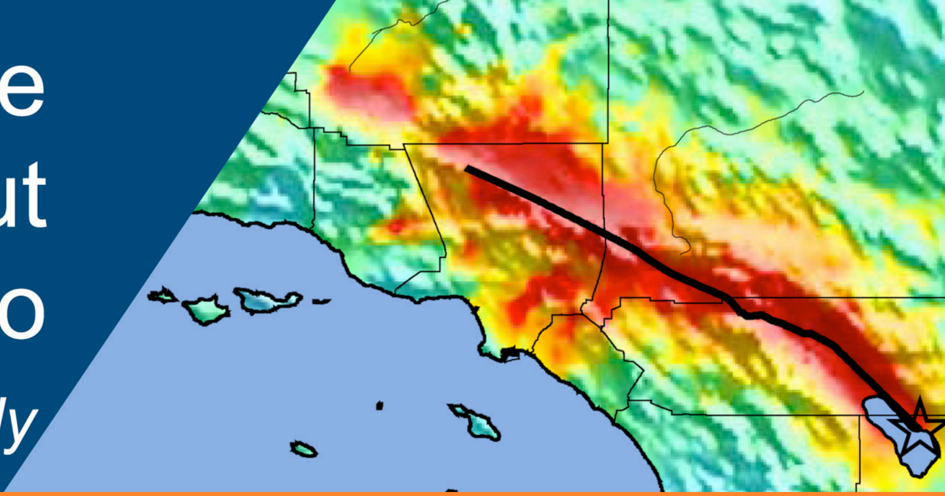
The ShakeOut Scenario

Supplemental Study



Telecommunications

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Note: over the course of the ShakeOut Scenario, the project name evolved. Where a study mentions *the SoSAFE Scenario* or *San Andreas Fault Scenario,* it refers to what is now named the ShakeOut Scenario.

Assessing the Impacts of A M7.8 Southern San Andreas Fault Earthquake on Telecommunications

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Abstract

The information provided within this document is based on the scenario earthquake of M7.8 Southern San Andreas Fault. The performances of the telecommunications system in past earthquakes provide the basis of extrapolating the possible outcome in this scenario event. The telecommunications assets (nodes and links) and network performance will be discussed.

A high level description of the telecommunications system is used to provide the emergency responders a brief view of the components that they will be facing during their operation.

The lack of information relating to the locations of the facilities and the local links has a small degree of impact to the emergency responders. However, the technology change may have a larger impact to the operation of the emergency responders. In most cases, when the technology change is available to emergency responders, then it will be a positive impact.

After a large magnitude earthquake, such as this scenario event, one dominant impact to the telecommunications network is the increase volume of calls. Even when there is no physical damage to the telecommunications system, the increase in call volume (above normal usage) will impact the overall performance of the network in and around the earthquake-impacted area. This increase in all cases exceeds the capacity of the network. This causes a lot of incomplete calls, which the users interpret as “telephone is not working”. Forty years ago this increase when uncontrolled, will result in network overload. When that happens, part of the network will go down.

There are Federal programs available to help the emergency responders to deal with communications network issues. The programs are discussed in this document.

Description of the Telecommunications System

Internet Network

This network started as a developmental feature in the early 1970. With the advance in technology, this network started to converge with the Public Switched Telephone Network (PSTN) around mid-1990. The major components are shown in Figure 1. The End Office (EO) is the same as the Central Office (CO) in the PSTN.

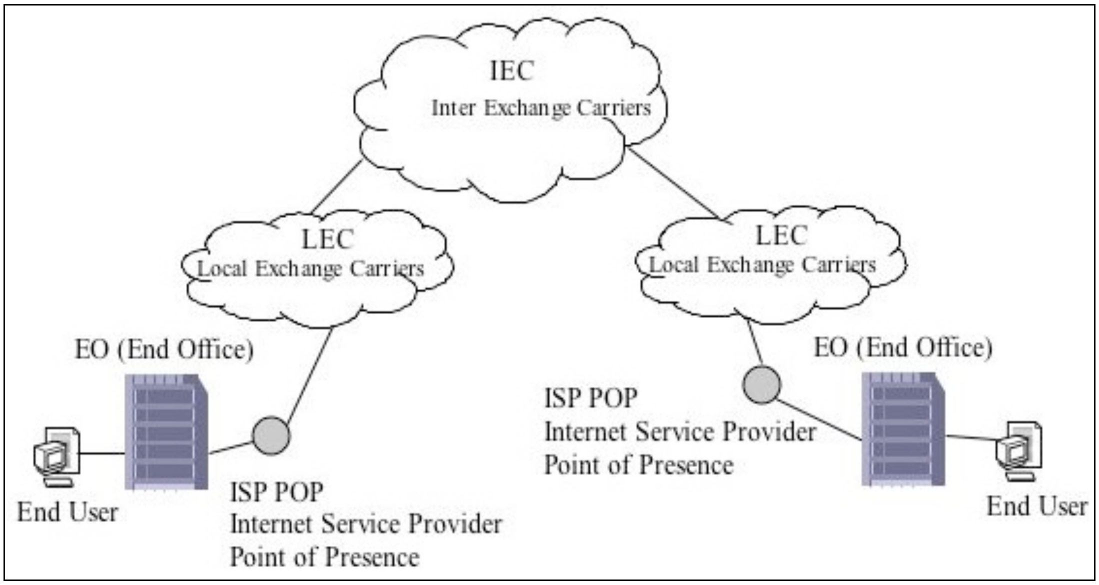

Figure 1 A over simplified Internet network

The exponential growth of this market created many Internet Service Providers (ISP), many of these companies are new and some of them are the traditional telephone service providers offering this service. Therefore the installation practices of hardware, the type of hardware, the software, etc are very different.

This network is now part of our daily life. Businesses (such as financial institutes, manufacturing operations, and logistics), transportations, universities, and government, etc. depend heavily on this network as part of their processes. These end users often have their own hosts that connect to the ISP.

Wireless and Bluetooth technology as well as availability of laptop computers and handheld devices renders the highly demanded Internet access available from anywhere with Internet access point (such as WiFi and hotspots).

This demand for data and commercial applications, such as banking, purchasing, etc created two key issues; the additional load on PSTN and security.

Wire-line Network

The divestiture, the changing technology, the competition and the demand of services and functionalities are the main drivers of this ever-changing network. The divestiture created many companies that own and operate the local and national networks. This also generates some degrees of redundancy of the network. However, the single point of contact (AT&T) is no longer available. The US Government and industry formed collaborative work groups in order to maintain interoperability and sharing of information for national emergency and security. The convergence of the networks due to additions of applications and new features such as cellular phones and Internet created many opportunities for improvements in terms of emergency response and security.

The common terms used are:

1. Links – connections between facilities and users, this can be cables (both copper and fiber optic) or microwave including satellite. Manholes that are used as splice and cross connect points are part of the links.
2. Nodes – facilities (with equipment such as switching, transport, repeater, power, etc.), call centers, and network control centers. These are buildings with a few underground vaults.

The pre-divestiture of network hierarchy is now replaced by the horizontal network, called the ring connection. This is a positive impact of fiber optics cable deployment, it is called fiber ring.

Figure 2 shows a simplified network with some major components in this network.

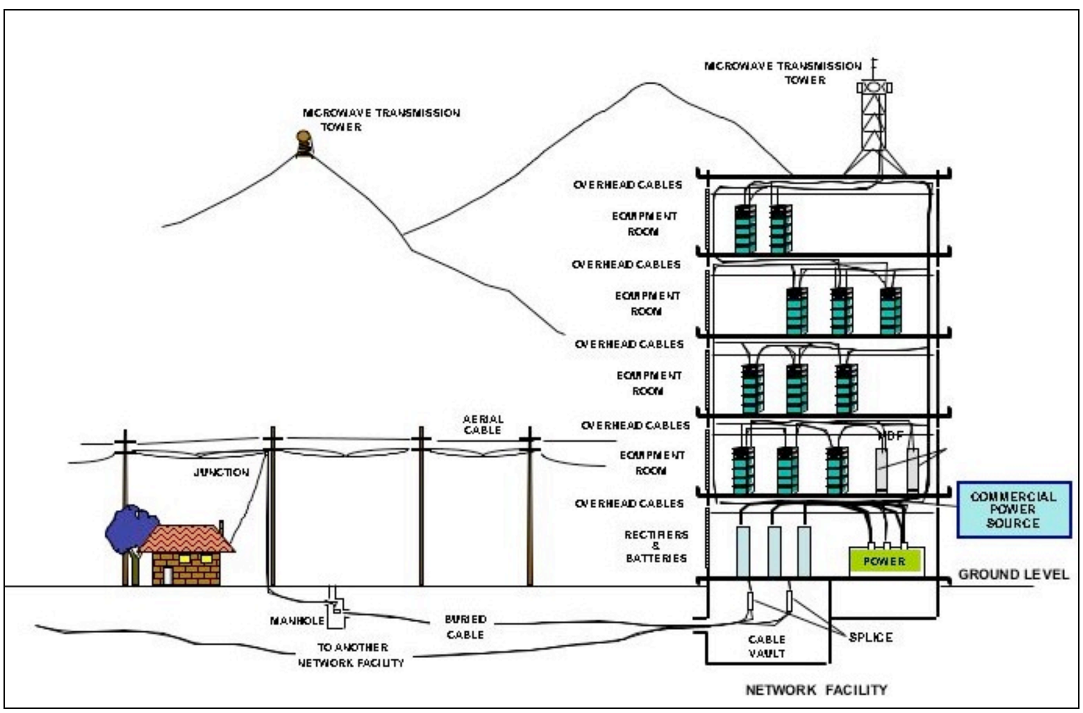

Fig. 2 Components of a part of the PSTN

Components of the Internet Network and the Cellular Network are often housed within the same CO facility; this is part of the point of presence requirement of the post-AT&T era.

The demand in services and functionalities created the need to install more capacity; therefore more fiber optic cables are installed, particularly in business centers such as New York City, Los Angeles, etc. The capacity of a fiber optic cable is 100s of times more than the same physical size copper cable. Therefore the magnitude of vulnerability is bigger.

Cellular (Wireless) Network

This network is now becoming the most preferred mode of communication for most people (particularly the younger generations) due to its flexibility and the miniaturizing of the handsets (cellular phone). The new features of Internet access, music and video streaming become a hot commodity among the young people. It is becoming a fashion. All these are good for business, however it does make this network more vulnerable. This will be discussed in the section of vulnerability of assets.

This network is very similar to the PSTN, except for the number of entry points due to limitation of coverage of wireless signal. The point of entry of this network is called Cell Sites (CS) or Wireless Base Stations (WBS). In this document I will be using the term Cell Sites instead of Wireless Base Stations. In many cases, these CSs are housed in commercial buildings, particularly in a downtown environment. These CSs are connected to CO by various means. This connection allows a landline phone to communicate with a cellular phone. I will be using the term cellular phones for the cellular network and wireless phone for the household phones to differentiate the two different hardware. The household wireless phone system has a base unit connecting directly to the landline with wireless handsets of limited range.

Figure 3 shows a simplified Wireless Network with its major components. The hexagon symbolizes the coverage of the antenna on the tower. The size of the cell (coverage) depends of many factors, such as topography, height of the tower, size of the equipment for the cell, etc. The CSs are connected by means of cables or microwave to Mobile Telephone Exchange (MTX) or CO. They can also connect to another CS. Recently, electric power transmission cable towers are being used to increase coverage and reducing costs of installation. In a densely populated area, most of the CSs overlap each other in order to reduce dropped calls when the cellular phone moves from one cell to another.

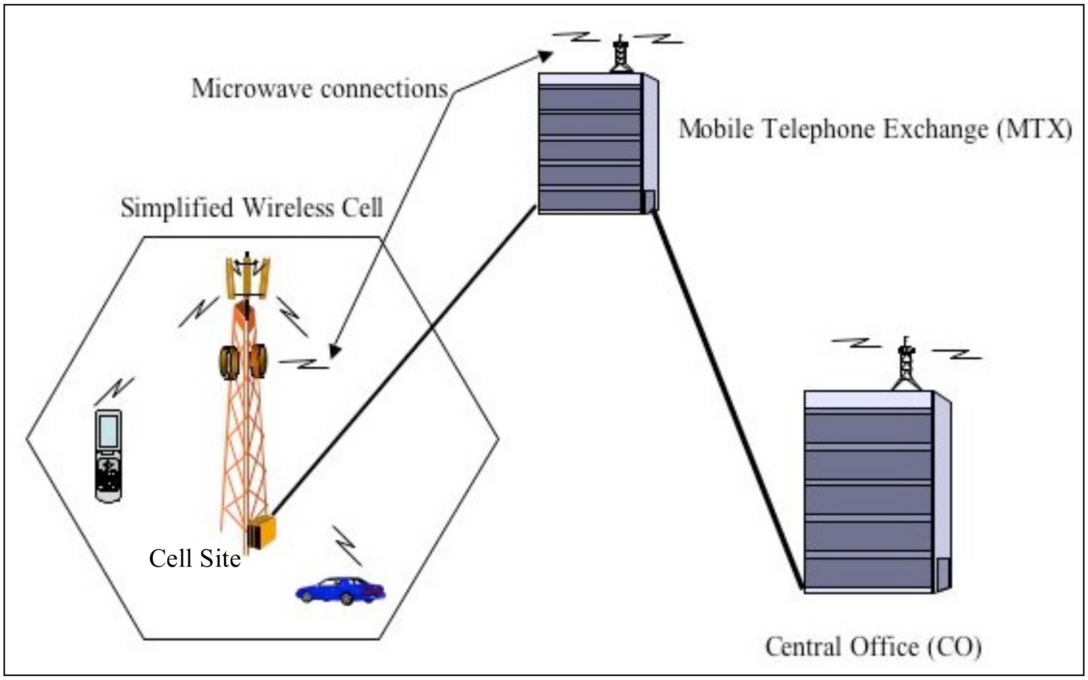

Fig. 3 A simplified Wireless Network.

Summarize past studies

The telephone network called the Public Switched Telephone Network (PSTN) was extensively regulated when it was owned and operated by AT&T (the single national operator). Bell Lab, an R&D subsidiary of AT&T developed many standards for the components of this network, including building, installation and testing of equipment, etc. Seismic installation criteria were part of the New Equipment Building System (NEBS). The standards were being used by most new telephone companies to a certain extend. It is not clear whether there is any inspection process in place to ensure the full adherence of the standards.

Cellular Network is not fully developed until after the divestiture. Again it is not clear whether there is a standards group mandating the performance of this network. With the different technologies available, it becomes very difficult to enforce one set of standards. It is largely up to the service providers to enforce standards.

The National Communications System (NCS), a Federal program for the national security and emergency preparedness community is now under Department of Homeland Security with mandates to support national security and emergency preparedness. Before the September 11 incident in New York, NCS was an independent organization. Some R&D had been done by the NCS to reduce loss of communication during and after disasters. Some of the recommendations include diversity of nodes and decentralization of hubs aiming at reducing congestions and network vulnerability. The organization recognized that the PSTN was a robust network. In view of divestiture, NCS was instrumental in organizing the National Security Telecommunications Advisory Committee (NSTAC) to influence the multiple service providers, to encourage cooperation and interoperability, and to deal with security issues.

One of the key implementations was the Government Emergency Telecommunications Services (GETS). This service allows the qualified emergency responders to complete calls at a faster and higher completion rate. The other was the priority service called Telecommunications Priority Services (TPS), this sets priority provisioning and restoration services upon requests from emergency responders and service providers. Both of these services proved to be effective during the September 11 incident in 2001.

The NCS Internet Technology and Standards Program established in 1999 produced some recommendations and identified vulnerabilities of infrastructure protection, information assurance, and security. Cyber attack was the main focus. However, the importance of physical damage to this network was recognized. The discussions include protection of assets, network security, wireless technology vulnerability, reliance on e-services and applications and concentration of assets. The need for standard access control procedure at disaster site and the need for Wireless Priority Services (WPS) were also recognized. The issues are liability protection for carriers and technology limitation to arrive at an executable plan.

There remains a lot of work to be done to fully understand the Internet Network, including the wireless access, to be able to identify the vulnerabilities and threats in a disaster. However, with the PSTN lessons from disasters, all realized that redundancy and alternate capability would be in the solutions in addition to equipment and buildings designed and installed to seismic standards.

We must recognize that damage to the telecommunications components is inevitable in a large magnitude earthquake. The network is spatial and has to be where it is, that means one or more components of the network will be experiencing a high level of shaking or faulting or ground deformation. Networks convergence will impact performance of PSTN, Cellular Network and Internet Network as a result of increased call volume in and out of the disaster area.

Summarize assets exposed to loss

As discussed above in the description of telecommunications system, the three networks; voice network (PSTN), cellular network, and Internet network, exist nation wide. Connections nationally and internationally exist as well. About 90% of the links are routed along highways, and railways. Some of these links are buries and some of these are aerial, using poles (Figure 2) or exposed on the ground along easements railway tracks. Since the locations of assets are not available for this study, examples of regions similar to the region of this study are used.

With the growth of cellular phones, in the mean time the number of public phones has reduced due to high maintenance cost and low revenue. In general, the public phones are the priority lines that mean a higher call completion rate.

Unless a subscriber of a telephone applies for a high priority line due to his/her profession needs, the normal household telephone lines are connected to a single point in the network. It may be an aerial drop wire from a pole or an underground cable from the closest manhole or cross connect pedestal on a street. Almost 95% of landline connections are single pint connections to a Central Office or a Remote Office.

Large institutes, such as banks, financial institutes, large corporations, airports, university campus, utilities, and emergency services, such as hospitals, police and fire department may have redundant lines connecting their phone system to a different circuit. The large institutes often have their own PBX (Private Branch Exchange) system on site to provide their own internal network interconnection. Therefore the PBX system can be viewed as a sub-network with a redundant connection the PSTN. This sub-network is as vulnerable to damage depending on the location and the installation practices of the PBX system. When a PBX system went down, the users within the institute could not make calls within or without the institute. Often fax lines within an institute are not connected to the PBX system; they can be used when the PBX is not working due to power outage or damaged.

In many cases, the redundant link is not a true redundant link as the link is run along side the primary link to the same CO. A true redundant link must be a dispersed link with a different path and a different CO.

Within the region of this scenario study, there are links, either copper or fiber optic cables crossing the fault. With the number of Inter Exchange Carriers (IECs), the probability of a total failure will be extremely small. Some small communities close to the foothill areas may have only one remote office serving them. The remote office will be within a radius of 25 km of the community and may have two links connecting to two different COs. In the unlikely event of a total failure of this remote, the area will be covered by the cellular network. The probability of total isolation from telecommunication will be small. The delay in call completion will surely happen due to congestion. When physical damage to links does occur, the level of delay will be become worse due to the reduction of circuits.

The small businesses, such as fast food delivery outlets, flower shops, etc. in the region will be the most exposed to reduced telecommunications performance due to congestion, earthquake damage to CO equipment and/or links.

Emergency services answering points will also suffer due to congestion or damage to CO equipment and/or links. The 9-1-1 call centers, called Public Safety Answering Point (PSAP) are usually the first responders of disasters. Within the region of this scenario study, there will be at least 40 9-1-1 call centers. The number of calls will exceed the total number of stations in these call centers.

Another group of assets that are exposed to telecommunication network performance are the Internet Service Providers (ISPs). In time of emergency the Internet users will be competing with the voice call users for circuits. It is unknown whether some of these ISPs will be on the list of restrictive network management control that is used to reduce congestion and making circuits available to the registered GETS emergency responders.

The airports, such as Burbank Glendale, Ontario International, John Wayne and Palm Springs Regional, in the high intensity shaking area will be exposed to loss of links. Airports and airline passenger services are highly dependent on Internet services; the loss of links may cause chaos of delays and cancellations.

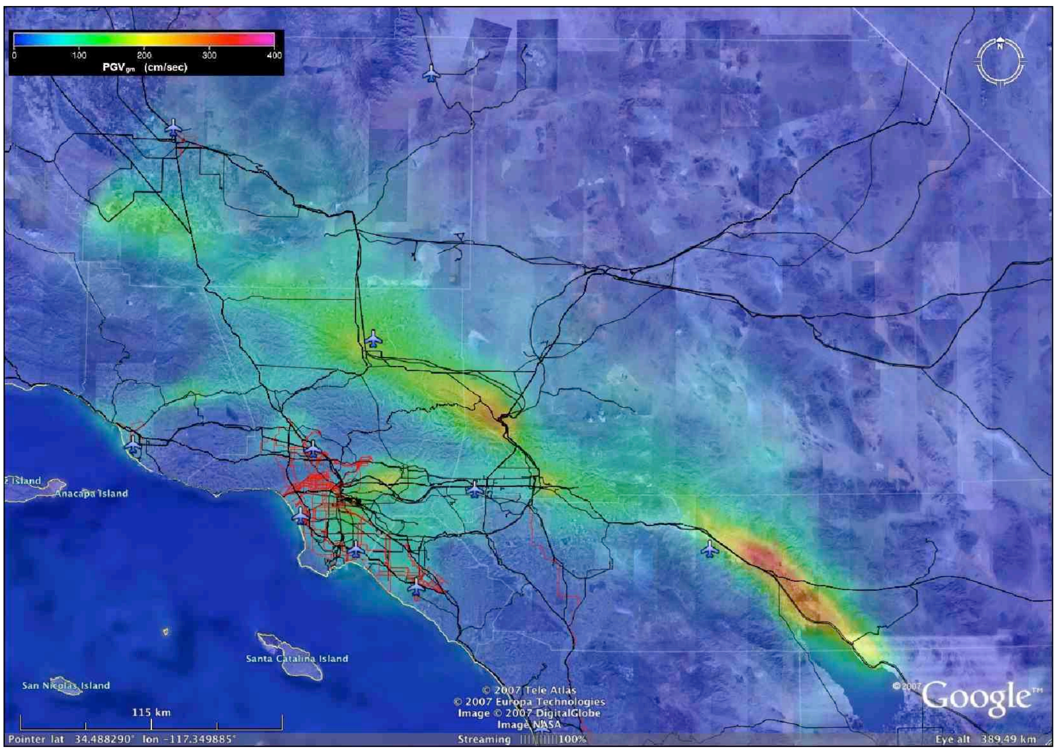

Fig. 4 The black lines are the IEC fiber optic cables connecting the region to the outside. The red lines are the LEC fiber optic cables in the Los Angeles area. (Confidential information provided by USGS for this study only).

Summarize vulnerability of telecommunications assets

In this section the discussions are divided into three major elements of the telecommunications assets:

1. Nodes,
2. Links, and
3. Software/Applications.

Nodes

The voice network (PSTN) in the United States demonstrated its robustness in earthquakes after the lesson learned from the1971 San Fernando earthquake. The convergence of Internet Network and Wireless Network may cause the network to be more vulnerable. Since there is no data available to definitively show how vulnerable it will be in future events, we can only use our judgment basing on the past performance data and information available to evaluate vulnerability. There is a need to perform studies to identify vulnerability and threats to these networks – PSTN, cellular and Internet, producing a tool that can help the carriers to reduce loss both physical and performance.

The San Fernando earthquake in 1971 had equipment collapsed in a CO (Figure 5); this is the landmark earthquake that started the focus of lifelines performance in earthquakes. The Mexico City earthquake in 1985 had collapsed top three floors of a communications building for local and long distance services, equipment on the floors below sustained extensive damage (Figures 6 and 7). The Armenia earthquake in 1988 recorded a total failure of a CO due to collapse (Figure 8). These are significant damage to a node in the network.

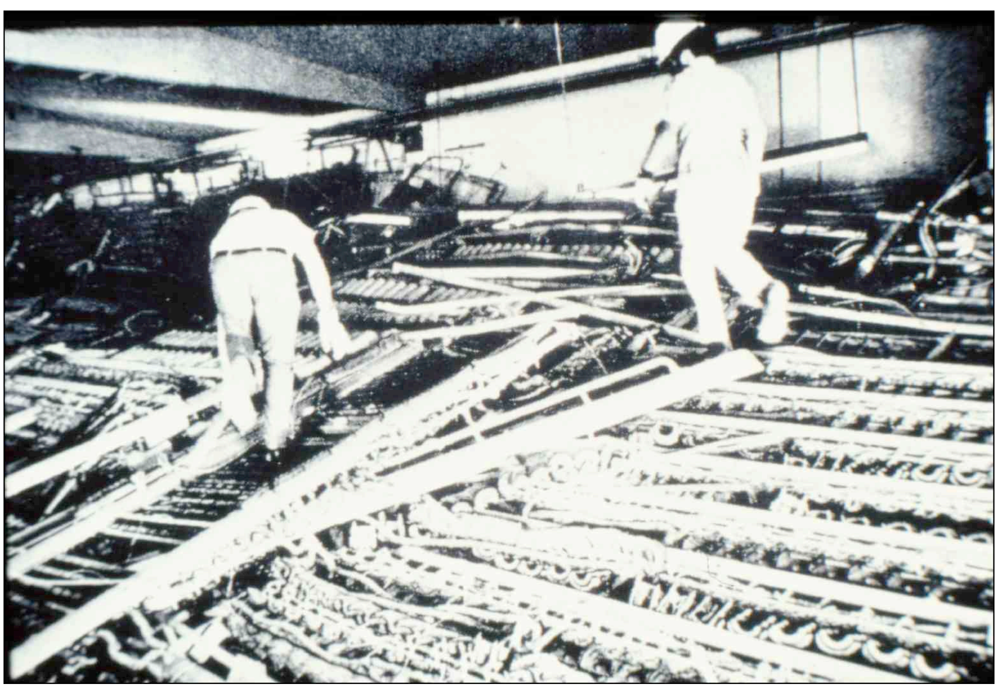

Figure 5. The switching equipment toppled in a Central Office in San Fernando after the 1971 earthquake, the single story building sustained minor damage.

Figure 6. The top three floors of this communications building collapsed, cutting off long distance calls and significantly impacting local services in Mexico City in 1985 earthquake.

Figure 7. The equipment in the building (Fig.6) above toppled on each other.

Figure 8. This Central Office in Spitak collapsed.

Nodes are defined here as the Central Offices, Remote Offices, Call Centers, Network Control Centers, Mobile Telephone Exchanges, and Cell Sites. International Gateway Centers are not considered in this document or the landing sites of the submarine cables for international connections across the oceans. Nodes range from a single story structure to a high-rise building of more than ten stories. Major Central Offices of large cities will be multi-story high-rises, while for small communities it will be single story buildings. Most of these buildings are built to a higher standard under the AT&T regime, as the analog equipment used pre-1980 is very heavy. Today the electronic equipment is much lighter and occupies much less space. There is no record of Central Office collapse due to earthquake in the United States.

Since the electronic equipment can handle more capacity than the old equipment, concentration becomes a concern. In some large Central Offices in big cities such as Los Angeles, each floor becomes a node in the network. That is one physical location/building houses multiple nodes in a network or networks (wireless, Internet). There are many such critical facilities in the telecommunication infrastructure today. Although competition has a positive impact to some degree, any loss to such facility still has a large effect to the performance of the telecommunications system.

Most of the damage observed is non-service impacting, that is the damage was not service affecting. However, regardless of how small the damage that is service affecting, the overall telecommunications performance can be felt by the users. For voice calls, except for emergencies it is inconvenience to the users in most cases, while for Internet users it may mean loss of business opportunities.

Switching equipment, transport equipment, radio equipment, cable conveyance system, electric power equipment (rectifiers, AC/DC converters, and batteries), HVAC equipment, backup power generators, the cable entry and exit points and other supporting equipment such as computers, telephone sets, modems, alarm, tools and spares, etc. are some of the contents of a node. Any deficiencies in design and installation of the equipment can result in loss of function after an earthquake. With the constant functional upgrades and addition of equipment to a node, a mix of design and installation practices will occur. Identifying the weaknesses in the system and correcting them will ensure a more uniform performance. The following figures show the damage of the contents of nodes in different earthquakes.

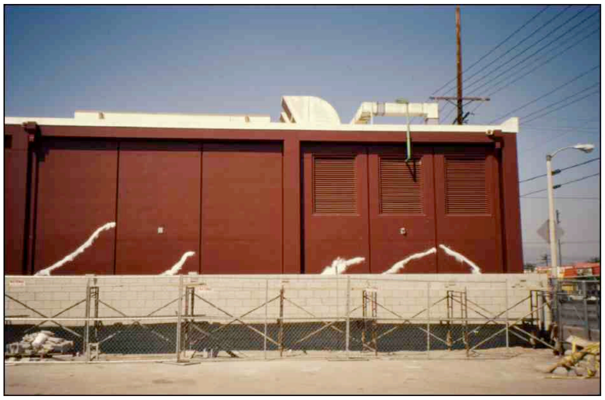

Fig. 9 A CO in Northridge after the 1994 earthquake with a few external wall cracks.

Fig. 10 This CO was upgraded, but the added bracings sustained damage but the building was saved.

Fig. 11 This shows the anchors securing the diagonal bracing member to the structure were sheared.

Fig. 12 The damaged bracing beams were removed and placed in the yard.

The above Figures 9 to 12 demonstrated the need to evaluate the CO structure against the latest seismic knowledge of the region. Although some of the equipment in this CO sustained minor damage, there was no capacity reduction due to the damage. The air condition unit on the roof was damaged and was replaced. Luckily the earthquake occurred in January and by opening doors with electric fans kept the air circulation and the equipment cool before the air condition was installed Figure 13.

In other earthquakes, both COs building and equipment inside did not perform as well. The following figures show equipment damage. Damaged CO structures were shown in Figures 6 and 8. Damage to the equipment was mostly a result of insufficient anchorage or load carrying capacity, unanchored cabinets, and overloaded cable conveyance system.

Fig. 13 Fan was used to cool the electronics, note that the units were pulled out to have better cooling effect.

Fig. 14 The cable racks fell and were supported by jiffy poles, in Whittier Narrow earthquake.

Fig. 15 This cable rack was overloaded and sustained extensive damage in Northridge earthquake.

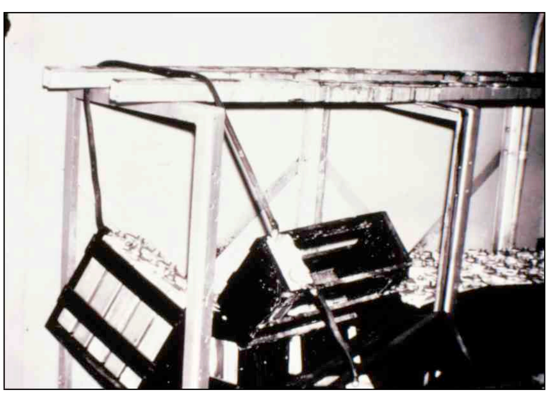

Fig. 16 The batteries were not secured and fell off the rack that has no railings.

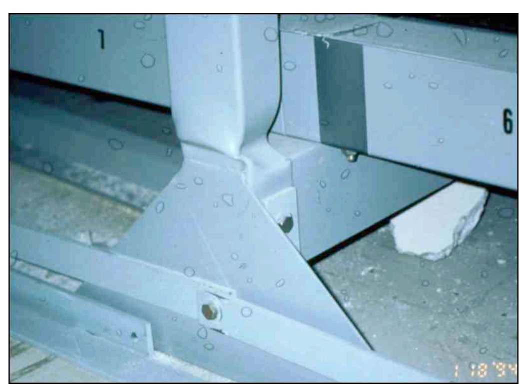

Fig. 17 This battery rack column showed in sufficient load carrying capacity in Northridge earthquake.

Fig. 18 This CO was non-functional equipment damage. Also this becomes a safety concern for the technicians working among the equipment.

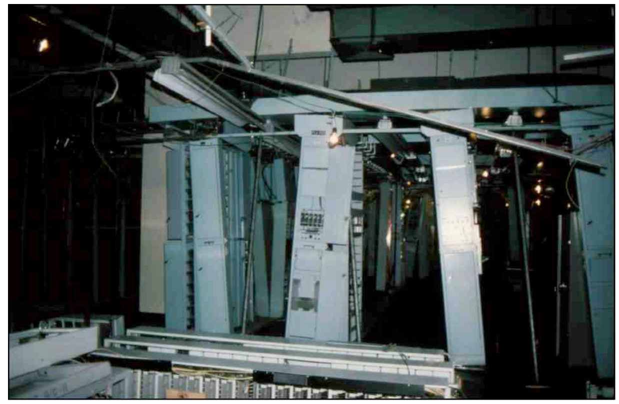

Fig. 19 The tops of these lineups of equipment were connected, thus preventing them from total collapse. The equipment lying on the foreground was toppled.

Fig. 20 This is the exterior of the CO after the 1971 San Fernando earthquake. The trailer outside housed a small switching unit to provide limited service to the area.

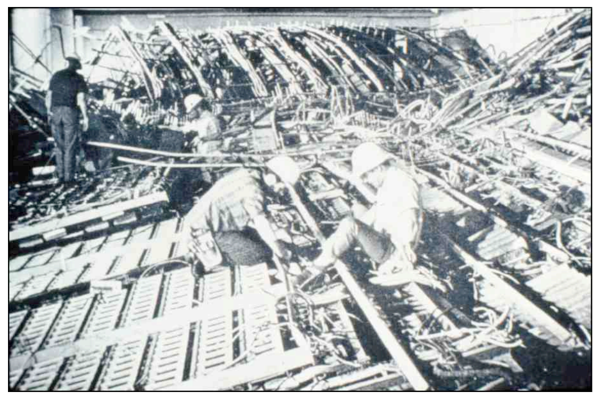

Fig. 21 The inside of the CO with all the switching equipment toppled. This was the old electro-mechanical switching unit.

A telephone service provider in the Northridge earthquake had to transfer their network control function from a control center in the earthquake impacted area due to damage to some equipment reducing the capacity and capability of managing large volume of traffic. This demonstrated the flexibility of the PSTN network and its state-of-the-art equipment, as well as the need of having dispersed redundant capability in the system to handle disaster.

Cell Sites are nodes of the wireless network. Most of these nodes consist of a tower, a single story building on the side of the tower and equipment inside the building and on the tower. In other case, the tower is the rooftop of a commercial building and equipment room is a small room building on the roof or just one story below. There are many cases of collapsed buildings taking the cell sites down at the same time. There are also records of cell site and transmission tower damage after an earthquake. In general, the biggest impact to cell sites is the lost of electric power. Most of the cell sites have about 3 hours of backup power from batteries. Usually there is no power generator on site. As mentioned before, loss of electric power in earthquake is a common occurrence.

Fig. 22 A cell site that was installed on the roof of a commercial building was damaged due to building collapse. This is 1999 Chi Chi earthquake.

Fig. 23 This cell tower on top of the CO building had a few bent members. Later this tower was removed. This was in the 1995 Kobe earthquake.

Mobile Telephone Exchanges (MTXs) are the same as COs, the only difference is the equipment used. As the number of cell sites grows so does the number of MTXs. Most of the MTXs co-locate with COs.

Links

The definition for this part of the telecommunications network is not confined to cables or signals through air (such as microwave or radio wave), it includes poles, manholes, underground tunnels, conduits, repeaters, cross connect pedestal, etc. International links such as submarine cables and the landing sites are not considered in this document. The links are general called outside plants of the telecommunications network. Figure 24 shows a simplified view of the outside plants in the telecommunications network and possible mode of failure.

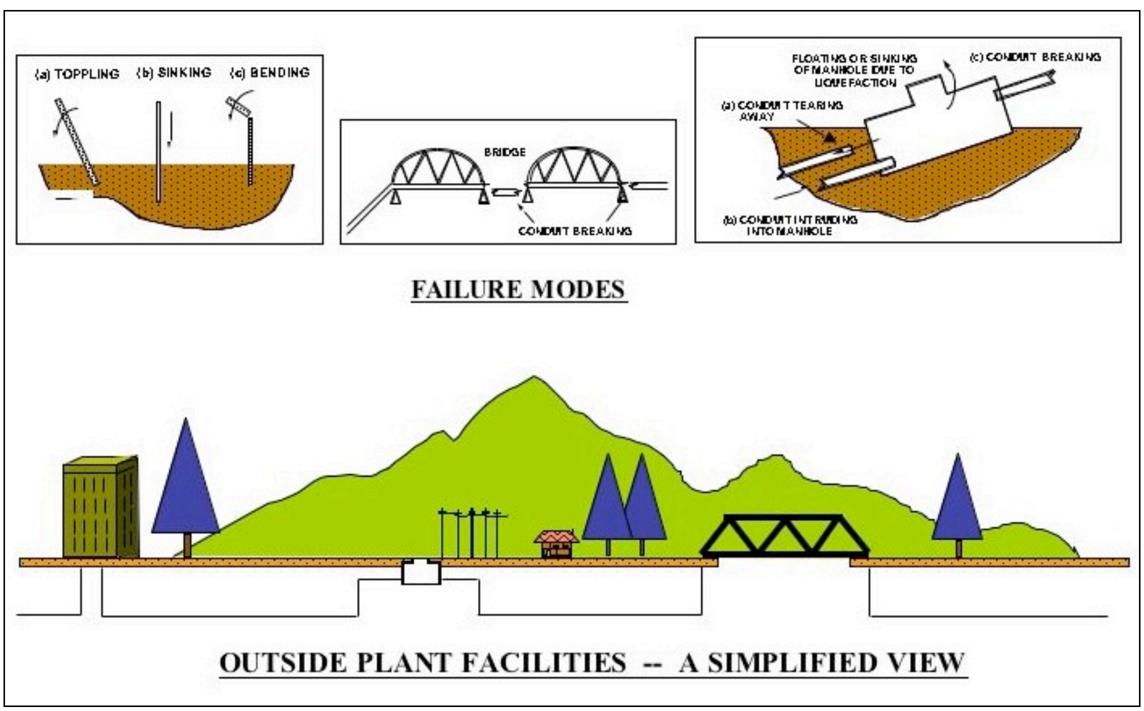

Fig. 24 The components of the outside plant and the probably failure modes in an earthquake.

Telecommunications cable damage occurred in all medium to large magnitude earthquakes. Cable damaged by back hole digging is a common occurrence. The telecommunications service providers had to deal with the cables damage problem often enough that they are quite resourceful when it comes to earthquake damage. The only complication the technicians had to deal with was access to site due to damage of roads and highways or landslide/rockslides. Fire is also another source of damage to cables. Fire following earthquake could create additional problem to the suffering network. Underground cables damage generally happened in poor soil conditions that caused liquefaction, lateral spreading and permanent deformation. Toppled poles that are used for the distribution network can sever cables. Cable routing that requires the cable to be co-located with a bridge or an overpass can be damaged when the bridge or the overpass is damaged.

Both copper and fiber optic cables are quite robust. Fiber optic cable strength is due to its design, while copper is due to it material. When cable slack is provided in routing cables, the chances of cable damage will be reduced. Strain relief of splices at a manhole or at entry and exit points to a building (such as CO) or on the aerial cable can reduce earthquake damage to a cable.

Microwave reception is by line of sight, when a microwave dish is dislocated by a few degrees the reception will be lost. This misalignment problem is usually fixed within the first two hours.

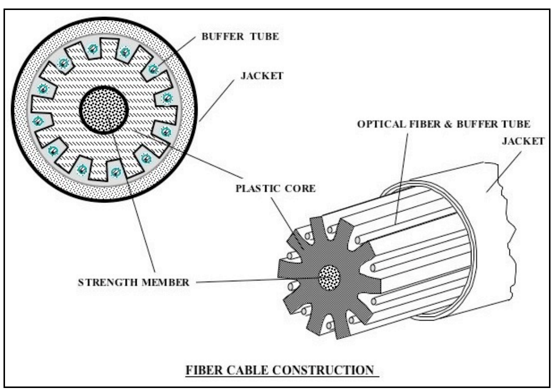

Fig. 25 This shows a 12 strand fiber optic cable (fiber optic cable now has 1,000 strands) with its structural elements and environmental shield to protect the fiber optic strands.

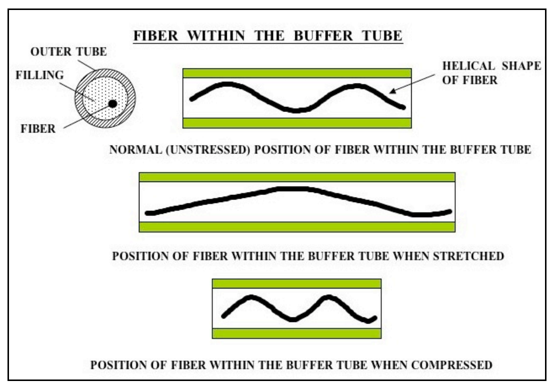

Fig. 26 Fiber optic strand inside the buffer tube are placed with inherent slack for expansion and compression.

Fig. 27 Damaged poles due to lateral ground spreading

Fig. 28 Fire burned these poles taking out both electric power and telecommunications.

Fig. 29 One of the bridge deck collapsed and severed the cables under the bridge deck.

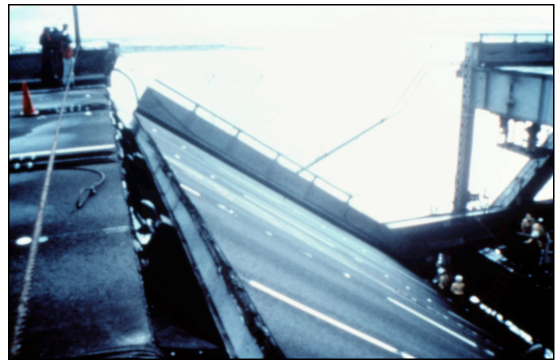

Fig. 30 This fiber optic cable using the Bay Bridge to route the connection from San Francisco to Oakland, cable slack reduced the damage to a few strands in the cable.

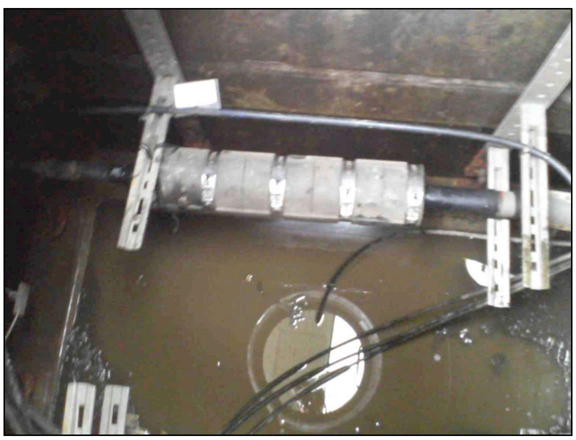

Fig. 31 Manhole with a splice case, note when water level rises above the splice case and the cable inside will be damaged if there is a leak.

Fig. 32 Microwave dish on the roof of this CO.

Software and Applications

The equipment used in the telecommunications network today is state-of-the-art electronic equipment. It requires a very complex and sophisticated set of computer programming codes and sub-routines to carry out the functions of control, management, finance/accounting, route calls, identify shortest path, and applications for subscribers, etc. The edge of the Internet network is the entry points of programming virus to the system. Security becomes more difficult with the wireless access increasing the number of entry points.

In the early 1990, a small software problem after an upgrade caused the international long distance link between New York financial district and Europe shut down for about an hour. The loss was estimated to be in the billions of dollars. eBay reported a $30 million loss per day due to a small glitch of a change a few years ago.

This kind of problem is most unlikely when coupled with a catastrophic earthquake. However, after the September 11 incident, the most likely time for this to happen will be when the service providers focus their efforts in recovery.

Depict a realistic damage scenario

Telecommunications Assets

Based on the PGA map of this scenario earthquake, there are five areas that are densely populated (Figures 33 to 37) with the PGA of 0.4g and above. These five areas are the primary telecommunications performance discussions in this section. In general, MMI map is the best map for emergency planning purposes. As it is more related to damage condition after an earthquake. Therefore the area east of Los Angeles will also be evaluated, Figures 38 and 39. The reason for choosing densely populated area is that telecommunications will be more developed and both landline and wireless density will be high. Any damage to the telecommunications system in these areas will have a greater impact to the users and the emergency responders. The reason for choosing PGA range is that there is no record of damage to telecommunications network for earthquakes with PGA of 0.4g and below. In terms of service impact, it will affect the low PGA zones such as Los Angeles, due to saturation of the system even when there is no damage.

There is no information of the number and location of the nodes of the telecommunications networks in the areas of this scenario earthquake. A more precise prediction of damage scenario can be developed when the locations and numbers of nodes are available. The numbers provided in this section will be estimates. With respect to location of these facilities, the lack of information means that emergency responders cannot plan ahead in terms of access to the facility. However, they can use the information to plan resource needs.

All services (voice and Internet) will be impacted in these areas; the degree of service interruption depends on the PGA expected in the area and the location of the assets. For example, when the cables serving a community are down, that is disconnected, both the voice and Internet services will be out for the community.

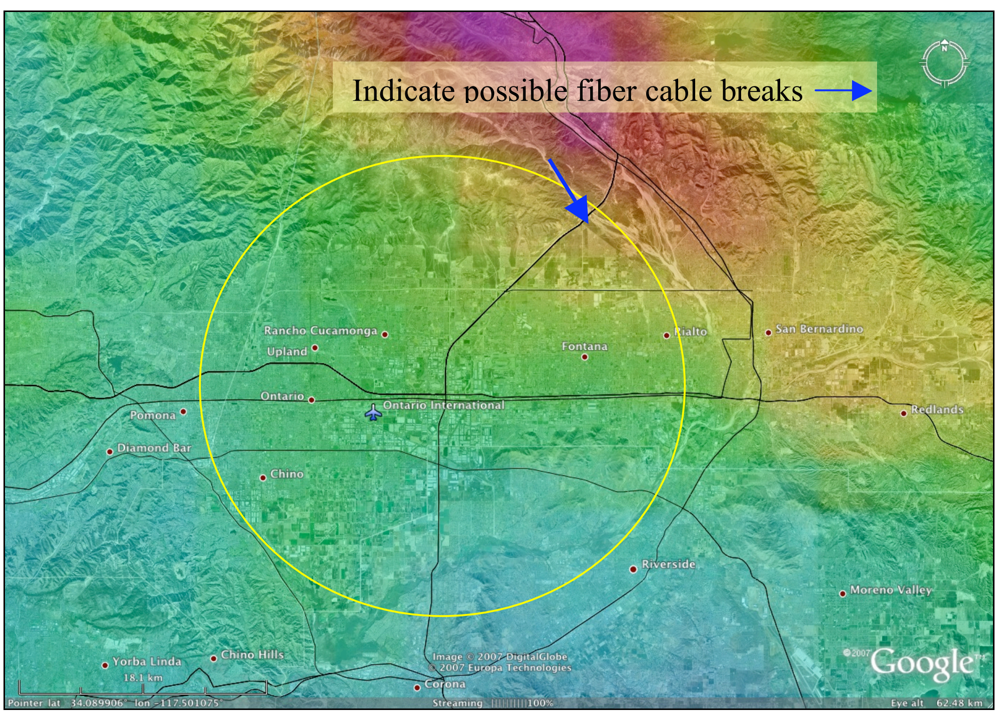

Fig. 33 The area (yellow circle) about 30 km radius of the Ontario International Airport

The number of CO/MTX/Remote within this area will be 15 to 20 buildings and the number of cell sites will be more than 40. There are about 5 to 8 9-1-1 PSAP call centers. A number of these facilities house multiple service providers as the point of entry (POE) and point of presence (POP).

Based on the performance of the network assets in the Northridge earthquake (1994), structural damage to CO/MTX/Remote will be minimum. Those that are located close to the foothill will sustain more damage. The probability of equipment damage will be small except again the equipment in buildings in the foothill areas may have loose cards, dislocated cabinet doors and fallen panels and light fixtures, etc. The cable conveyance system in these buildings will experience more damage that may cause collateral damage to the functional equipment below. Service affecting damage will more likely occurred in the buildings in the foothill areas. COs with lead-acid batteries may have acid spills on the floor. COs using this type of batteries have neutralizing chemicals on site when this happens. There may be one or two red-tagged facilities. The HVAC system in these buildings will most likely be out of service, damaged due to strong shaking. Keeping the equipment cool shall be in the emergency response plan.

The cell sites in the foothill areas will also experience some damage. The loss of electric power will surely take place, when the loss is more than 3 hours the reserve power within the cell sites will be drained and the cell site will stop functioning. Emergency responders serving the area shall be prepared with other means of communication, such as two-way radio handsets with mobile base stations. Do not forget to bring more charged batteries as a back up. Emergency responders to repair damage shall be prepared with portable power generator.

The roads and bridges in the area will sustain damage or may have collapsed sections, limiting access to the facilities. Detailed planning of alternate routes shall be in place for the emergency responders. Collapse bridges and/or highway overpasses will impact co-located fiber optic cables. The arrow in Figure 33 will be a possible point of failure.

Resource for serving the facilities has to be considered. Many of the resources for the telecommunications service providers live in the same area. They may need to look after their own family and asset after the earthquake, reducing the capacity to service multiple damage locations.

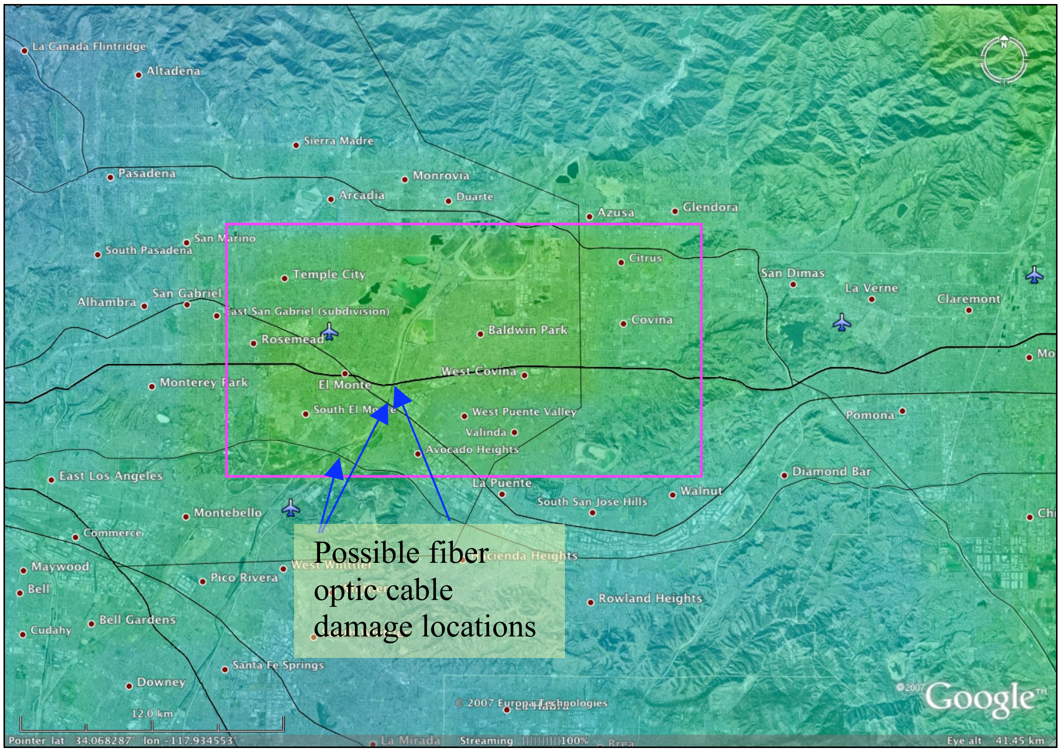

Fig. 34 The area bound by Rosemead and Covina (east & west), and Azusa and Avocado Heights (north-south), within the rectangle.

The number of CO/MTX/Remote within this area will be 10 to 15 buildings and the number of cell sites will be more than 25. There are about 3 to 4 9-1-1 PSAP call centers.

The Whittier Narrow earthquake (1987) caused cable conveyance system damage to a few COs in the areas. None of the damage is service affecting. With a bigger magnitude than the Whittier Narrow earthquake, the damage will be more than just cable rack and cable support damage. It is expected to have some non-structural damage to the buildings.

The cell sites will have similar fate as mentioned above.

There are three locations of fiber optic cables (IEC owned) that co-locate with the overpasses (indicated with arrows in Figure 34) may be damaged by collapse of the overpass sections. In addition, local fiber optic cable network (LEC owned) within this area may also be damaged. This will reduce the circuit capacity of this area. It will have a big impact on congestion with call completion rate drastically reduced. Cellular calls to landline phone will further burden the network; this was experienced by NTT, Japan during the Kashiwazaki earthquake 2007. NTT also had a number of fiber optic strands in the transmission cables damaged in five different locations due to liquefaction and lateral spreading.

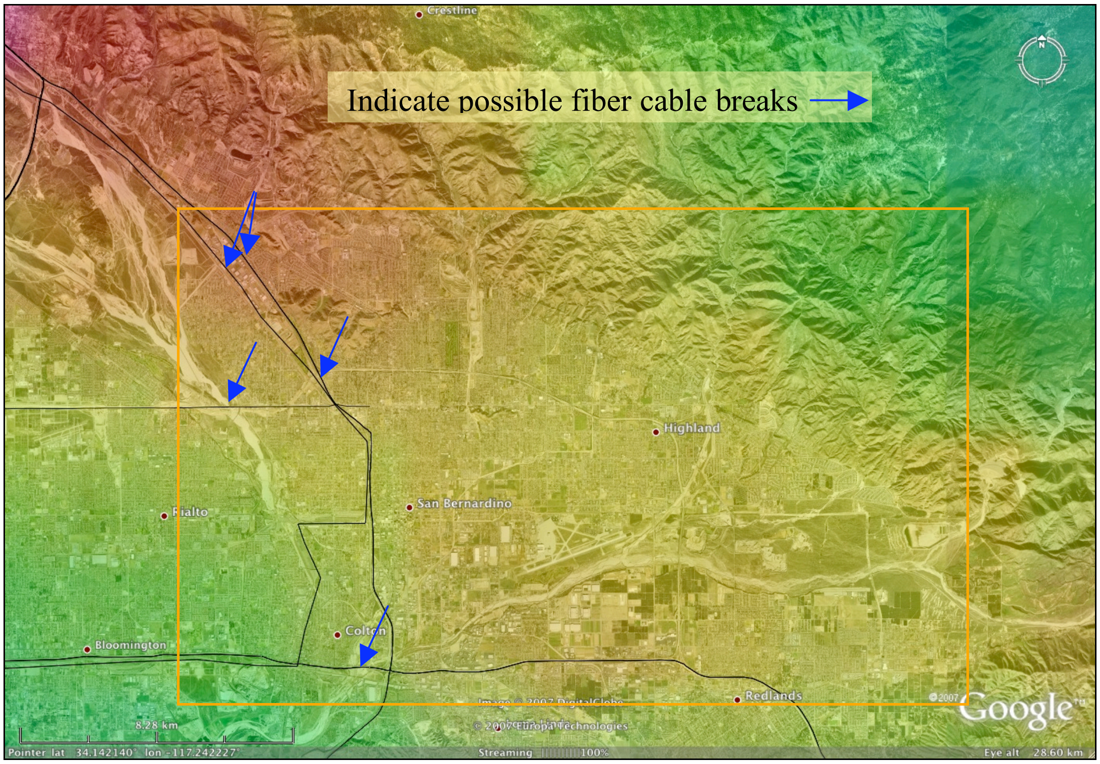

Fig. 35 The area within the orange rectangle, the San Bernardino area.

The number of CO/MTX/Remote within this area will be 15 to 20 buildings and the number of cell sites will be more than 40. There is about 8 to 10 9-1-1 PSAP call centers.

This area is in the high PGA zone; it is estimated to reach 0.8g. Extensive damage to CO/MTX/Remotes in the upper left hand (north-west) corner of the orange rectangle will occur. It will not be surprised to have a few red-tagged CO structures. The contents will sustain some damage, toppling of equipment is not expected if the equipment is anchored according to NEBS requirements. Ground deformation in this area may cause damage to some cellular towers. For CO buildings in the lower middle part of the rectangle, the amount of damage will be less.

Along the riverbanks, the probability of liquefaction may cause damage to COs and cables within that area.

The HVAC system in these buildings will most likely be out of service, damaged due to strong shaking. Keeping the equipment cool shall be in the emergency response plan.

Backup power generator without a good seismic anchoring system will be damaged and cannot be started to provide the need electric power for the telecommunications equipment. This happened to telecommunications service providers in both Loma Prieta (1989) and Northridge (1994) earthquakes.

The blue arrows in Figure 35 indicate the locations of highly probable fiber optic cable damage due to co-locating with bridges and overpasses.

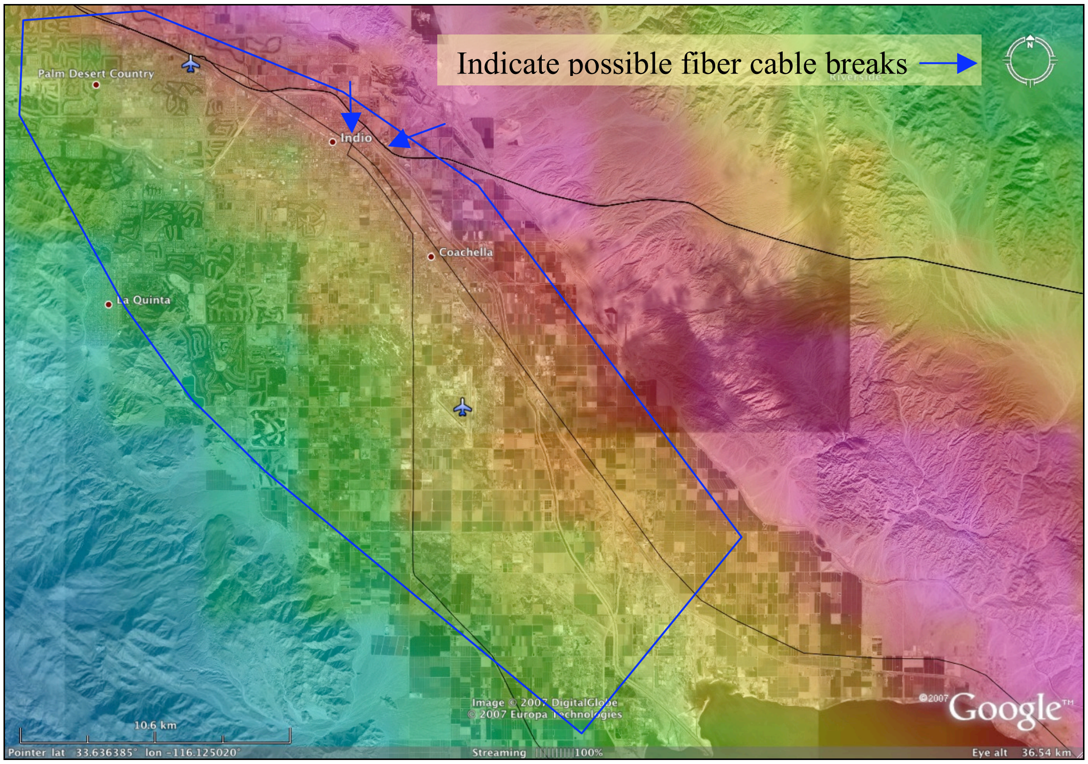

Fig. 36 The area bound by the blue line, the North of Salton Sea area.

This is another high PGA zone, as it is very close to the fault zone. The expected degree of damage will be similar to that discussed in the San Bernardino areas above.

The number of CO/MTX/Remote within this area will be 20 to 25 buildings and the number of cell sites will be more than 40. There is about 8 to 10 9-1-1 PSAP call centers.

The damage to telecommunications assets expected in this area is the same as those in the San Bernardino area.

The arrows in Figure 36 show the locations of possible fiber optic cable damage due to co-locating with bridges and overpasses.

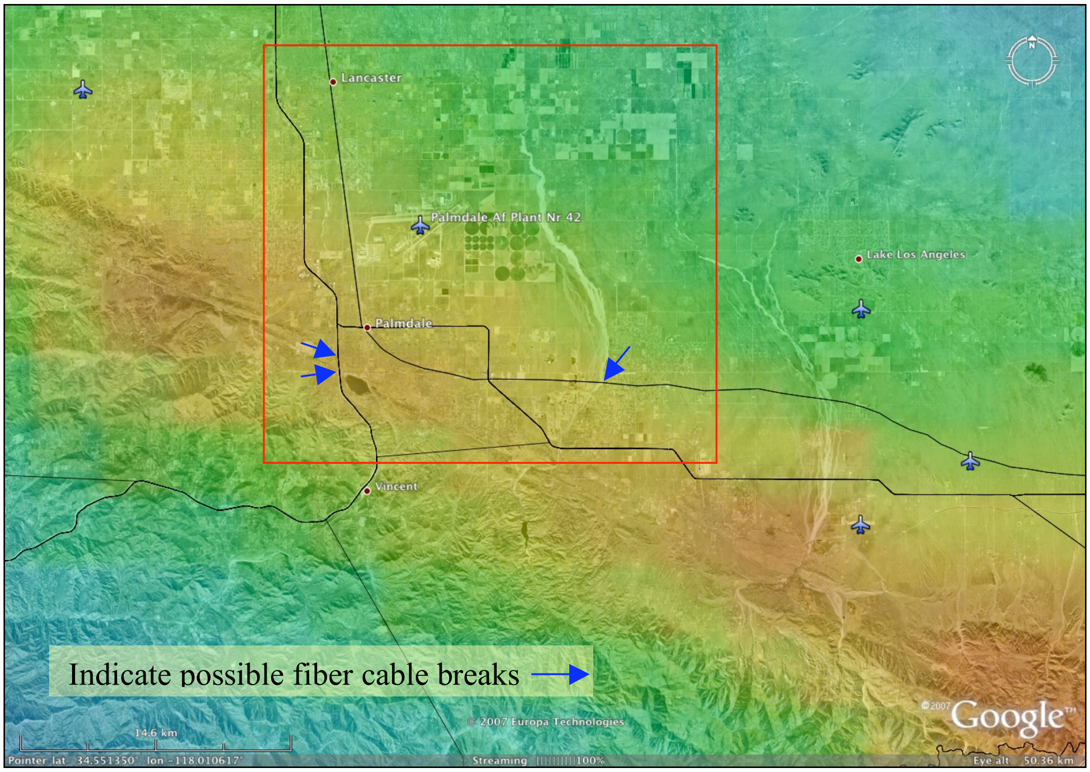

Fig. 37 The Palmdale area bound by the red line.

The number of CO/MTX/Remote within this area will be 6 to 8 buildings and the number of cell sites will be more than 30. There is about 4 to 6 9-1-1 PSAP call centers.

Telecommunications assets that are close to the Palmdale area (south-west corner of the red rectangle) will experience some non-service affecting damage. The level of damage in this area is very similar to the area shown in Figure 34.

The arrows indicate the locations where the fiber optic cables can be damaged by collapsed bridge or overpass, Figure 37.

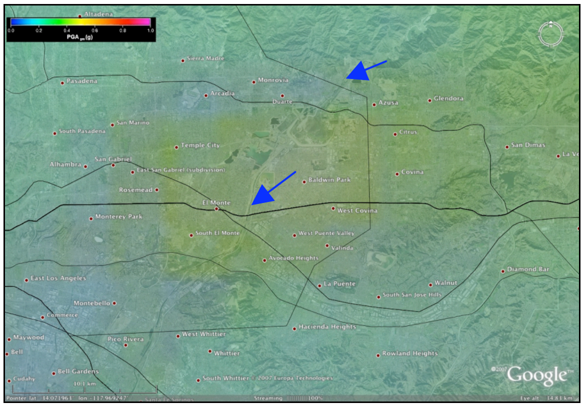

Fig. 38 The area just east of Los Angeles is expected to have PGA of 0.4g or lower. The expected telecommunications asset failure or damage will be extremely low. The arrows indicate fiber optic cables co-locating with bridges and overpasses may sustain damage due to collapses.

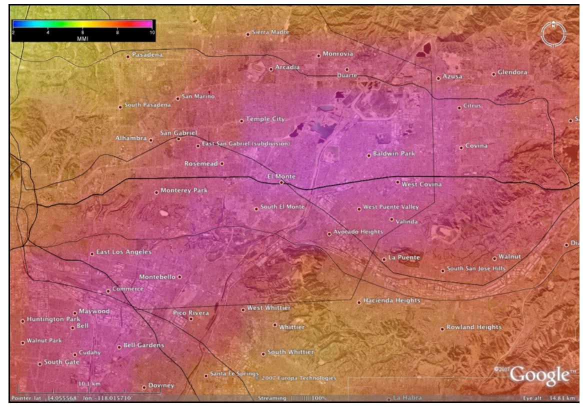

Fig. 39 The same area as shown in Fig 38 is quite different when using MMI scale. The damage expected will be residential or commercial buildings. This may impact Cell Sites that are located in these buildings.

The number of CO/MTX/Remote within this area will be 20 to 25 buildings and the number of cell sites will be more than 50. There is about 8 to 10 9-1-1 PSAP call centers.

Inn this area, even when there is no damage to the telecommunications networks, the traffic volume will be very high. This area is very similar to the Northridge area of the Northridge earthquake (1994). The average call completion for the area was 77 million calls per day with normal call volume. After the earthquake, the call volume went up to more than 2 times the normal call volume, and only 150 million call completions was achieved with restrictive network management control. More than a decade after the Northridge earthquake, the call volume is expected to be much more than 2 times normal, and the call completion will be more than 150 million. Congestion is still expected.

This is the area that emergency responders will experience delay in communicating with each other and the base of operation. Alternate means of communication have to be considered for this area.

Fault Crossing Fiber Optic Cables

The scenario earthquake fault offset is provided and the estimated offset experienced by the fiber optic cables crossing the fault is shown in Figure 40. The fiber optic cables are assets of the Inter Exchange Carriers (IECs). A list of owners of these cables is in the Appendix. Many of these owners are also local service providers of both voice (landline and cellular) and Internet services. Fragility of fiber optic cable and the size of the cables are not known, its performance in earthquakes has been good. There are two recorded incidents of fiber optic cable damage in two different earthquakes. The Loma Prieta earthquake (1989), the fiber optic cable crossing the Bay Bridge (Figure 29) and the Kashiwazaki earthquake (2007), the underground fiber optic cable in poor soil.

There are three recorded fiber optic cable damage not related to earthquake. One of them was caused by a technician who cut the cable (New York) mistaking it as a dead cable, the other was the mid-west flood (Des Moines), when water entered the cable causing the signal to deteriorate and the last one was a fiber optic cable routed along the easement of a railway track and was damaged by the rail that was dislocated by a flood (Southern California). The damage impacted a local area and did not affect the system network.

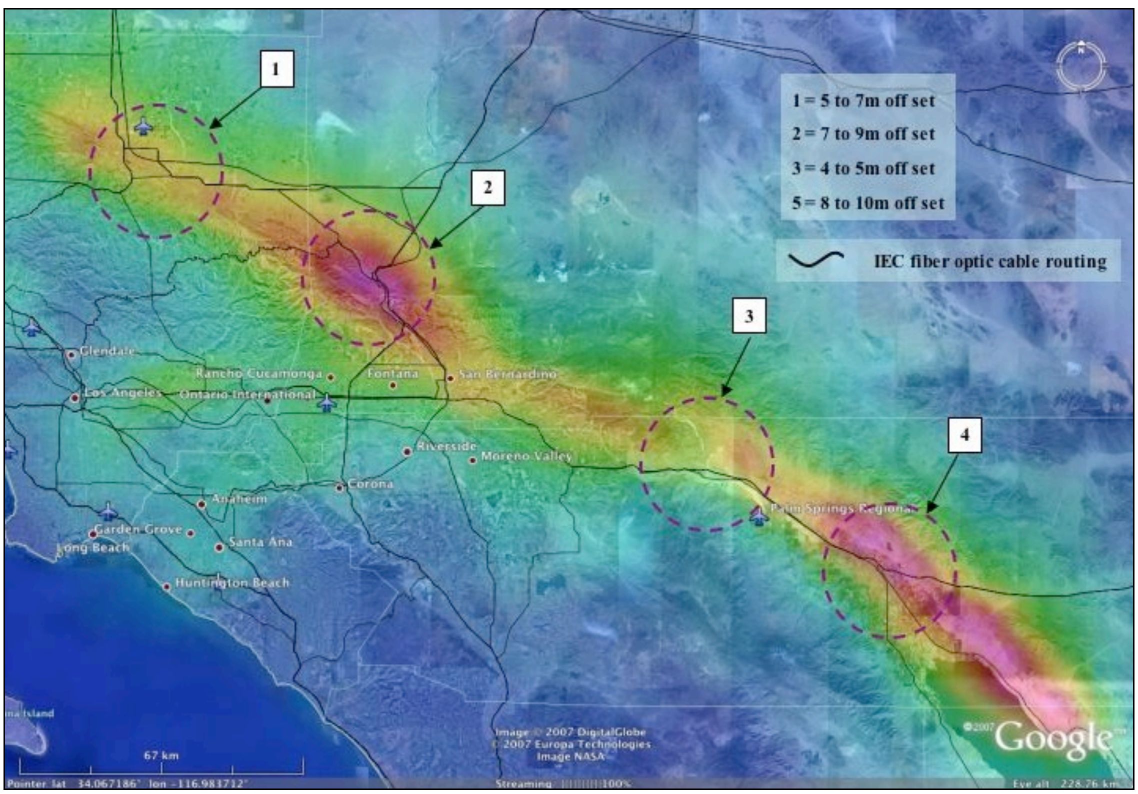

Fig. 40 Locations where fiber optic cables cross the fault are shown in circles, locations 2 & 4 have the largest off set.

Many of these cables are expected to sustain damage and depending on the method used to route the cables, some of them may be severed by the large off set. The most vulnerable cables are those buried cables in conduits that cross a fault. At least 80% of the cables will be damaged, creating a major loss of capacity to communicate in and out across the fault. The impact will extend to both north and south of immediate area, as the unaffected cables connecting east west in these areas will be used to its full capacity. For example, San Diego Airport will experience difficulty communicating with the east due to volume of traffic on the cables going east bound or coming west bound around the San Diego area.

Definitely there are links crossing the fault using other technology. Microwave has been used by IECs for a long time. Transmitting and receiving towers locating far away from the fault off set may survive and remain functional. The question is whether the towers are designed to handle the strong shaking and possible ground deformation. The other technology used by IECs is satellite link. This is expected to be the privilege of high priority users, for example GETS subscribers.

Residual capacity and repairs

Estimating the residual capacity of a telecommunications network is extremely difficult in the current state. One of the reasons is that the network cannot be isolated as a single network of a particular carrier due to interoperability and the new links are being installed by the new comers in the industry. The convergence of the voice (landline and cellular) and data (Internet, fax, VOIP, etc) networks is making it more difficult to identify the total capacity as such for the telecommunications network. In a disaster, the capacity of a network will be reduced whenever there is any damage to the network elements (nodes or links).

From the start, the network is not designed to handle all subscriber calls or data accesses. It is designed to handle a traffic pattern of the highest usage in a certain area. For instance, in a residential area, the concentration of usage may be 20% that is twenty lines are available for 100 customers. When the lines connecting to the CO are severed or the CO is out due to damage, the residual capacity of the network serving that community is zero.

The reason of using restrictive network management control in time of disaster in a region is to reduce network congestion and manage priority service users when some links are damaged.

The three to four times above normal volume of usage will off set the importance of dealing with the residual capacity.

From past earthquakes, on the average the telecommunications service providers are able to fully return to normal within three days of the event. Most of the large service providers are well prepared for adversities, such as earthquakes, wind storms, snow storms, ice storms, and floods. They have mobile CO that is CO in a trailer with quick hook up facilities and power units to restore minimum service when an area is out of service. In many cases, these units provide free phone service for the victims. These mobile units are equipped with microwave or satellite dish to connect to other CO in the network. Today TV stations are using the same type of technique to transmit on site videos to the world via satellite network. The real need is a standard procedure whereby all service providers adhere to in terms of access control and network control with both LECs and IECs in a disaster site.

Many service providers also have agreements with manufacturers to fill emergency orders within a day. Mutual aid among the service providers in a state of emergency is an un-written agreement. Spare parts and components are stored in all facilities. The more expensive spares will be stored in a few secured locations. Small power generators for cell sites without power can be delivered by the service technicians from a central location within a region. Large electric power generators can be delivered within a day, this happened in the Northridge earthquake, Figure 41.

As cable cuts are common occurrence in the industry, techniques and tools are well developed to locate the cut quickly from a CO where the transport equipment is located. The equipment will identify the link ID and the exact location of the cut or trouble point. In the case of multiple cuts in different locations, the technicians can identify the critical links and set priority to repair them first. When multiple cable cuts repair teams are required, out of State service teams will be called in to help.

Telecommunications Service Priority (TSP) is a Federal program aiming at providing priority installation and restoration of the telecommunications lines that are considered critical in times of emergency. As of 2003, 52,000 circuits are protected under TSP; most of them serve the State and local agencies. About 10% of the nation's PSAPs are registered with TSP; there are over 7500 PSAPs nation wide.

Fig. 41 Temporary mobile electric power generator was used after the Northridge earthquake at this node. The backup power generator was damaged and would be replaced. This building houses the network control center, the PSAP call center and a CO.

Lifeline interaction

The lifeline services that need telecommunications most are the emergency response services, such as police, fire fighters, and ambulance services in post earthquake situation. Not only people who require their services need telecommunications but the emergency services people need telecommunications service, too. Dispatching and managing emergency service resources in the field is extremely important to deal with urgency effectively. Electric power, gas, transportation, water and wastewater lifelines have many features that require telecommunications network to remain functional. Traffic signaling system for urban rail system, for example, is using the telecommunications network to communicate with the control centers. The freight and passenger railway signaling and control system also use the telecommunications network to manage all the trains moving on the rail system. All lifeline repair service units require a functioning telecommunications network while working in the field for reporting and/or requesting addition resources. As it was mentioned above, the PSAP call centers require a functioning telecommunication network to be able to execute their important role in emergency response, in most cases they are the first emergency responders.

However, as reflected in the scenario section above, this lifeline is being affected by other lifelines such as electric power and water supply. Prolonged loss of electric power means loss of service of a node. This will have a huge impact on the subscribers served by that node. Some of these subscribers may be business units, or ISPs. Large size air conditioning units require water for the diffusers, without water these units will stop functioning. In a hot day, the electronic equipment inside a node can be overheated and stop functioning. For security reasons, the buildings for the nodes are almost windowless, that means keeping the equipment cool without air conditioning is difficult.

Both fire and flood have a large impact on the telecommunications networks. The Northridge earthquake gas explosion and fire on Balboa St is a good example of taking out both aerial and underground transmission cables (fiber optic and copper cables). A broken water main flooded a power room of a CO in the Loma Prieta earthquake, resulted in millions of dollars clean up and equipment replacement.

Also as mentioned in the scenario section, when a link is co-located with a bridge or an overpass for obvious reasons, the link is vulnerable to bridge and overpass collapse.

In order to reduce loss of the telecommunications network, whether physical loss to the nodes or collateral damage resulted from other lifelines, a systematic analysis of all the layers as shown in Figure 42 is required. When the data is collected, a computer model can be developed, similar to HAZUS that the service providers can use to reduce potential loss.

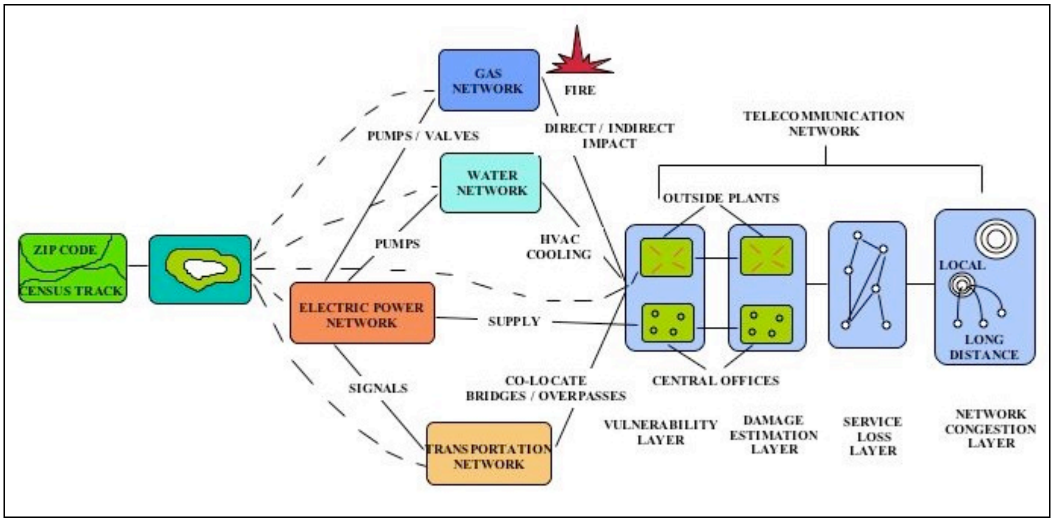

Fig. 42 Lifeline interdependence model for the telecommunications network

Mitigation

Starting from late-1980, telecommunications service providers in California initiated a seismic upgrade program to bring all the equipment installations to the current NEBS standard. It was a seven-year program involving more than 150 COs. Then right after the Loma Prieta earthquake, an effort to improve electric power backup was established. COs without backup power generators were equipped with a quick connect system on the outside of each CO for external power hook up. The effort of upgrading buildings was another program after the Loma Prieta earthquake. Both efforts were lessons learned from the earthquake.

The basic objective of all these programs was to maintain full operation during and after an earthquake, as set in the NEBS. In terms of system performance, these programs did not address the congestion problems right after an earthquake. However, it is a big step forward to lighten the burden of network congestion.

With more and better knowledge of seismic impact due to ground conditions on building structural and foundation designs, the telecommunications service providers shall be encouraged to evaluate the older buildings for their structural performance based on the information, and upgrade where necessary. This is of particular importance to cell sites that are located in commercial buildings, such as apartments, office buildings, that are not designed and built with the same importance factor as COs.

In addition, more and more raised floors are installed for new equipment offices and control centers. Good engineering practices must be applied to reduce loss.

From a network perspective, redundancy and diversity of both nodes and links shall be encouraged. Network redundancy with diversity is an excellent approach to deal with adverse situations in a disaster. Although it may not seem to be a good financial model, in fact the benefits of preparedness against disasters (earthquakes, floods, cyber attacks, etc.) will always be greater than the costs.

The most cost effective mitigation effort, in terms of reducing equipment loss is sufficient anchorage for the equipment. This is based on the assumption of a structurally sound building. The material and labor cost comparing to the cost of the equipment is non-significant.

For emergency responders, joining the GETS and TSP programs are highly recommended.

Appendix and References

1. IEC Fiber optic cables belongs to:

   - GST
   - AT&T
   - Sprint
   - Qwest
   - Enron
   - PSI Net
   - PF Net
   - Internet Commerce and Communications
   - Ardent Communication
   - Sierra Pacific Communications
   - Williams Communications
   - Electric Lightwave

2. GETS – Government Emergency Telecommunications Service, http://gets.ncs.gov/
3. TSP – Telecommunications Service Priority, http://ncs.gov/
4. CO – Central Office
5. Financial Management of Earthquake Risk, EERI Endowment Fund White Paper, May 2000, Chapter 6 Lifelines.
6. NEBS – New Equipment Building System, a Bell CORE document.
7. PSAP – Public Safety Answering Point (9-1-1 call center).
8. PSTN – Public Switched Telephone Network (the voice network for landlines).
9. MTX – Mobile Telephone Exchange (CO of the cellular telephone network).
10. IEC – Inter Exchange Carrier.
11. LEC – Local Exchange Carrier.
12. PBX – private Branch Exchange.
13. AC – Alternating Current.
14. DC – Direct Current.
15. NCS – National Communications System.
16. CS – Cell Site.
17. NSTAC – National Security Telecommunications Advisory Committee.
18. ISP – Internet Service Provider.
19. EO – End Office.
20. National Hazard Mitigation Saves – An Independent Study to Assess the Future Savings from Mitigation Activities, MMC, 2005