

DYNAMIC CHANGES IN SUBSCRIBER BEHAVIOR AND THEIR IMPACT ON THE TELECOMMUNICATIONS NETWORK IN CASES OF EMERGENCY

Ahmad Jrad, Gerard O'Reilly, Stephen Richman
{jrad, goreilly, srichman}@lucent.com
Bell Laboratories / Lucent Technologies,
101 Crawfords Corner Rd.
Holmdel, NJ 07733

and

Stephen Conrad, Andjelka Kelic
{shconr, akelic}@sandia.gov
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

The telecommunication network is recognized by the federal government as one of the critical national infrastructures that must be maintained and protected against debilitating attacks. We have previously shown how failures in the telecommunication network can quickly lead to telecommunication congestion and to extended delays in getting calls to complete successfully.

However, even if the telecom network remains fully operational, the special telecommunication demands that materialize at times of emergencies and dynamically change based on subscriber behaviour can also adversely affect the performance of the overall telecommunication network.

The Network Simulation Modeling and Analysis Research Tool (N-SMART) has been developed to support detailed wireline and wireless network simulations. N-SMART is a discrete event (call level) telecom model that simulates capacities, blocking levels, retrials, and time to complete calls for both wireline and wireless networks. N-SMART supports the capability of simulating subscriber reattempt behaviour under various scenarios. Using this capability we will show how the network can be adversely impacted by sudden changes in subscriber behavior. We will also explore potential solutions and ways of mitigating those impacts.

INTRODUCTION

Previously in [1], we found a number of interesting results for wireline and wireless telecom networks under stress.

- Network congestion lasts until well after the causing disrupting event has subsided.
- Service providers should not place many key switches in the same central office. The failure of a

single office can cause ripple effects in blocking to reverberate throughout the entire network.

- Wireline and wireless networks in a metropolitan area support each other in times of trouble. As such, the presence of multiple networks enhances resiliency of overall network communications, even though they weren't originally designed for that purpose.
- Given that either network (wireline & mobile) is equally likely to suffer a disruption, the resiliency of the overall communication network is best when the networks are of relatively equal sizes in terms of load. If one is much larger and suffers a disruption, the load shift congests the smaller network.
- This resiliency is caused by customer behavior in switching networks when one is failed. But the switchover in demand onto the non-disrupted network may cause significant congestion in that destination network.

This last conclusion from our previous paper was one of the reasons that motivated the analysis in this paper. User behavior and changes to it can play a critical role in how a failure propagates during emergencies [2]. It also leads to potential mitigations by educating users on how to react in times of crisis.

In this paper, we investigate the resilience of the telecommunications infrastructure during emergencies (earthquakes, hurricanes, tornados, flooding, etc.) where traffic surges and the telecom infrastructure can be damaged. The infrastructure scenario represents the state of the networks today, where the wireless network size roughly equals the wireline network size. To perform our study, we introduce a model for the telephony infrastructure for metropolitan service areas. Our goal is to develop a baseline functional model of the telecom system and then study the customer behavior in the presence of telecom and/or other infrastructure system failures and overloads.

We first introduce our simulation that represents a metropolitan area telecommunications network. Then, we describe disruption and overload scenarios. We present simulation results and compare the emergency scenarios in terms of network call carrying capacity and customer behavior. Finally, we conclude our paper with a summary and future research directions.

N-SMART SIMULATION MODEL

The Network-Simulation Modeling and Analysis Research Tool (N-SMART) has been developed to support detailed wireline and wireless network simulations [3]. It studies telecom network readiness and traffic behavior on various disaster scenarios. It can create scenarios that demonstrate the pattern of telecom traffic loads and user behavior during the time of disaster, such as physical line disconnection and switching system failure.

N-SMART is a discrete event (call level) telecom model that simulates capacities, blocking levels, retrials, and time to complete calls for both wireline and wireless networks. Figure 1 depicts the building blocks of the N-SMART-Voice simulation model, information input, and model output.

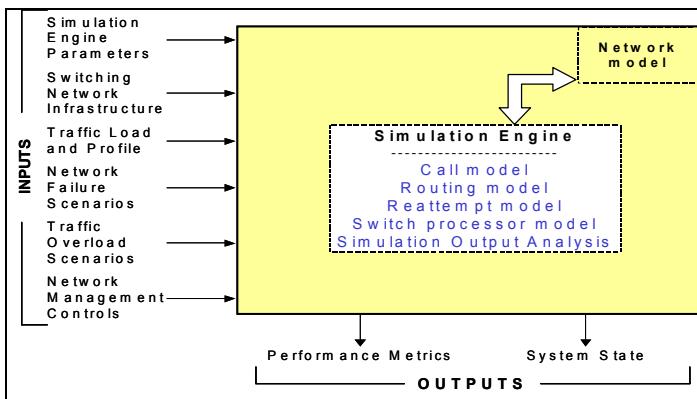


Figure 1. N-SMART-Voice Model

Various simulation scenarios analyze how different traffic patterns, traffic loads, user behaviors, and disaster severities impact network performance and recovery. By analyzing the results of simulations, the tool shows how different telecom elements, such as bandwidth deficiency, switch processor overload, and user behavior, impact the performance of the network and its robustness.

The simulation engine consists of algorithms to generate events related to calls, re-attempts, network failures, processor overloads, and simulation output. Central to the simulation depicted in Figure 2 is the call model across wireline and wireless networks.

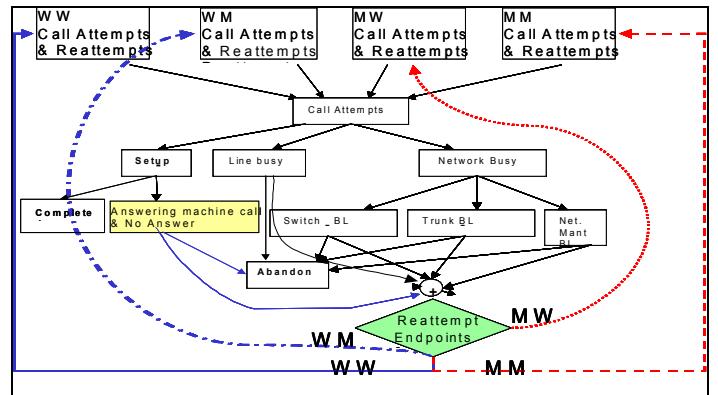


Figure 2. Call Flow Models

WW: Wireline to Wireline; MM: Mobile to Mobile
WM: Wireline to Mobile; MW: Mobile to Wireline

END USERS ACCESS DISTRIBUTION

End users have a choice among alternate communication means made possible through the rapid advances in networking technology (wireline - copper, coax, fiber, and wireless - cellular, wi-fi, wimax). At present we see some users with only wireline phones, other users with wireless phones only, and yet others with access to wireline and wireless phones at the same time.

Trends in recent years have shown that while the number of subscribers that rely exclusively on wireline access shrinks, the number of subscribers using wireless access is increasing at a faster rate. If this trend continues in the future it would mean that a majority of subscribers will eventually have access to both wireline and wireless communication in the future. The technology trend also promises to offer these users multiple modes of utilizing their telecommunication venues.

THE REATTEMPT MODEL

First a typical call attempt arrives at a particular switch for a certain destination switch as described by the traffic load and the traffic profile. The call is accepted and routed through the network (set up) if there are sufficient trunk and processing resources in the switch and the network. The call may be blocked if the called line is busy, or if the network is busy, which may be due to trunk blocking along the route of the call (direct route and alternate routes). The network can become busy due to switch blocking because of processor congestion, or network management blocking. If a call is blocked, the caller may abandon the call set-up request or re-attempt later on either the wireline or wireless network. Routing decisions are based on the originating and terminating

switches of the call. A call is referred to as incomplete if the call attempt results in no answer, line busy, or network busy. An incomplete call may be abandoned or re-attempted. A re-attempt model based on [6] is used in the simulation. According to this model, a call would re-attempt with a certain reattempt probability after an exponentially distributed reattempt time. Reattempt parameters are a function of whether the call was blocked due to a line busy or network busy. These dispositions determine how fast reattempts will be made. The historical reattempt model parameters [6] are shown in Table 1.

Table 1. Reattempt Model Parameters

	No Answer	Line Busy	Network Busy via Congestion
Probability	13%	6%	Dynamically computed
Reattempt probability	61%	72%	86%
Mean time to reattempt	3 Minutes	18 Minutes	24 Minutes

The reattempt model shown in Table 1 is applicable when there is only one telecommunication network available. The goal of this paper is to investigate the inter-dependencies between wireless and wireline systems as a function of these customer behaviors. When two different network technologies are available, a caller might retry an incomplete call in the alternate network. The retry would occur with the same pair of endpoints or may happen after changing one or both of the endpoints, e.g., wireline endpoint to wireless endpoint and vice versa, with a total of 4 options as shown in Figure 2. This depends, of course, on the availability of options for the end-user:

- For an initial Wireline user, is a wireless phone available? This will depend on the mobile penetration of the market for each user type in the metropolitan area.
- For an initial mobile user, is a wireline phone available? If they are on the move (i.e., not at home or business), then they might not have access to a Wireline phone.

The endpoint for the destination can also be changed based on the availability of an alternate phone number and the caller's knowledge of it. N-SMART incorporates a detailed probabilistic model to reflect these network switching events for reattempts. In fact, this switching of endpoints shifts the load from one network to the other network. For example, for a call blocked in the wireline network because of a failed

switch, the callers would reattempt their calls over the wireless network. This results in the shift of load from wireline to wireless network. If such calls are successfully completed over the wireless network, we can say that the wireless network alleviates the problem in the wireline network, and hence, increases the resilience of the telecommunications infrastructure. On the other hand, if these reattempt calls congest the wireless network, and cause the blocking of calls in this network, we can say that the wireline network impacts the performance of the wireless network negatively. In the following section, we investigate this interaction between networks in detail using the N-SMART simulation model.

THE METROPOLITAN NETWORK MODEL

We have analyzed a number of metropolitan areas in the course of our work. In this paper, we chose a medium sized metropolitan area, where there are as many wireline subscribers as wireless subscribers. In addition, we also assume that the traffic generated by each wireless subscriber equals the traffic generated by each wireline subscriber in Erlangs. Based on current trends; this is a reasonable representation of the expected future network.

Metro Network: 900,000 wireline subscribers and 900,000 wireless subscribers

NETWORK ASSUMPTIONS

We design the Metro network to carry the normal expected traffic at peak hour. We use high usage trunk groups to carry the bulk of the traffic and then allow any blocked calls to go over final trunk groups to the Local Tandems (LT's) or Access Tandems (AT's) based on the type of call. The design goal was to guarantee a maximum blocking of less than 1% on any given route.

In addition, we build high usage trunks only if there is sufficient traffic to utilize the trunk group. For routes where there is little demand all traffic would be sent on the final trunks to the LT(s) or AT(s).

Figure 3 shows the routing that is allowed in the network. The dashed routes in Figure 3 are high usage routes and the solid routes are the final routes. The dashed and solid routes of a given color show the routing rules for that traffic type. Therefore, looking at the blue trunks, we see that traffic between two MSC's is sent over a high usage trunk group, but in case that high usage group is not available, the call is sent via the corresponding AT's of the two MSC's.

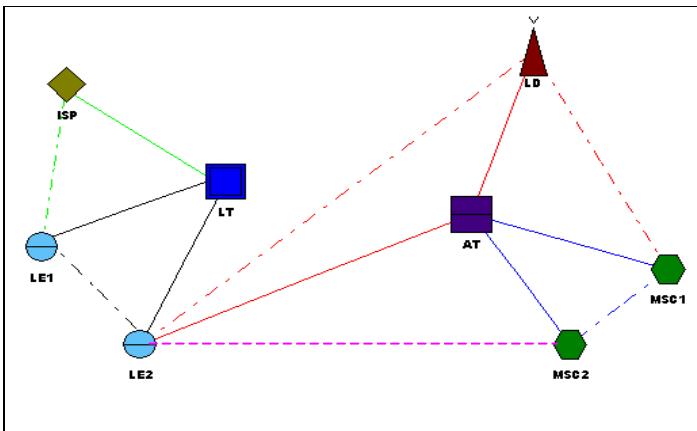


Figure 3. Traffic Routing Model

LE = local exchange
 MSC = mobile switch center
 LD = Long distance switch
 AT = access tandem
 ISP = internet provider
 The normal traffic pattern in a telecommunications network changes as a function of the time-of-day. During certain hours of the day, the traffic is at a maximum while some other hours there is very small amount of traffic. This is represented by a traffic profile, as shown in Figure 4, in the N-SMART model.

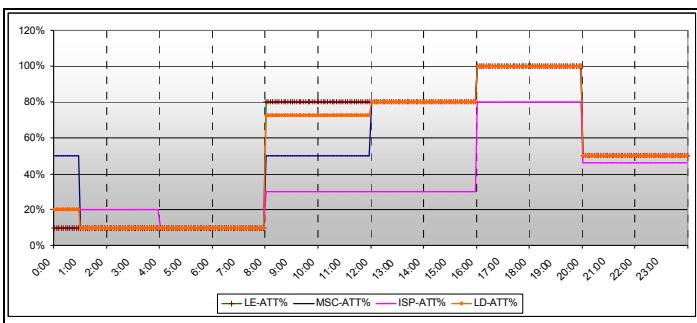


Figure 4. 24-Hour Traffic Profile

Figure 4 shows the actual profile during a typical 24-hour period.

HISTORICAL DISRUPTION SCENARIOS

During a disaster (or similar) scenario, telecom users are impacted by events that unfold around them and they respond in ways that almost invariably cause some stress on the telecom network. Oftentimes, these changes are difficult to predict ahead of time. However, in many instances, it is possible to foresee the trends that are likely to occur. It is therefore possible to develop disaster response plans that would incorporate disaster mitigation strategies that can minimize the resulting disruptions.

To show how a disaster can affect the telecom network, we present the following actual events and how they led to varying levels of network disruptions.

1. **Stock Market Crash 1987** – This was the precipitous fall of the stock market in 1987 that was largely attributed to automated panic selling.
 - a. Heavy distributed call load.
 - b. Broker 800 numbers in high use.
 - c. Above-normal SCP blockage.
 - d. Heavy specialized load impacted the signaling network and led to degradation of other services.
2. **First WTC Bombing of 1993** – This was the first bombing of the World Trade Center in 1993.
 - a. No damage to the 3 WTC switches at the time.
 - b. Telecom congestion seen on WTC switches. Heavy load of incoming calls.
 - c. No single number experienced a focused overload.
 - d. Complaints regarding E911 services. Overload on E911 operators.
3. **Olympic Park Bombing in Atlanta, 1996** – Even though this was a minor event, it can shed some light on how these events can affect telecom networks in unpredictable ways.
 - a. Congestion the morning after the Olympic park bomb. Cause unknown.
 - b. Incoming calls to one number were causing overload.
 - c. Root Cause: Atlanta paper held morning edition to add bombing coverage. This led to many non-delivery calls from customers.
4. **WTC Disaster of September 11, 2001** – This disaster combined the scenarios of user overload behavior as well as extensive damage to the telecom infrastructure.
 - a. 6 Total switches were lost in this event.
 - Two switches in WTC buildings.
 - Four in 140 West street. These were flooded due to firefighting efforts.
 - b. Operations network seriously impacted
 - c. Network alarm storm, largest alarm storm ever witnessed.
 - d. Call demand sustained 2X overload for 24 hours
 - e. Wide-spread Trunk busy due to heavy load
 - f. Lost connectivity to Manhattan switches (72 offices)
 - g. E911 services severely overloaded

5. **Houston Evacuation (Hurricane Rita), 2005** – This event shed some light on the types of things that can go wrong during a large scale evacuation in anticipation of an impending disaster.
 - a. With most subscribers on the move, there was an overload of the wireless network.
 - b. The base stations could not service all the subscribers in high concentration points on the highways.

SIMULATED SCENARIOS

In the forthcoming simulations we will consider the following scenarios:

1. **Baseline Condition** – This shows the traffic pattern under normal operating conditions.
2. **Case 1: Headline News Condition** – This is like the San Francisco Earthquake, or the WTC bombing where the call volume increases significantly and subscribers become more persistent in reattempting until they are able to get connected.
3. **Case 2: Major Evacuation** – This is modeled after the Houston evacuation. In this scenario, the wireless traffic is overloaded, and in addition, wireless subscribers are not permitted to switch to wireline devices on the originating side, since they are presumably on the road and in their cars.
4. **Case 3: Emergency Condition** – This is modeled after the WTC bombing of 1993 where the E911 services are overloaded causing a targeted overload in call volume on the wireline network. Of course subscribers are permitted to call 911 from whatever device they choose.

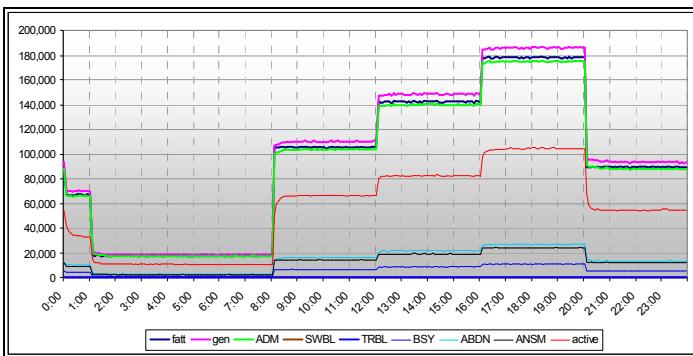


Figure 5. Baseline Calls

These scenarios will show how traffic is affected as a result of user behavior in heavier call volume, more persistent calling and the ability to use one or both networks given the conditions at hand. But first, we show the baseline traffic pattern for our network under normal operating conditions (Figure 5).

There are 9 statistics in Figure 5 as follows:

1. FATT - first attempts of calls
2. GEN - total calls generated
3. ADM - admitted calls which complete
4. SWBL - switch blocked calls
5. TRBL - trunk blocked calls
6. BSY - calls which end to busy line
7. ABDN - calls which are abandoned
8. ANSM - calls routed to an answering machine
9. ACTIVE - total active calls across the network

All of these statistics, with the exception of ACTIVE, are call counts within 5-minute intervals. ACTIVE is a snapshot of the total number of calls at the sampling instant. Figure 5 shows call statistics for the baseline scenario, also representing the 24-hour traffic profile for our metropolitan area. The busy hour is from 16:00 (4 PM) to 20:00 (8 PM). Under normal conditions (no disruptions), most first attempts (FATT) are admitted (ADM) and complete except for a small fraction encountering busy. But most of them are retried and complete on subsequent attempts if the user doesn't abandon.

In the following sections, we present a discussion of the simulation results. Our objective is to compare how each network is affected by the failure condition, and, where instructive, the impact on the individual sub-networks within the overall network

CASE 1: HEADLINE NEWS CONDITION

This condition envisions a sudden rise in call volume on all telecom networks. This is also accompanied by a more persistent re-attempt behavior on the side of the users. This means the following:

Table 2. Case 1 Reattempt Model Parameters

	No Answer	Line Busy	Network Busy via Congestion
Reattempt probability	80%	80%	80%
Mean time to reattempt	3 Minutes	10 Minutes	5 Minutes

In addition, the new traffic profile is shown in Figure 6. The red line indicates the normal peak hour traffic level. The overload traffic condition occurs at 14:00 and continues till 21:00 where traffic returns to the peak normal traffic.

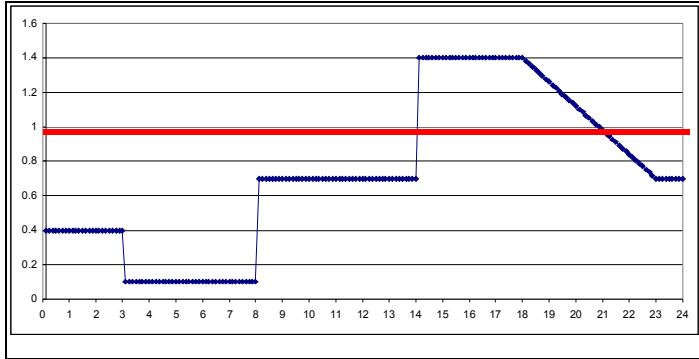


Figure 6. Traffic Profile for Case 1

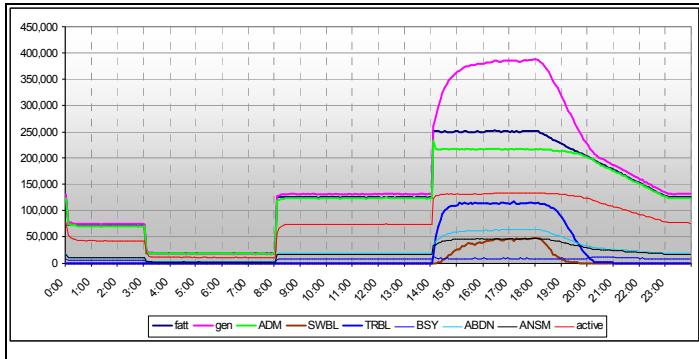


Figure 7. Case 1 Headline News - Overall traffic

Figure 7 shows the overall traffic of case 1. Note the clear rise in generated calls at 14:00, which leads to a rise in switch blocking and trunk blocking. This occurs as a result of increased demand even though the network does not suffer from any failure at that time.

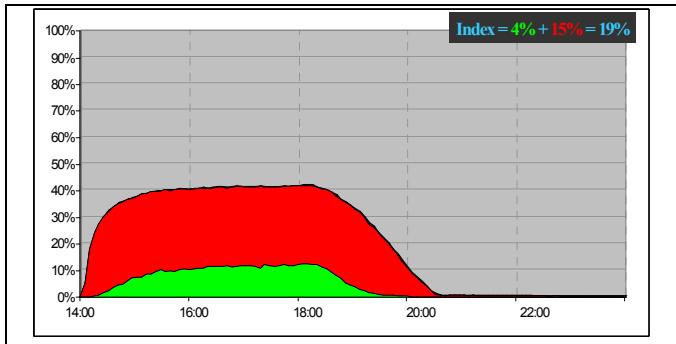


Figure 8. Case 1 Headline News - Overall Blocking

Figure 8 shows the impact of the traffic overload in terms of blocked calls. It shows the amount of blocking caused by switch blocking (green region) and trunk

blocking (red region). The regions in the plot are cumulative, therefore, the overall height of the curve indicates the total blocking at any given time. We can see that blocking of calls rises slightly above 40% at peak blocking conditions.

CASE 2 – MAJOR EVACUATION

The factors that lead to traffic overload in this case are the number of users that are confined to use their mobile phones and without access to landlines. We model an overload of wireless traffic (2X overload) and also disable wireless users on the originating side from switching to their landlines.

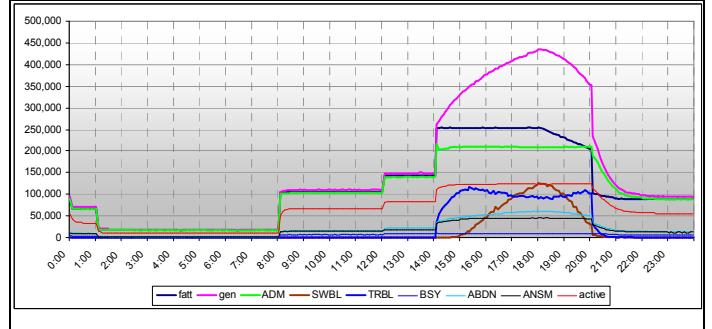


Figure 9. Case 2 Major Evacuation - Overall traffic

Figure 9 shows the impact of traffic overload during the evacuation on the entire network. Again we see the switch blocking and trunk blocking become a significant factor quickly after the traffic overload. This simulation was done with normal reattempt behavior. However, we also tested another scenario with frantic reattempt and we observed a greater amount of blocking at peak hours.

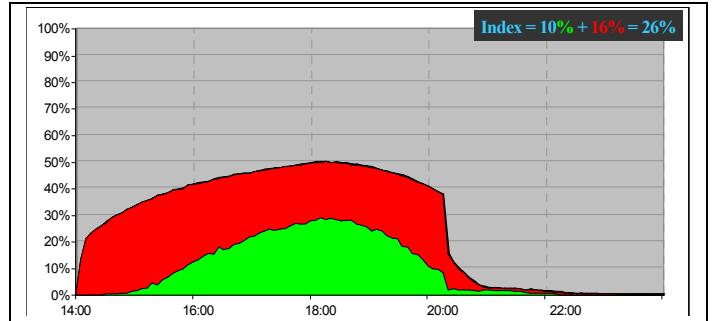


Figure 10. Case 2 Major Evacuation – Overall Blocking

Figure 10 shows the overall temporal blocking for case 2. The total level of blocking reaches 50% at peak level. Switch blocking also is more of a factor in this case than in the previous one.

CASE 3 – EMERGENCY CONDITION

We model the E911 overload by overloading the traffic on the major wireline switches to 2X level. This leads to an overall increase in traffic, which is substantially, less than a 2X global overload. However, it would also simulate the uneven distribution of the overload and the greater burden posed on E911 service centers. We also assumed a frantic reattempt behavior as would be expected for blocked emergency calls.

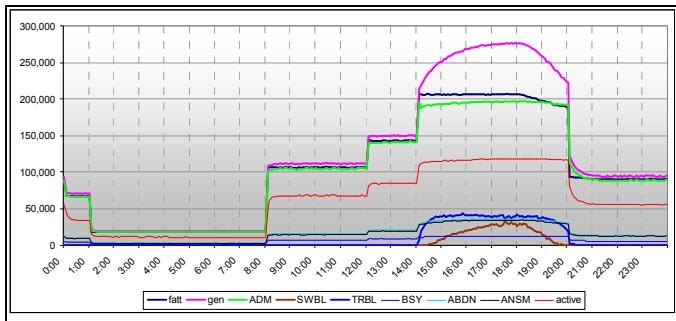


Figure 11. Case 3 E911 Overload - Overall traffic

Figure 11 shows the overall impact on the entire network from the E911 overload.

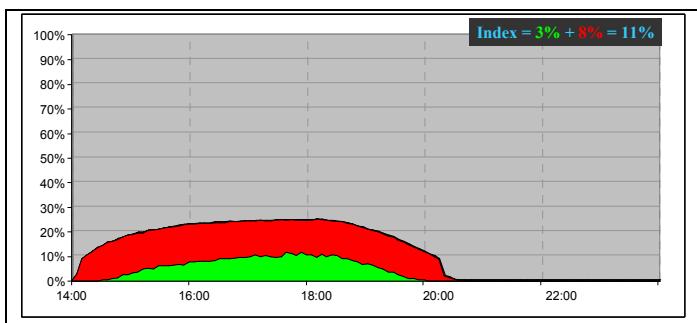


Figure 12. Case 3 E911 Overload – Overall Blocking

Figure 12 shows the overall temporal blocking for case 3 above. The peak level of blocking reaches 26%. The overall traffic blocking in this scenario is much less than in the previous two cases.

MITIGATION VIA CUSTOMER BEHAVIOR CHANGE

The previous sections showed the significant congestion resulting from typical customer behavior during an emergency situation.

There are several ways to mitigate the scenarios that we have studied earlier ranging from the ones that depend on changing customer behavior to others that can simply be effected by the service providers themselves.

To illustrate the dependence of the network degradation on the subscriber behavior we show how the network blocking is affected by the probability of subscribers reattempting their calls, and then how that is further impacted by the average waiting period before a reattempt is made. The resulting chart is shown in Figure 13. This figure corresponds to scenario 1 earlier, but we can expect similar results for the other cases.

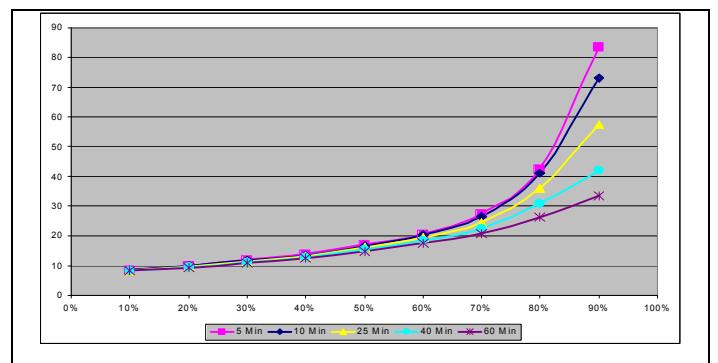


Figure 13. Case 1 Headline News - Overall traffic

The above mitigation has the disadvantage of relying on the users to change their behavior. This may not always be possible nor practical. Other mitigation solutions that do not rely on customer behavior include the freeing up of less critical telecom resources in favor of allowing the more critical ones to have a better chance of completing. Therefore, in cases where it is critical to reach emergency operators locally, the telecom providers may choose to drop most or all the ISP traffic that use modems during the peak conditions. This will free up some circuits that can be utilized in completing more critical voice calls. In addition, long distance traffic can be also reduced in favor of allowing local traffic to complete more readily. We simulated the above cases by dropping the ISP traffic completely and reducing the long distance traffic to 50% and the results showed varied improvements for the 3 scenarios.

Table 3. Effects of Reducing ISP and LD Traffic

	Case 1	Case 2	Case 3
<i>Original Overall Blocking</i>	22.7%	34.4%	12.2%
<i>Blocking with 50% LD and no ISP</i>	10.3%	24.3%	9.9%

SUMMARY AND CONCLUSIONS

In this paper, we have shown how changes in subscriber behavior can have a decisive impact on the operation of a telecom network. Our simulation scenarios support the following conclusions:

- Changes in subscriber behavior drive network congestion during emergencies.
- If re-attempt probability can be decreased and the time between reattempts can be increased on the part of subscribers, this reduces network congestion dramatically. One way to accomplish this is to encourage subscribers via broadcast television to use their phones selectively. This reduces traffic load and the probability of successful call completion.
- Frantic reattempt behavior (those with high probability of a reattempt, and a smaller wait interval between reattempts) are especially degrading to the overall network performance.
- Reducing less critical traffic in an emergency condition (like ISP and long distance) can help reduce the overall level of blocking during peak hours of use.
- Lastly, network management controls are not usually done within local metropolitan area networks. They are done in long distance networks. Adopting network management controls in local networks would be another way to reduce congested networks. This might require expensive modifications to switches, which are not likely to be done on the

legacy networks. For newer IP based networks, these management controls should be put in place.

FUTURE DIRECTIONS

So far we have been dealing with circuit switched voice networks, which dominate today in metropolitan carrier networks. More and more networks nowadays are starting to migrate to IP based networks supporting VOIP (Voice Over IP). In addition the network architecture is changing to support the requirements of newer and more advanced services. The modeling of this network evolution and its impact on the critical infrastructure is one of our future goals in this study.

REFERENCES

- [1] A. Jrad, H. Uzunalioglu, D. Houck, G. O'Reilly, S. Conrad, W. Beyeler. "Wireless and Wireline Network Interactions in Disaster Scenarios," MILCOM 2005.
- [2] Gerard O'Reilly, Ahmad Jrad, Theresa Brown, Stephen Conrad, "Critical Infrastructure Analysis of Telecom for Natural Disasters," Networks 2006, November 2006.
- [3] David J. Houck, Eunyoung Kim, Gerard P. O'Reilly, David D. Picklesimer, Huseyin Uzunalioglu, "A Network Survivability Model For Critical National Infrastructure," Bell Labs Technical Journal, Volume 8, Number 4, 2003.
- [4] Gerard P. O'Reilly, David J. Houck, Eunyoung Kim, Thomas B. Morawski, David Picklesimer, Huseyin Uzunalioglu, "Infrastructure Simulations of Disaster Scenarios," Networks 2004, Vienna, Austria, June, 2004.
- [5] Walt Beyeler, Stephen Conrad, Thomas Corbet, Gerard P. O'Reilly, David D. Picklesimer, "Inter- Infrastructure Modeling - Ports and Telecommunications," Bell Labs Technical Journal, Volume 9, Number 2, 2004, 91-105.
- [6] K.S. Liu, "Direct Distance Dialing: Call Completion and Customer Retrial Behavior," Bell System Technical Journal, 59:3 (1980), 295-311.