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A Generalized Framework for Modeling Next Generation 911 Implementations

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A Generalized Framework for Modeling Next Generation 911 Implementations

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Abstract

This document summarizes the current state of Sandia 911 modeling capabilities and then addresses key aspects of Next Generation 911 (NG911) architectures for expansion of existing models. Analysis of three NG911 implementations was used to inform heuristics, associated key data requirements, and assumptions needed to capture NG911 architectures in the existing models. Modeling of NG911 necessitates careful consideration of its complexity and the diversity of implementations. Draft heuristics for constructing NG911 models are presented based on the analysis along with a summary of current challenges and ways to improve future NG911 modeling efforts. We found that NG911 relies on Enhanced 911 (E911) assets such as 911 selective routers to route calls originating from traditional telephony service which are a majority of 911 calls. We also found that the diversity and transitional nature of NG911 implementations necessitates significant and frequent data collection to ensure that adequate models are available for crisis action support.

ACKNOWLEDGMENTS

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- Anna Stratham, Office of Emergency Management and Communications, City of Chicago

The time and patience of these individuals helped us in modeling and more deeply understanding emergency communications. Their input greatly enriched this product.

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EXECUTIVE SUMMARY

In support of the United States Department of Homeland Security (DHS), the National Infrastructure Simulation and Analysis Center (NISAC) program at Sandia National Laboratories (SNL) is developing system-level network models to aid in identifying the risk of disruption to 9-1-1 calling and emergency response nationwide.

There are three 9-1-1 architectures in use in the United States: Basic 911, Enhanced 911 (E911), and Next Generation 911 (NG911). To date Sandia has developed a communications connectivity model capable of representing Basic 911 and E911. This network model, VoiceNet, visualizes key assets for voice and emergency service call routing.

This document only depicts VoiceNet's capability concerning emergency communications. The goal of VoiceNet is to provide decision-makers with a measure of consequence (i.e. service disruption) given a disruption of a key asset within the emergency communications system anywhere in the United States. VoiceNet has the necessary data, connectivity definitions, and heuristics to represent E911 but not NG911.

This document identifies the key data and heuristics needed to model Next Generation 911 (NG911) implementations. We also specify a heuristic for modeling NG911 given existing data. Where possible, we contacted operating agencies to gather detailed information about their implementations. In addition, we reviewed and assessed NG911 functional standards to characterize key assets that need to be modeled.

NG911 is the newest and most flexible of the three emergency services architectures. NG911 re-architects and extends traditional 9-1-1 service capabilities allowing for flexible call routing based on caller locations, call volumes, and other factors. In contrast with the traditional telephone system, NG911 takes advantage of Internet Protocol (IP) to flexibly route calls depending on routing policies designated by system stakeholders.

In addition to voice, NG911 supports transmission of text-to-911, photos, video, and other information when the implementation includes the necessary equipment to process these additional modes of transmission. These additional transmission modes can aid 9-1-1 dispatchers and provide responders with further situational awareness.[1]

The advantages of NG911 also come with new potential risks. For example, Emergency Services Internet Protocol networks (ESInets)—the networking backbone of NG911 implementations—are accessible to the open Internet. This change in accessibility would provide new threat vectors into the 9-1-1 system. As States and jurisdictions transition to NG911 service there will need to be careful management of these risks to ensure that emergency calls continue to be answered.

As of September 2016, twelve states have implemented or are implementing NG911. Meanwhile, nine states are preparing to implement NG911. In addition, there are six sub-state jurisdictions that are in the process of implementing or have implemented NG911.[2, 3]

The diversity of NG911 implementations necessitate the collection of specialized data to model each implementation. However, no central repository of NG911 data exists; therefore, significant outreach is needed to collect the appropriate information that can be used to develop models for decision support.

Using the data we have collected in this effort, we are able to produce simplified models of NG 911 and have presented a heuristic for doing so; however, further outreach and data collection would enhance the decision support capability of the models we are developing. The following information is needed to enable comprehensive modeling of NG911:

- The Emergency Service Internet Protocol Network service boundaries—the area serviced by the ESInet is central to characterizing the consequence of a potential outage;
- Next Generation 911 core services hosting locations and backups—the NG911 core services hosting locations contain major functions that allow for call routing using an ESInet. The outage of any one NG911 core service hosting site could, depending on the implementation, result in degradation of service and is therefore important to characterize;
- Legacy network gateway locations—legacy network gateways control the delivery of calls placed via traditional telephony service providers. The outage of these nodes could result in dropped calls;
- Location information server sites and dependencies—location information servers control the delivery of location information when queried by the NG911 core services or PSAPs. If these services are disrupted, the NG911 implementation will not be able to effectively route calls and emergency service delivery could be delayed;
- Legacy PSAP gateway locations—legacy PSAP gateways connect calls to PSAPs using traditional emergency communications architectures. Outage of legacy PSAP gateways could cause call misrouting; and
- Session Initiation Protocol (SIP) provider connectivity—Characterizing the connectivity of SIP routed traffic (e.g. Voice over Internet Protocol [VoIP]) onto the ESInet would enable consequence assessment in case of a SIP connectivity outage.

Further research steps include using the developed heuristic to model NG911 implementations as we simultaneously conduct outreach to enhance the information available to develop models. Once an implementation is modeled, the capability can be demonstrated and vetted by subject matter experts at the National Emergency Number Association and the state and local agencies that provided information. This should be done in an iterative manner to build confidence and credibility in the modeling capability.

NOMENCLATURE

Abbreviation	Definition
911SR	911 Selective Router
ALI	Automatic Location Information
ANI	Automatic Number look-up Information
BCF	Border Control Functions
CAD	Computer Aided Dispatch
CO	Central Office
DHS	U.S. Department of Homeland Security
E911	Enhanced 911
ECRF	Emergency Call Routing Function
ESInet	Emergency Service Internet Protocol Network
ESRP	Emergency Services Routing Proxy
FCC	Federal Communications Commission
GPS	Global Positioning System
IL	Illinois
IN	Indiana
IP	Internet Protocol
LIF	Location Interwork Function
LIS	Location Information Server
LNG	Legacy Network Gateway
LoST	Location to Service Translation
LPG	Legacy PSAP Gateway
LVF	Location Verification Function
Mbps	Mega-bits per second
MEVO	Message Evolution
MF	Multi-Frequency signaling
MSC	Mobile Switching Center
NENA	National Emergency Number Association
NG911	Next Generation 911
NGCS	Next Generation 911 Core Services
NIF	Next Generation 911 specific Interwork Function
NISAC	National Infrastructure Simulation and Analysis Center
PIF	Protocol Interwork Function

Abbreviation	Definition
PSAP	Public Safety Answering Point
SIP	Session Initiation Protocol
SME	Subject Matter Experts
SNL	Sandia National Laboratories
SS7	Signaling System 7
TTY	Teletypewriter
URI	Uniform Resource Identifier
URN	Uniform Resource Name
VoIP	Voice over Internet Protocol
WC	Wire Center

1. INTRODUCTION

In support of the United States Department of Homeland Security (DHS), the National Infrastructure Simulation and Analysis Center (NISAC) program at Sandia National Laboratories (SNL) is developing system-level network models to aid in identifying the risk of disruption to 9-1-1 calling and emergency response nationwide. There are three 9-1-1 architectures in use in the United States: Basic 911, Enhanced 911 (E911), and Next Generation 911 (NG911). To date Sandia has developed communications connectivity models capable of representing Basic 911 and E911. This network model, VoiceNet, visualizes key assets for voice and emergency service call routing. This document only depicts VoiceNet's capability concerning emergency communications. The goal of VoiceNet is to provide decision-makers with a measure of consequence (i.e. service disruption) given a disruption of a key asset within the emergency communications system anywhere in the United States. VoiceNet has the necessary data, connectivity definitions, and heuristics to represent E911 but not NG911.

NG911 is the newest and most flexible of the three architectures; therefore, modeling of NG911 necessitates careful consideration of its complexity and diversity of implementations. As opposed to functioning on the traditional telephone system NG911 takes advantage of Internet Protocol (IP) to flexibly route calls depending on rule sets determined by the firms, jurisdictions, and other stakeholders responsible for a particular implementation.

NG911 re-architects and extends traditional 9-1-1 service capabilities allowing for flexible call routing based on caller locations, public safety answering points (PSAP) (i.e. 911 call center) call volumes, and other factors. In addition to voice, NG911 supports transmission of text-to-911, photos, video, and other information when the implementation includes the necessary equipment to process these modes of transmission. These additional transmission modes can aid 9-1-1 dispatchers and provide responders with further situational awareness.[1]

There are advantages and risks associated with NG911 when compared to more traditional architectures (Basic and E911); a significant risk stems from Emergency Services Internet Protocol networks (ESInets)—the network backbone of NG911—and their accessibility to the open Internet. This change in accessibility would provide new threat vectors into the 9-1-1 system.

In addition, existing NG911 implementations rely on traditional routing infrastructure for many 9-1-1 calls. The reliance on traditional systems is due to traditional signaling protocols within the voice networks that will take years to transition. As jurisdictions transition to NG911, there will need to be careful management such that emergency calls continue to be answered. The transitional environment creates great uncertainty for modeling the key assets in the 911 calling system, necessitating more data (or alternatively more assumptions to fill in data gaps) concerning the emergency call routing system that so many depend on.

As of September 2016, twelve states have implemented or are implementing NG911. Meanwhile, nine states are preparing to implement NG911. In addition, there are six sub-state jurisdictions that are in the process of implementing or have implemented NG911.[2, 3]

This document identifies the key data and heuristics needed to model NG911 implementations. We specify a heuristic for modeling NG911 given existing data and identify data needs that will enhance the decision support capability of our models. To aid in the development of this report we conducted a comparative study of NG911 implementations. Where possible we contacted operating agencies to gather detailed information about their implementations and included that information in our report. In addition, we reviewed NG911 functional standards to characterize key assets that need to be modeled.

2. BACKGROUND

2.1. 911 Primer

Emergency services encompass a range of response functions to save lives, assist in disasters, and aid in recovery from emergencies. Communications are key to supporting emergency service response functions.

Figure 1 illustrates key assets and functions associated with the 9-1-1 system. The objective of the 9-1-1 system is to send resources to people in need. To promptly dispatch resources, caller information is transmitted to a PSAP which can then dispatch the appropriate first response agency to the caller.

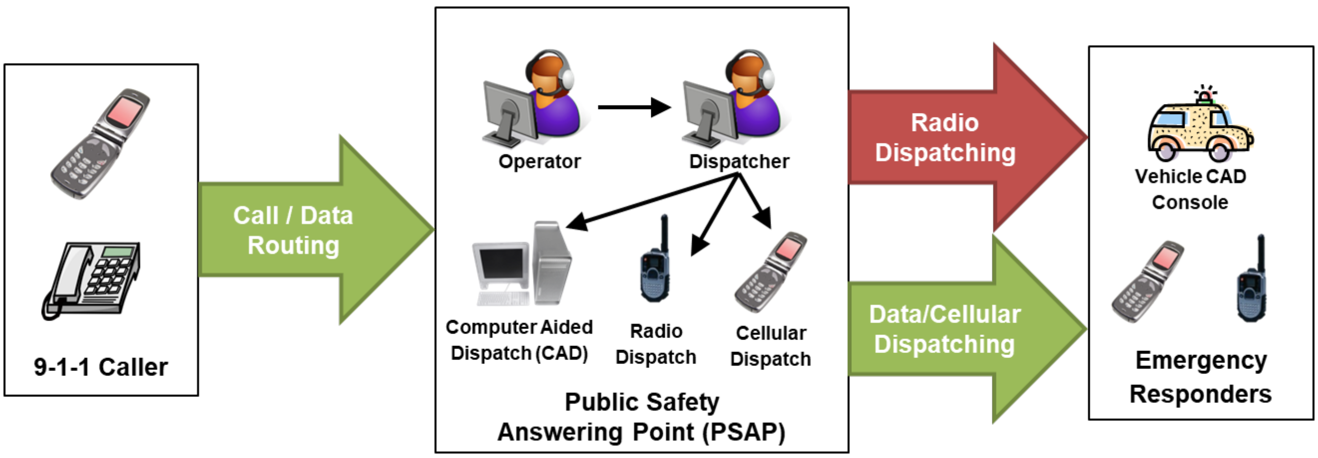

Figure 1. Functional overview of emergency services functions and communications

Central to delivering calls to PSAPs are call and data routing functions that transfer information from the caller to the PSAP. Telecommunications companies support the ability for a caller to dial "9-1-1" and be connected to the appropriate PSAP. Listed by complexity and FCC implementation timeline, three different call routing architectures enable 9-1-1 calling: basic 911, E911, and NG911. The routing architecture within a region is determined by:

- The infrastructure at telecommunications providers,
- State- and local-level resources, regulations, and policy, and
- Equipment at the PSAPs served by the network.

As of 2017, a majority of areas use the E911 architecture.

2.1.1. Public Safety Answering Points

PSAP operators answer 9-1-1 calls and dispatch essential resources. A PSAP can dispatch resources in the field via radio, mobile phone service (usually used if there are radio difficulties), or computer aided dispatch (CAD). If implemented, CAD systems transfer information (location, nature of emergency, etc.) to emergency vehicles and provide vehicle location information to the dispatcher along with the location of the nearest emergency services vehicle. CAD systems use mobile data service or the P25 radio platform to transfer data between the PSAP and the responder.

There are over 6,000 PSAPs in the United States.[4] PSAP service boundaries are defined by state and local authorities in conjunction with the Federal Communications Commission (FCC). PSAP service territories do not necessarily adhere to jurisdictional or state boundaries; they can vary radically in geographic extent or service non-contiguous areas.

In the United States, funding for PSAPs originates at the State (using the 9-1-1 telecommunications surcharge) or local levels. Each State has leeway in PSAP funding and regulatory mechanisms; however, general regulatory requirements regarding 9-1-1 operations must adhere to national reliability and other standards set by the FCC and other regulatory bodies.[5]

2.1.2. Basic 911

Basic 911 call routing is used by approximately four percent of U.S. PSAPs. Basic 911 service routes 9-1-1 calls from a given telephone central office (CO) to a designated PSAP irrespective of jurisdictional boundaries. Jurisdictional boundaries do not adhere to telephony CO service boundaries; therefore, Basic 911 calls are often answered by an agency that may not have jurisdiction to dispatch resources to the caller's area. This situation necessitates call transfers that waste critical moments that could be used to respond to the caller.

When a CO or mobile switching center (MSC) detects a 9-1-1 call, it routes that call to the designated emergency answering point, irrespective of whether or not the 9-1-1 call originated from a destination in the jurisdiction of the PSAP answering the call. All calls from a given CO will route to the same answering point.

Depending on the basic 9-1-1 system design, the PSAP may also receive automatic number look-up information (ANI), which displays the caller's telephone number. Once a 9-1-1 operator receives the call, they must ask the caller for the phone number (if the PSAP does not have ANI service), location, and nature of the emergency to be able to dispatch resources. [6]

2.1.3. Enhanced 9-1-1

E911 represents the majority of 9-1-1 service in the United States, providing call routing, ANI, and automatic call location information (ALI) for wireline and wireless calls. Once a 9-1-1 call is detected at a CO or MSC the call is routed to a 911 selective router (911SR) for routing.

The major difference between Basic911 and E911 is that E911 selective routers contain rules for routing calls to the PSAP within the originating caller's jurisdiction—reducing the time that it takes to respond to an emergency call. Also standard in the E911 architecture are ANI and ALI information, which allows the operator to identify and dispatch resources more readily.

Figure 2 is a notional example of Enhanced 911 routing. The small black diamonds represent COs and green pentagons are PSAPs. Light borders are CO service territories within the darker bordered counties. In the example below, calls from a particular town can be answered by a northern PSAP or a southern PSAP depending on where the caller is in the CO boundary. The areas in red will route to the northern PSAP, and the areas in blue will route to the southern PSAP. E911 uses the 911SR to ensure calls are routed to the proper PSAP.

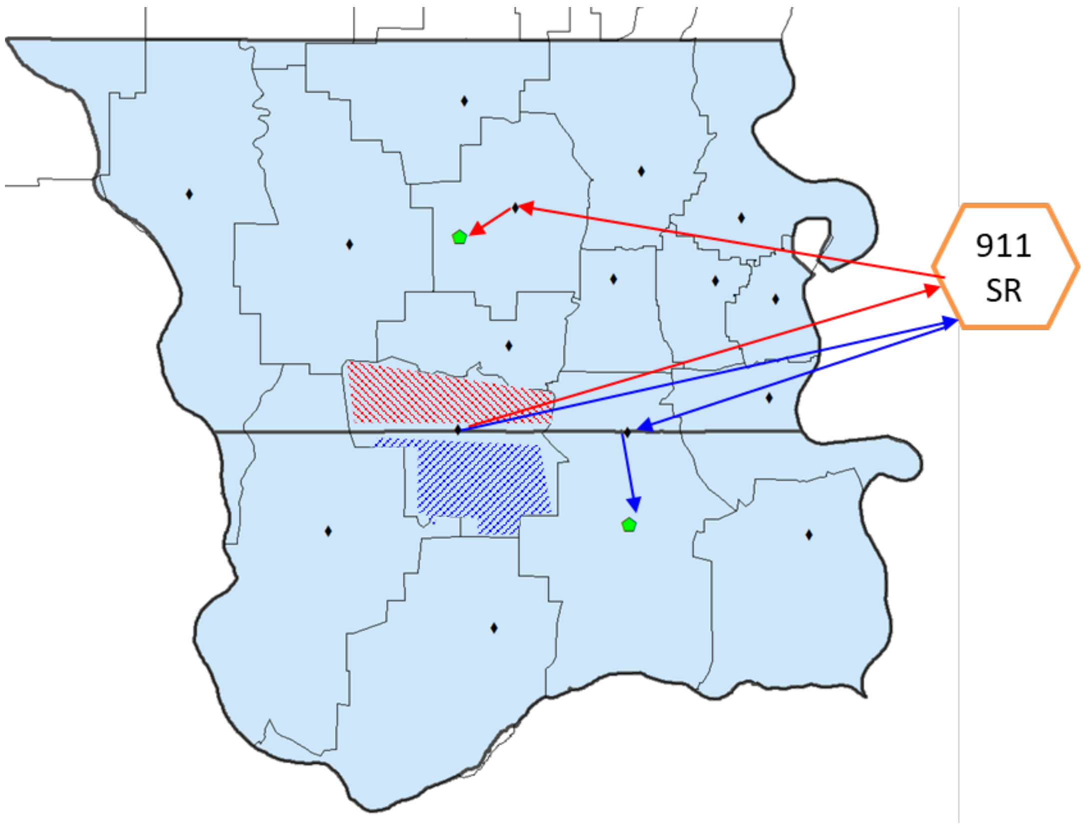

Figure 2. Example of Enhanced 911 routing

Newer implementations of E911 also support “text-to-911” service. Most PSAPs do not currently support text-to-911 service, and text-to-911 service has various levels of response priority based on the jurisdiction.[7]

2.1.4. Next Generation 9-1-1

NG911 re-architects and extends traditional 9-1-1 (i.e. Basic 911 and E911) service capabilities allowing for flexible call routing based on caller locations, PSAP call volumes, and other factors. In addition to voice, NG911 supports transmission of text-to-911, photos, video, and other information when the implementation includes the necessary equipment to process these additional modes of transmission. These additional transmission modes can aid 9-1-1 dispatchers and provide responders with further situational awareness.[1]

Fundamental to NG911's flexibility is the IP-based implementation that serves as the backbone of information transfer and routing function called the Emergency Service IP network (ESInet). Under NG911, connectivity between the 9-1-1 caller and the PSAP is a function of agreements between the PSAP and its ESInet provider. These connectivity rule-sets differ from those that are used under E911, which relies on local telecommunications providers' infrastructure to route calls. Given the flexibility in IP traffic routing, ESInet service providers may route calls through a state different than the originating caller and destination PSAP. This routing flexibility introduces efficiency benefits and risks.[8]

In many cases, NG911 routing is still reliant on E911 infrastructure, in particular the 911SRs. During the transition to NG911, a majority of calls being placed on traditional telecommunication providers' networks are still be routed through E911 selective routers, which in turn route calls to the ESInet's Emergency Services Routing function. This routing structure occurs for several reasons:

- Telephone service providers are using traditional signaling to connect their calls; or
- Telephone service providers that use modern signaling protocols to connect calls may not wish to incur the additional cost for equipment needed to interconnect to the ESInet.[9, 10]

The NG911 architecture is discussed in greater detail in section 3.

Figure 3 shows routing under the NG911 example (that relies on the E911 infrastructure to operate). In this case, calls received through traditional telephone networks are routed to the 911SR. Under NG911 the 911SR then transfers the calls to the ESInet, which then routes the calls to the proper CO and PSAP (as with the northern PSAP example) or directly to the PSAP (as with the southern PSAP example).

The final routing step is dependent on the capabilities of each PSAP. In states that have implemented NG911 some PSAPs are directly connected to the ESInet and can accept calls directly. PSAPs that are not directly connected to the ESInet rely on the call being routed via the CO servicing the PSAP. Only PSAPs that are connected to the ESInet can utilize the multimedia functionality of NG911.

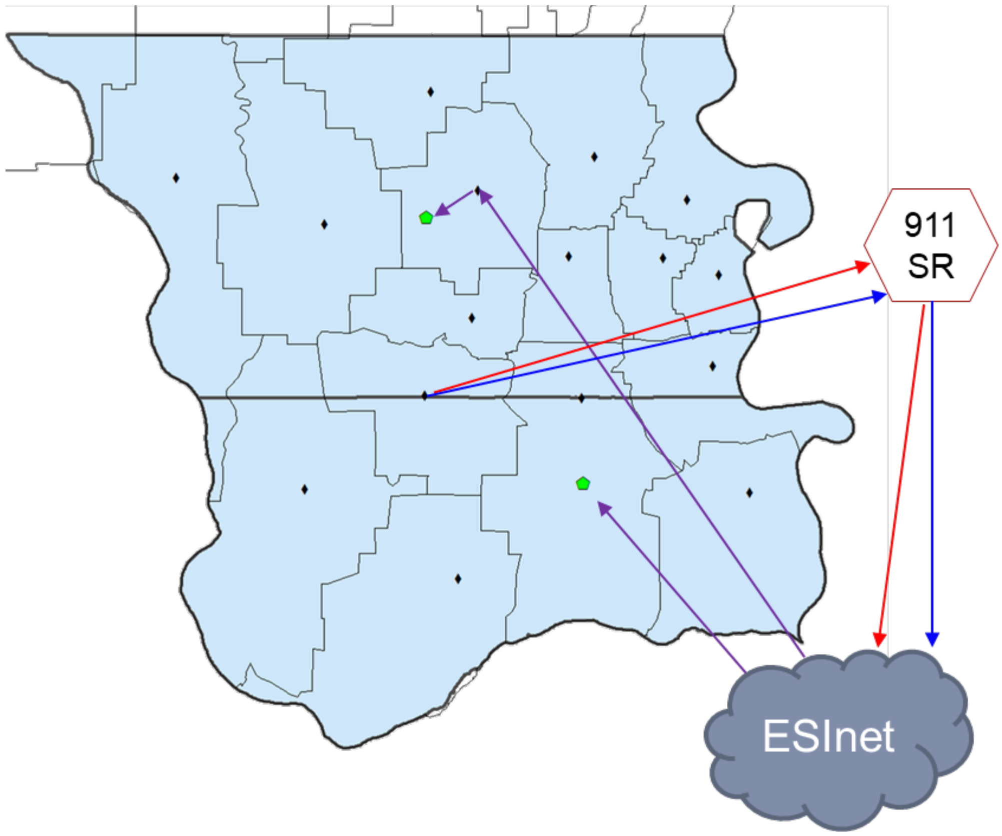

Figure 3. Example of Next Generation 911 routing

2.2. Current Capabilities in 911 System Modeling

SNL NISAC's existing emergency services modeling capability provides the necessary framework to implement an initial NG911 model. SNL has developed a network model, VoiceNet, that visualizes key assets for voice and emergency service call routing. This document only depicts VoiceNet's capability concerning emergency communications.

The goal of VoiceNet is to provide decision-makers with a measure of consequence (i.e. service disruption) given a disruption of a key asset within the emergency communications system anywhere in the United States. VoiceNet has the necessary data, connectivity definitions, and heuristics to represent E911 but not NG911.

VoiceNet relies on various disparate data sets to model the voice and emergency communications networks. These data sets are not always consistent, and they do not have all of the necessary information to model the E911 network completely. Data gaps present a challenge to precisely predicting outages given a particular disruption; therefore, we present outage results as a potential service degradation.

VoiceNet does not capture the micro-scale details of how communications systems function (i.e. VoiceNet does not take into account call volumes or procedural actions that are automatic to the voice network), but rather it takes a functional level approach to capture the major assets whose disruption—given perfect information on assets, connections and rule-sets—would certainly cause outages of the emergency communications system.

2.2.1. Assets Considered in VoiceNet to Model E911

Figure 4 is a screenshot of VoiceNet zoomed into New Mexico showing assets used within the E911 architecture:

- PSAPs;
- Incumbent wire centers—assets that enable landline phone service to PSAPs and callers;
- Access and Local tandems—interconnection points for incumbent wire centers, allowing for call routing between incumbent wire centers; and
- 911SRs.

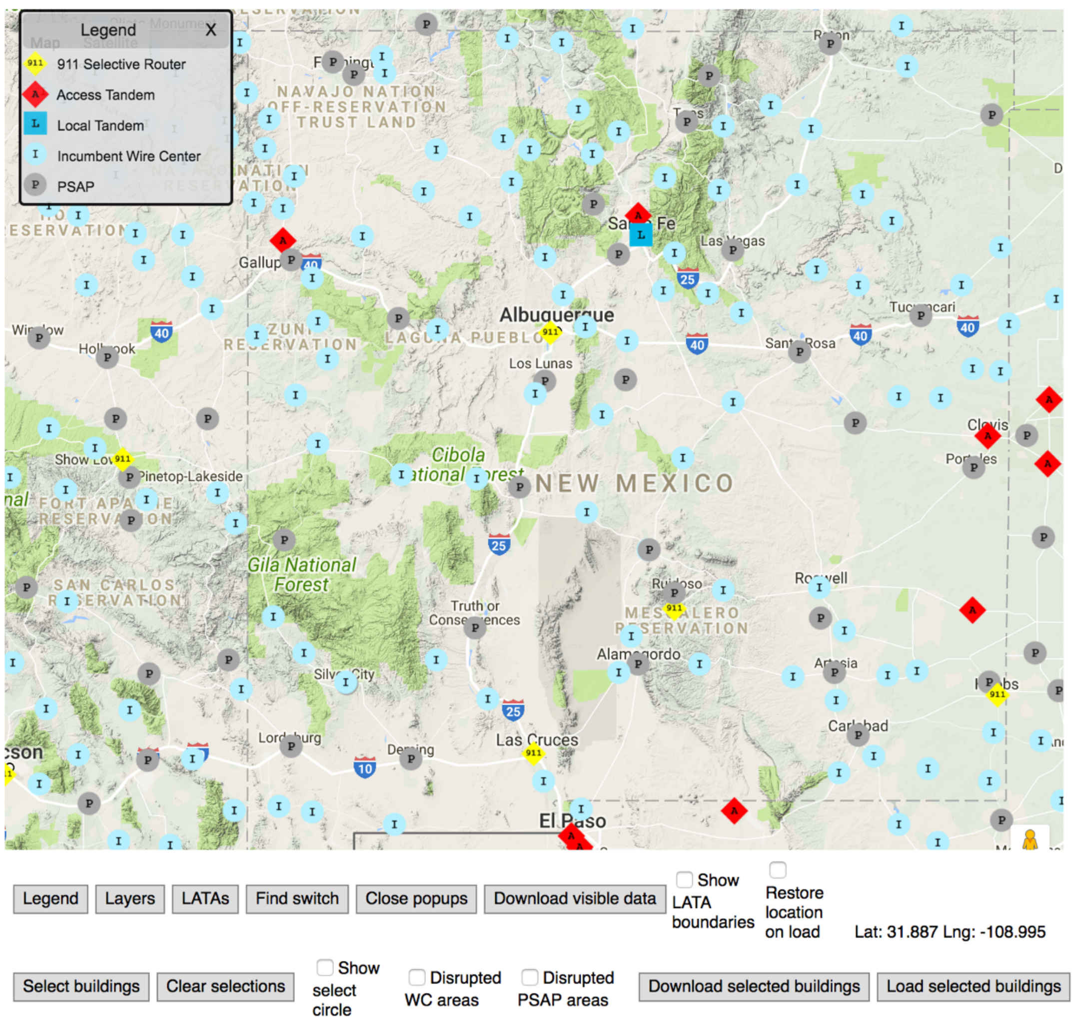

Figure 4. VoiceNet screenshot: Albuquerque area E911 relevant assets shown

2.2.2. *Connectivity between PSAPs and Incumbent Wire Centers*

The connections presented in Figure 5 are the functional connections between the various assets relevant to the E911 system. PSAP to incumbent wire center connections are represented in the black lines. Incumbent wire center to local tandem connections are in red.

It is important to note that red lines emanate from the Albuquerque local tandem outwards beyond the mapped area (note: local and access tandem icons are obscured by the 911SR icon in Albuquerque due to the resolution of the figure).

There are no available data that supply connectivity between PSAPs and the voice communication system. This necessitated the development of a heuristic that computed the connectivity between PSAPs and incumbent switches. This heuristic was based on incumbent wire center service boundaries and input from subject matter experts (SMEs) at the National Emergency Number Association (NENA). See Appendix B for further detail concerning PSAP to incumbent wire center connections.

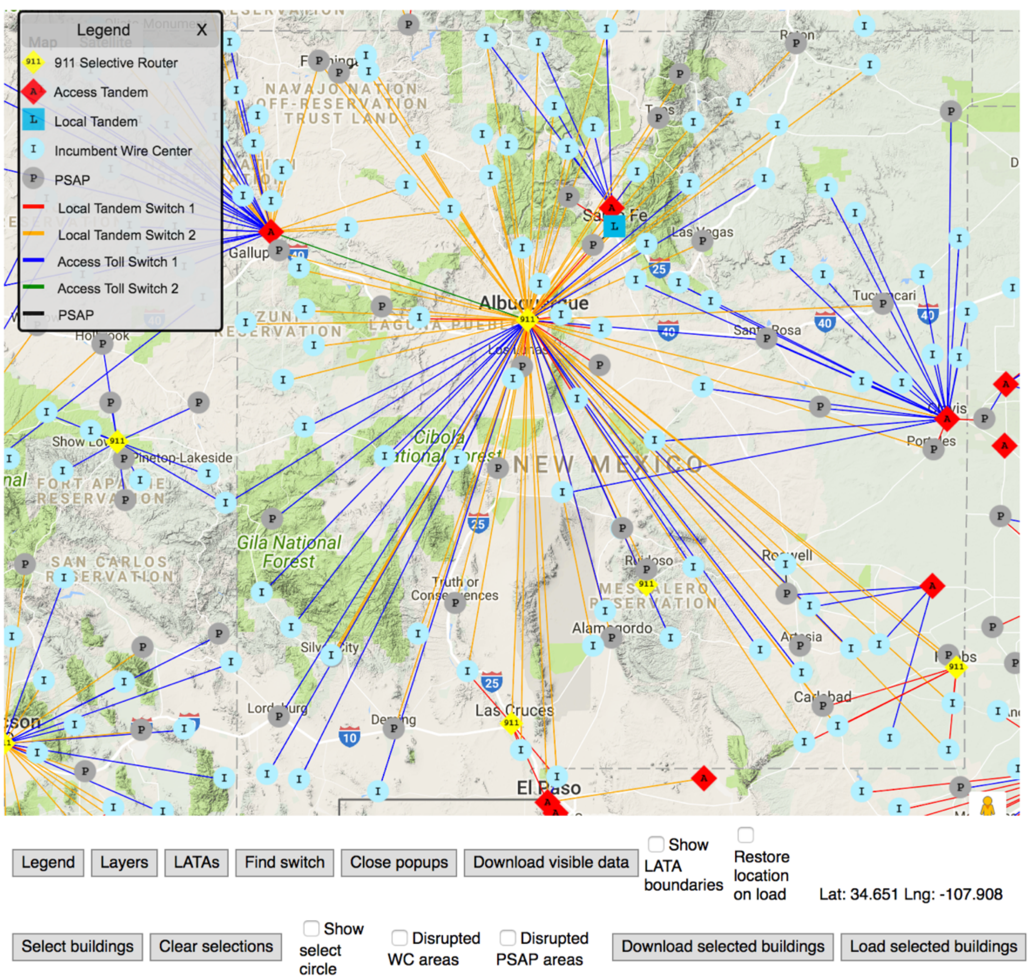

Figure 5. VoiceNet screenshot: Albuquerque area E911 relevant assets connected

2.2.3. *Dependency of PSAPs on 911SRs for Routing*

There are also other classes of logical connections modeled in VoiceNet that are relevant to E911. For 9-1-1 calls to be routed to the correct PSAP with jurisdiction over the caller's area the E911 architecture uses 911SRs. PSAPs are connected to 911SRs through the voice network where traffic goes through an incumbent wire center that connects to a local or access tandem that connects to a 911SR. If the 911SR is unavailable the voice network has no means of routing emergency calls to a PSAP, meaning that calls could be dropped or misrouted; therefore, understanding the logical dependency between PSAPs and 911SRs is useful to understanding the potential of disruption to 911 service in an area.

Figure 6 is a screenshot of VoiceNet which presents the logical dependency of PSAPs on 911SRs. These service connections were not available from known data sources. A heuristic was developed based on information we were able to find for the States of North Carolina and California. For this connectivity heuristic, we assume that the PSAPs are reliant on the geographically closest within-state 911SRs that is owned by the same provider as the incumbent wire center that the PSAP is connected to.

Analysts were surprised that geographic closeness and not network connectivity was a better predictor of 911SR service territory, but this pattern was particularly evident in the available California information and was corroborated by the North Carolina data. See Appendix C for more details on the heuristic that computes the dependency between 911SRs and the incumbent wire centers that serve PSAPs.[*]

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[*] The developed heuristic is not always correct, but it represents the "80%" solution given our lack significant data concerning PSAP to 911SR dependencies. The data regarding California and North Carolina provided a means of developing and validating our model. The heuristic would benefit from additional data that would allow for further validation.

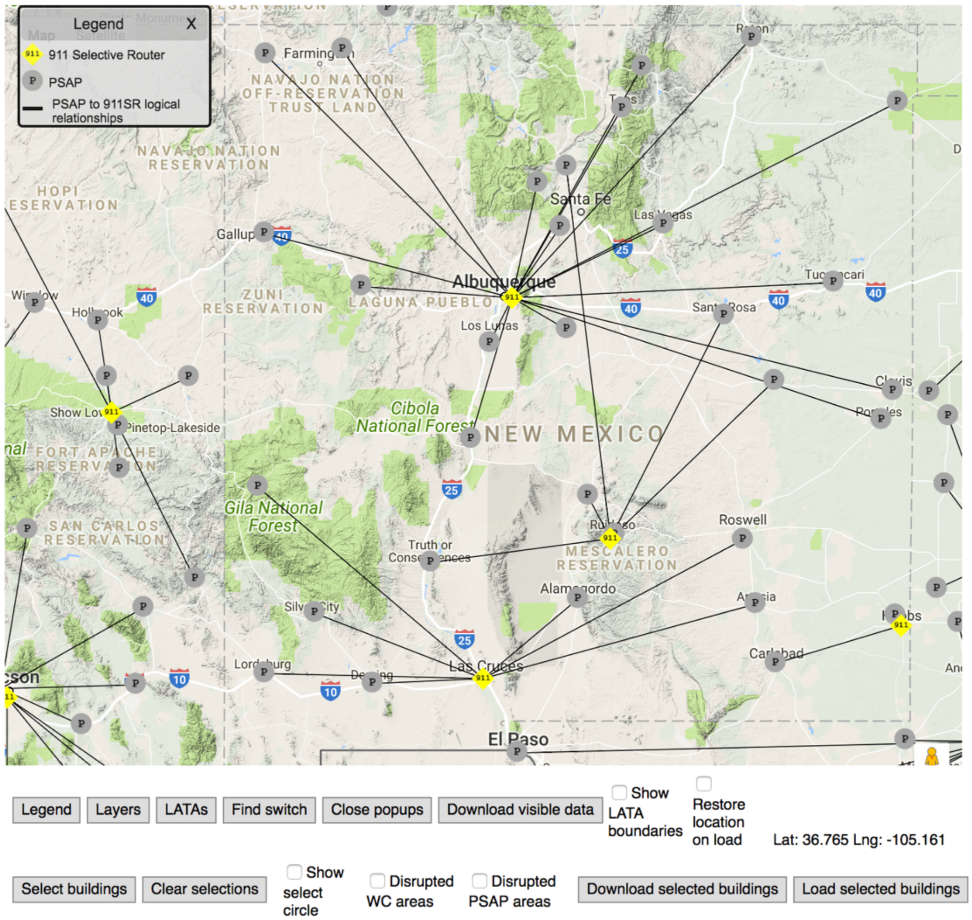

Figure 6. VoiceNet screenshot: Albuquerque area 911SR to PSAP logical connections

2.2.4. Modeling Disruptions within VoiceNet

The purpose of VoiceNet is to model the potential for disruptions. Figure 7 shows the impact of disrupting both of Albuquerque's 911SRs. VoiceNet calculates the impacted regions from data regarding PSAP service areas. The dark blue areas are areas impacted by an outage of a PSAP or an incumbent wire center that a PSAP relies on. The teal areas are areas that are expected to have degraded 911 service due to network effects because 911SRs that service those PSAPs are off-line.

Modeling the functional relationships between assets used for emergency communications allows for analysis of how outage of interconnected assets can cause outages and impacts for emergency services. These results can aid decision-makers in better preparation, planning, and situational awareness.

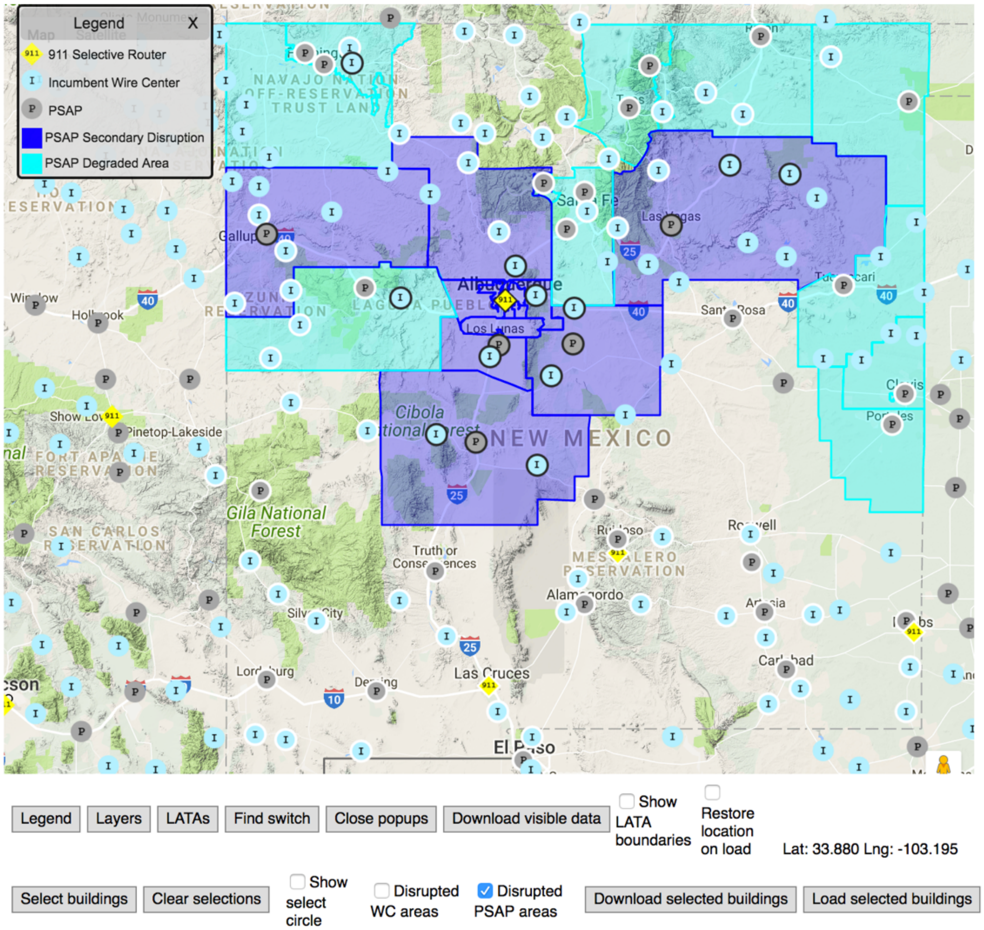

Figure 7. VoiceNet screenshot: Albuquerque area disruption of both Albuquerque 911SRs

3. KEY ASPECTS OF THE NG911 ARCHITECTURE

There are many technical standards that exist for NG911.[11] However, only one of these standards provides a functional architectural overview† of the key functions within NG911–the *NENA Detailed Functional and Interface Standards for the NENA i3 Solution*‡. This section summarizes NG911 based on the descriptions in NENA's i3 solution.

Figure 8 is an overview NENA's NG911 gateway architecture which is useful to reference when reading the sections below. There are several major aspects of NG911 functionality that exists in the architecture and is further described below:

- The ESInet including connectivity and
- Next Generation 911 core services

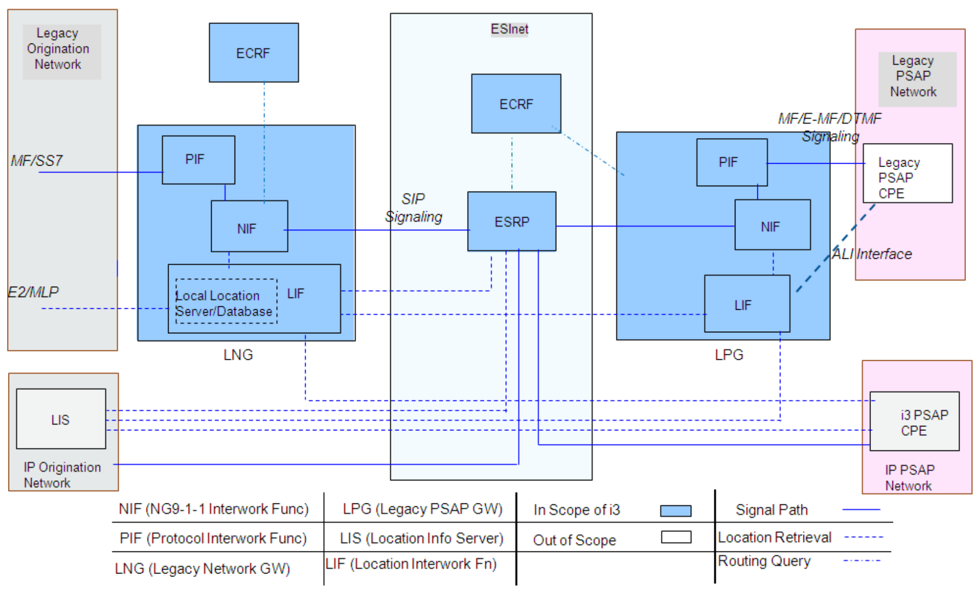

Figure 8. NENA NG911 i3 Standard Functional Architecture for Gateways[12]

† It is possible to select one of various levels of granularity to model. Given that we are assessing the ability to model NG911 architectures for disruption impacts, a functional architectural level description is most useful to the efforts in this paper.

‡ According to NENA: "The i3 solution supports end-to-end IP connectivity; gateways are used to accommodate legacy wireline and wireless origination networks that are non-IP. NENA i3 introduces the concept of an Emergency Services IP network (ESInet), which is designed as an IP-based inter-network (network of networks) that can be shared by all public safety agencies that may be involved in any emergency. The i3 Public Safety Answering Point (PSAP) is capable of receiving IP-based signaling and media for delivery of emergency calls conformant to the i3 standard." [1]

3.1. Emergency Service IP Network (ESInet) and Connectivity

The ESInet is a managed IP network that serves the function of receiving and routing emergency calls and multimedia to PSAPs. A state's or jurisdiction's ESInet is designed to carry emergency services traffic for all of the public safety agencies including but not limited to, NG911 participants. These participants can and should include PSAPs.[13]

The ESInet denotes a network. While the network includes key functions for NG911 it does not within itself constitute the functionality for emergency call routing.

ESInets can be set up to cover any region, collection of regions, states, or other boundaries to support emergency communications traffic. The technology is agnostic to boundaries[14]; however, it is useful to consider the ESInet with respect to jurisdictional boundaries, especially when considering efficient information delivery to the right authorities in an emergency.

ESInets are accessible from the public Internet. This is particularly true for connecting agencies to the ESInet. In particular PSAPs typically connect to the ESInet via a high-speed commercial Internet connection. This facilitates set up of ESInet and NG911 service[15].

The NENA i3 architecture further states that: *"PSAPs will be connected, indirectly through the ESInet, to the global Internet to accept calls. This means that PSAPs will likely experience deliberate attacks on their systems. The types of vulnerabilities that NG9-1-1 systems must manage and protect against will fundamentally change and will require constant vigilance to create a secure and reliable operating environment. NG9-1-1 systems must have robust detection and mitigation mechanisms to deal with such attacks."*[15]

As part of these mitigation system, ESInets are architected with border control functions. The border control function is composed of access controls, firewalls, and other security mechanisms that prevent unauthorized access and malicious attacks against the ESInet.[16] In addition, ESInet must also have *"no single point of failure for any critical service or function hosted,"* which can further mitigate against attacks.[13]

3.1.1. ESInet to PSAP Connectivity

In contrast with traditional telephony signaling, ESInet service routes calls using the Session Initiation Protocol (SIP), which is used in Voice over Internet Protocol (VoIP), instant messaging, and other IP-based communications.[14] PSAPs can be connected to the ESInet via two means:

- Directly, via the Internet if the PSAP is able to send and receive SIP traffic, or
- Through interwork functions if the PSAP has traditional equipment using Signaling System Seven (SS7 in Figure 8) or Multi-Frequency (MF in Figure 8) signaling.

The first option is the simplest from a connectivity standpoint—the ESInet can route the data (inclusive of voice calls) to the PSAP via its Internet connection. However, this implementation requires significant investment on the part of the PSAP or its sponsoring agency as existing E911 console equipment must be upgraded to use SIP.

The second option involves post-processing to enable call delivery. The processing of these calls happens via the legacy PSAP gateway which includes three basic functions:

- The protocol interwork function, which determines and translates SIP signals to the proper protocol needed by the caller or the PSAP. This includes the translation of the SIP signals to SS7, Multi-frequency signals, or proper transmission of Teletypewriter signals.
- The NG911 specific interwork function, which transmits information about the signal including the ANI used to look up locations by PSAPs.
- The location interwork function, which supports location look-up (via ALI queries) by the legacy PSAP equipment.[17]

In principle the legacy PSAP gateway can be physically located anywhere in the network and the location can vary depending on the implementation. For instance an FCC report on the State of Washington implementation of NG911 outage has the legacy PSAP gateway functions located at legacy PSAPs.[8]

3.1.2. *ESInet to Voice Network Connectivity*

The same issues with respect to connectivity to PSAPs (concerning different signal protocols) exists with connectivity to the voice network. The majority of call traffic for NG911 implementations we reviewed originated from legacy networks which routed call traffic using 911SRs. This will be the case as networks transition to VoIP and interconnect their SIP networks with ESInets.

While voice networks transition to SIP, legacy network gateways are able to convert SS7 signals to SIP for routing and processing through the ESInet. The same functions—protocol interwork function, the NG911 specific interwork function, and location interwork function—that convert the traffic for legacy PSAPs in the legacy PSAP gateway perform the inverse for the legacy network gateway.

In the case of the legacy network gateway:

- The protocol interwork function translates SS7 or other protocols to SIP;
- The NG911 specific interwork function translates the ANI information for the routing using the ESInet; and
- The location interwork function queries and stores location information for ESInet routing.[12]

3.2. Next Generation 911 Core Services

Hosted within the ESInet are Next Generation 911 core services, which are the key functions needed to perform 9-1-1 call routing. Next Generation 911 core services include:

- Emergency services routing proxy,
- Emergency call routing function,
- Location verification function, and
- Border control functions (previously described).[18]

The emergency services routing proxy is a proxy server. These servers serve as intermediaries in routing the call to the appropriate location. In NG911, emergency services routing proxies (ESRP in Figure 8) interconnect the originating emergency services routing proxy which receives the call into the ESInet from the border control function that then routes it through intermediate emergency services routing proxies in a hierarchy (which may represent local, regional, or state routing functionality).[19] Once the call is routed it then reaches a terminating emergency services routing proxy that routes the final call to the border control function of a PSAP (if the PSAP is NG911 compliant) or a legacy PSAP gateway (if the call is routed to a legacy PSAP).

As emergency services routing proxies route calls or data, they use an Uniform Resource Name, an address that specifies the origination point within the network of the call, to identify the caller.[20] Within the emergency services routing proxy routing chain one of the emergency services routing proxies must interface with the emergency call routing function (ECRF in Figure 8), which addresses and determines the final routing for the call.

The emergency call routing function is the functional element that routes calls or data within an ESInet. The emergency call routing function uses information regarding the location of the caller and the Uniform Resource Name to identify the proper routing for the caller to get resources using the Location to Service Translation protocol server.[21]

The Location to Service Translation protocol server uses the caller location and Uniform Resource Name to output a Uniform Resource Identifier, an addressing scheme that identifies the unique resource that the call should be routed to, to route the emergency call to the appropriate PSAP. The Uniform Resource Identifier is passed as an instruction set to the emergency services routing proxies that route the calls to the proper PSAPs.[21]

The routing of the call is not “hard-coded” into the network; rather the emergency services routing proxy and emergency call routing function can route a particular caller’s call depending on network conditions and network policy.[21]

The location validation function verifies that the resulting location of the caller is a valid location. The location validation function is performed as the call is being provisioned through the ESInet. The location validation function relies on the location information server to provide an address to verify.[21]

The location information server is also used to identify the location of the caller. This can come in the form of a location database or a network interwork function that is provided information regarding the caller's location from an out-of-ESInet protocol (i.e. E911 wireless phase 2 information for GPS location of callers). This information is provided as queried by the emergency call routing function or PSAP.[22]

4. CASE STUDIES OF NG911 IMPLEMENTATIONS

The understanding gained from reviewing NG911 functional standards in section 3 is enhanced by studying actual implementations. This section studies three implementations of NG911: State of Indiana, the Counties of Southern Illinois, and the State of Maine. Where possible, we contacted operating agencies to gather detailed information about their implementations.

4.1. State of Indiana NG911 Implementation

The state of Indiana's NG911 implementation encompasses all of Indiana serving 6,633,053 people.[23] The system processes approximately 2.7 million calls a year.[24] The state has a PSAP in each county totaling to 92 PSAPs.

There are two major providers of NG911 service in Indiana: AT&T and INdigital. Figure 9 shows the area and PSAP serviced by each provider—AT&T in blue, and INdigital in red.

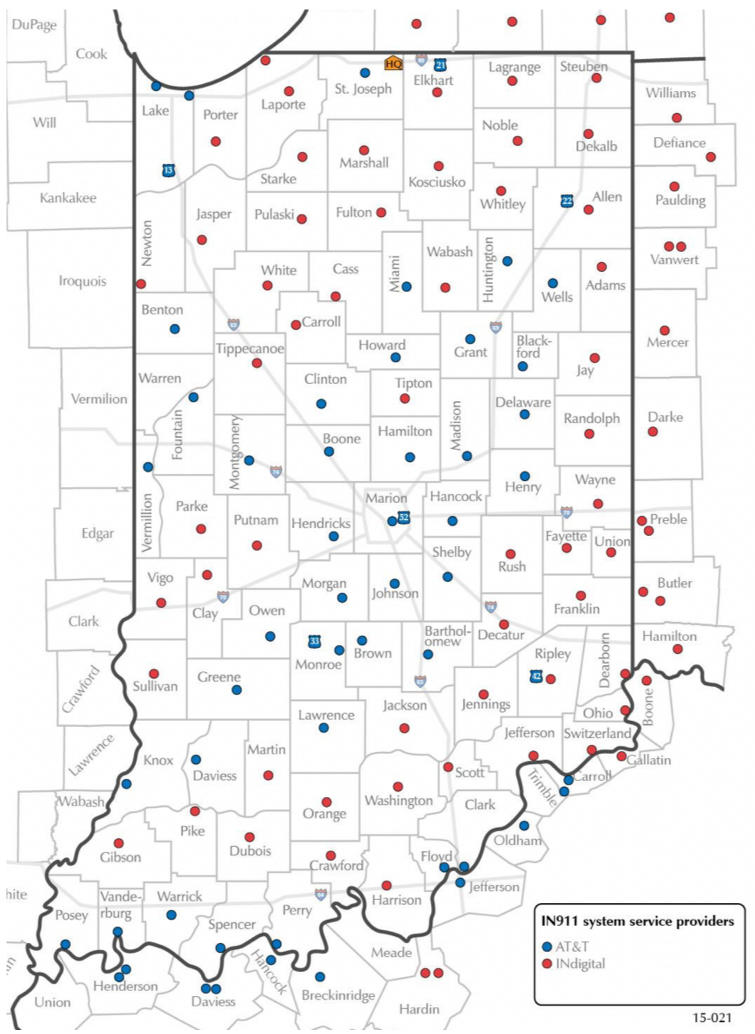

Figure 9. Areas served by provider in Indiana's NG911 implementation[25]

The two-provider implementation was motivated by the fact that there were two major voice providers in Indiana, each with a distinct service region and both wanted to implement Indiana's NG911 service. Instead of choosing a single NG911 provider, the state opted for each provider to develop and implement their own ESInet. As a result Indiana has two ESInets:

- AT&T's ESInet which services 33 counties, and
- INdigital ESInet which services the remaining 59 counties.

The two ESInets are redundant, having fail over capabilities; however, technical capabilities have limited the ESInets from being fully integrated.[26]

INdigital's NG911 service is hosted out of three sites within Indiana. The network management policy for INdigital's network is set up to load balance traffic between the two main hosting sites.[26]

The INdigital ESInet is connected to several legacy network gateways to other carriers which route calls to the ESInet. Calls are first routed through one of the state's seventeen 911SRs before reaching the ESInet for routing to PSAPs. [26]

To ensure call-delivery the INdigital ESInet has made several innovations. The first is routing call delivery through toll-free services in case of a partial network outage at one of the legacy network gateway. The second is special equipment, known as Message Evolution consoles that can be used for call answering functions when there is a network outage between the servers and PSAPs. Message Evolution consoles are designed to connect to consumer level telecommunication services, allowing for remote emergency call answering from anywhere with an Internet connection.[27] These back-up services allowed Indiana to answer calls despite a fiber cut that resulted in an outage to Southern Indiana PSAPs.[26]

4.2. Southern Illinois NG911 Implementation

The NG911 implementation of Southern Illinois is composed of 13[§] counties within Southern Illinois that created a not-for profit entity to deliver emergency services with NG911 capabilities (voice, video, text, etc.). The main driver for implementing this NG911 capability is because of significant infrastructure inadequacies in the region's traditional 911 service and because these counties had a history of working together to recover from various national incidents.[10]

Figure 10 shows the geography that the Southern Illinois NG911 system serves. These counties account for 335,742 people or 3% of Illinois' total population[28] and include 21 PSAPs with 47 call-taking positions.[29]

[§] Note: Different sources cited different numbers of counties. A 2017 IEEE paper (written by a member of the Southern Illinois NG911 design committee) stated 13 counties were part of the implementation, but does not list the counties, whereas a service provider involved in the project (NG911 Inc.) mapped and listed 15 counties as part of the implementation.

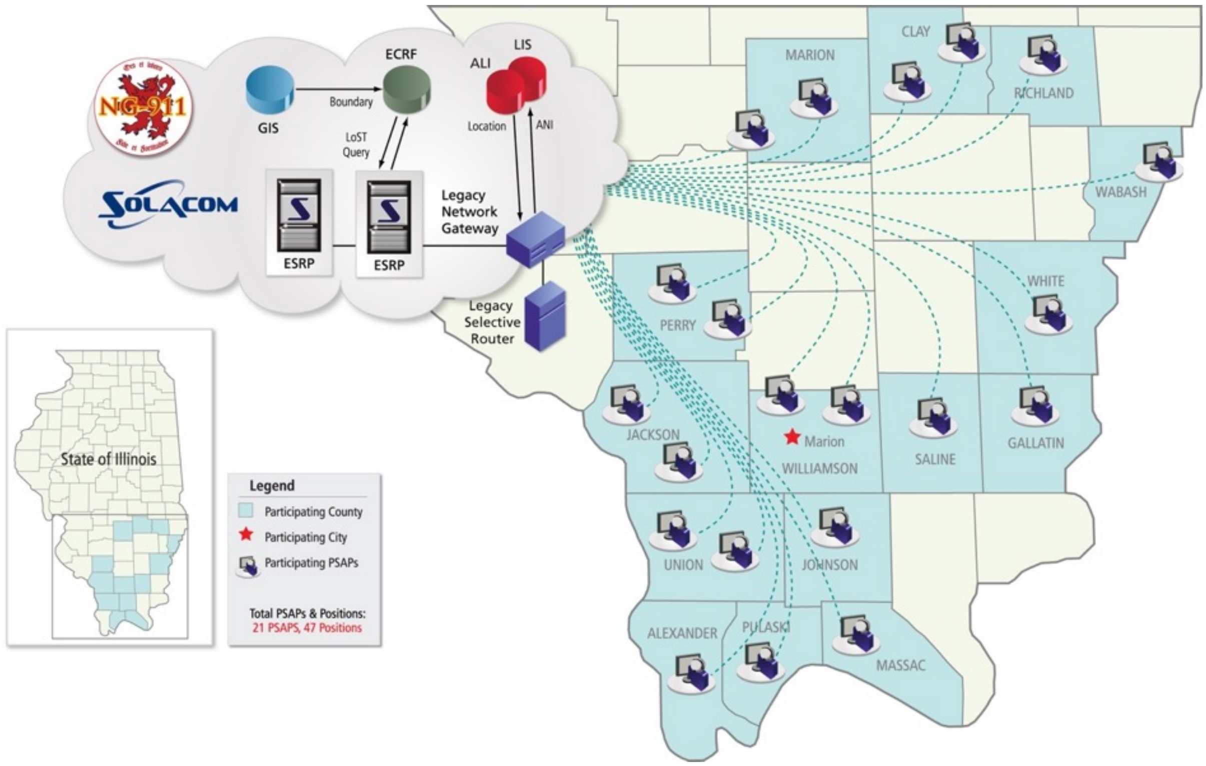

Figure 10. Geography Served Southern Illinois NG911 Implementation[29]

The Southern Illinois NG911 implementation is self-hosted. Figure 11 shows an overview of the architecture which features two data centers that load-share call routing functions. These two call centers are 54 miles apart in Murphysboro, IL and Harrisburg, IL. [30]These data centers have back-up power generation and are proximate to COs.[10]

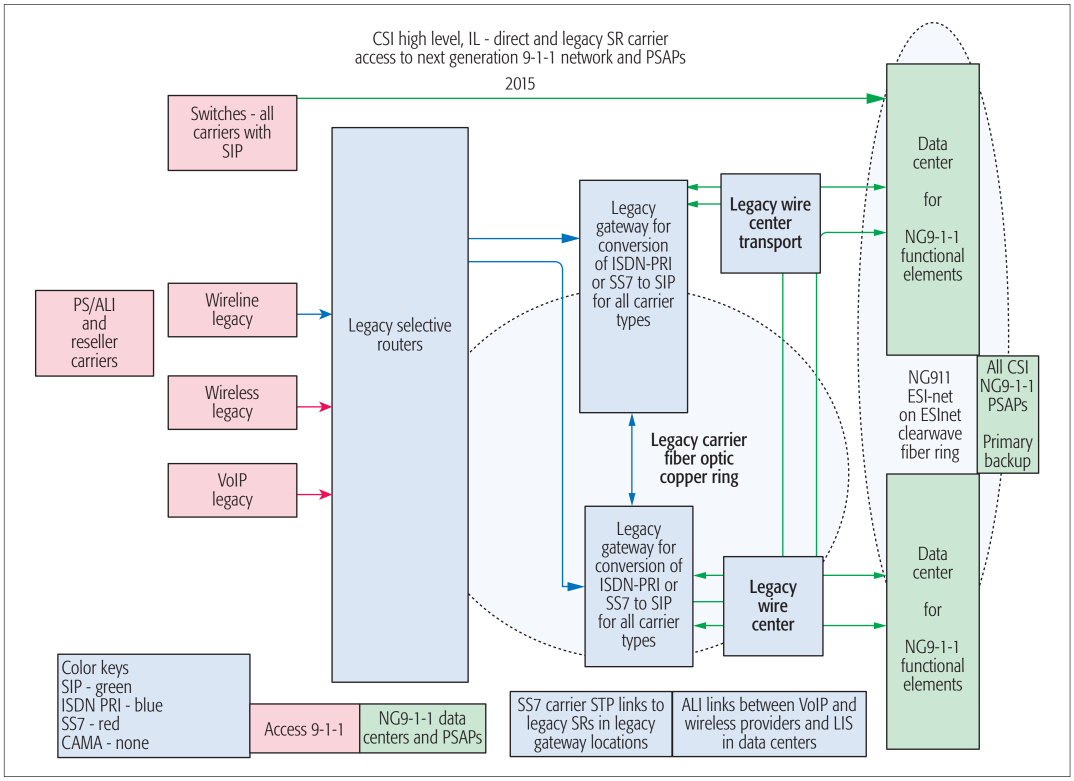

Figure 11. Southern Illinois Network NG911 Network Architecture[10]

Various carriers connect to the Southern Illinois ESINet. Carriers using SIP can route IP calls directly to the data centers; however, 99% of the calls are routed using legacy systems and E911 selective routers because of uncertainty concerning payment for SIP connectivity to the data center.[10]

Southern Illinois takes advantage of NG911's flexibility in routing. Its routing policy is based on PSAP staffing, call volumes, geography, ability to support foreign language, and outages. The routing of calls changes in real-time as conditions change.[10]

As a result of NG911 policy and the architecture that Southern Illinois has implemented, the back-up PSAPs have been able to handle calls in case of outages. In particular a person involved in the implementation of the NG911 system in Southern Illinois wrote: *"In the case of a recent unplanned event, there were no calls completing to three PSAPs covering four counties, but the alternate PSAPs handled all the calls via the system reroutes while service was restored, and no 9-1-1 calls were lost. The event was observed by [the] monitoring system, but a public formal FCC Report was not required since no calls were lost and the public was not endangered."*[10]

However, there has been at least one call routing failure that led to some land-line calls being blocked. The failure was due to an error in routing from a legacy 911SR to the ESInet. This kind of failure indicates both the reliance of NG911 (while in transition) on the E911 selective routing and the potential risk of disruption due to the transition.

4.3. State of Maine NG911 Implementation

The Maine NG911 Implementation serves all of Maine, covering 1.3 million people. There are a total of 26 PSAPs containing between two and twelve answering positions.[31] In 2014 the state received 646,900 calls. Of these calls 417,648 were from wireless phone, 184,681 were from land-lines, 44,464 were from VoIP, and 107 were texts.[32]

The state of Maine's NG911 service provider is Fairpoint Communications. According to Fairpoint, they have a: *"redundant core architecture with support for Public Safety Grade IP Networks and geographically diverse call-processing platforms. Networked PSAPs enable call overflow to be sent to other PSAPs. If a PSAP location goes down, all calls can be automatically routed to another PSAP."*[33]

Other than being a NENA i3 based NG911 implementation we have few additional details on the State of Maine's implementation regarding hosting and call routing.[**]

[**] Several attempts were made to contact the State of Maine for further details; however, the authors did not receive a response.

5. CASE STUDY ANALYSIS AND MODELING IMPLICATIONS

This section serves as an analysis of information collected regarding NG911 standards and implementations. We use this information to outline a heuristic that is currently implementable in VoiceNet to model NG911. However, additional data can significantly enhance the decision support capability of our models. Therefore, we have outlined the key assets, data, and potential heuristics that would be needed to develop an improved network model of NG911 routing.

5.1. Case Study Analysis

There are 12 states that use or are transitioning to use NG911. In addition there are six states that have sub-state level of implementations complete or in transition.[2, 3] Table 1 summarizes key observed similarities and difference from the NG911 implementations reviewed.

Table 1. Table of key observed similarities and differences between compared NG911 implementations

Key Similarities Observed	Key Differences Observed
1. Usage and reference of NENA i3 standards for implementations 2. Redundancy of NG911 core services 3. Network monitoring services were important to network operations 4. The implementations have proven able to resolve issues in network disruption 5. NG911 implementations continue to rely on E911 routing functions to deliver calls to the ESInet	1. Location of key services being provided vary by state; and data are unavailable about the hosting locations 2. Different service providers 3. Different means of implementation—selecting a provider that already hosts telecommunications in the state, selecting a provider that can implement and operate the NG911 system, or a self-implementation 4. Different technologies implemented as part of NG911 that enhances service 5. Different level of responsibility/ownership of PSAPs that are part of NG911 system

The observed similarities indicate that there are key structures that can be used to generalize a modeling framework for NG911, given the data about the assets modeled are available. In addition, observed similarities indicate that there is currently a dependency of NG911 on E911 routing resources because the voice network is largely routed using SS7 or SIP routed voice providers have not connected to the implemented ESInets due to costs or other concerns. This dependency indicates that any NG911 network model that is built would benefit in also modeling E911 routing structure.

The observed differences indicate that there will be difficulty in obtaining information concerning NG911 implementations. In the three NG911 implementations reviewed, there were three different service providers. In addition, if we are to model NG911, various ESInets per state may have to be considered. The relationships between the ESInets may not be clean cut; making their modeling complicated. The consideration of different PSAP reliance on NG911 legacy PSAP gateways may complicate consequence assessment of a legacy PSAP gateway outage.

As a general observation, the NG911 system is still transitioning and evolving. This means that changes to the standards and implementations would necessitate changes in modeling rules and data. If data or information sources are identified it would be critical to ensure that the datasets are kept current. In addition, significant effort is needed to build relationships with NG911 system operators to obtain a level of awareness given the operators NG911 transitional state.

5.2. Heuristic for Modeling NG911 in VoiceNet with Existing Information

It is possible to model NG911 with existing data from case studies. The minimal set of information needed is the location of hosted NG911 core services and the service area of the implementation. As discussed in section 3.2, the core services encompass the main routing functions for NG911. There may be additional infrastructure that routes data and calls from the network to NG911 core services and then to PSAPs but without the core services, NG911 routing is not possible.

We can then model the service territory and locations of NG911 core services by:

1. Mapping each of the NG911 core service hosting sites for a given implementation.
2. Mapping the service territory for the NG911 implementation.
3. Assuming that all NG911 core service hosting sites are redundant to one another, specify that if all the NG911 core service hosting sites are disrupted, the NG911 service territory for the implementation is disrupted.

It is important to consider connectivity between the traditional voice network and the NG911 core service hosting site. This connectivity can help in assessing cases where NG911 service is disrupted because of a cut line between NG911 and traditional voice services. This connectivity can be modeled as follows:

1. Find the nearest CO (including access and local tandems) to each of the NG911 core services hosting sites.
2. Assume voice network connectivity to the NG911 core services at that CO.
3. In cases where multiple types of switches are at the same distance, assume that the highest hierarchical switch type (from highest to lowest: access tandems, local tandems, and incumbent wire centers) is connected to the NG911 core service.

From an NG911 transition perspective, it is important to map out the connectivity between the NG911 core services hosting site and the 911SR. This dependency can be found through:

1. Assessing routing between NG911 core service connected COs and 911SRs.
2. Any disruption resulting in the connectivity between the NG911 core service and the 911SR would result in a disruption of NG911 service for the areas that are serviced by the 911SR routers.

3. Use the PSAP CO to SR911 connectivity heuristic (Appendix C) as a guide to specify calling service areas of 911SRs.

5.3. Key Assets and Data Needs for Improved NG911 Modeling

In addition to the service boundaries and the location of NG911 core services the following data would enhance SNL NISAC's ability to model NG911:

- Legacy network gateway locations—legacy network gateways control the delivery of legacy network traffic from telephone providers, the outage of these nodes could result in dropped calls;
- Location information servers' sites and dependencies—location information servers control the delivery of location information when queried by the NG911 core services or PSAPs. If these services are disrupted, the NG911 implementation will not be able to effectively route calls and emergency service delivery could be delayed;
- Legacy PSAP gateway locations—legacy PSAP gateways connect calls to PSAPs using traditional emergency communications architecture. Outage of legacy PSAP gateways could cause call misrouting; and
- SIP provider connectivity—characterizing the connectivity of SIP routed traffic (e.g. VoIP) onto the ESInet would enable consequence assessment in case of a SIP connectivity outage.

In addition, it is important to note that some states that have transitioned to NG911 have used the opportunity to centralize PSAP services. If that is the case in a particular implementation, the new PSAP structure would have to be considered.

5.4. Need for Further Heuristics and Assumptions to Fill Gaps

Heuristics may need to be created and assumptions may need to be made regarding:

- Routing policies on the ESInet—the policy not only determines how a call is routed but also how routing is handled when nodes in the ESInet are disrupted. This aspect is important in considering work-arounds during a partial network-outage.
- Enhanced heuristics for connectivity between the voice network and ESInet that includes the legacy network gateways and SIP connection points—this would be data that only the telecommunications providers would have. As it would be time consuming to get the connectivity information from each telecommunications provider, we would have to make assumptions about how these systems connect to the ESInet.
- Implementation status—the NG911 implementations are in a state of transition. As the developed models are capturing a point in time during the transition, we would have to select a transition state to model for the particular ESInet that would be sufficiently representative of ESInet conditions until the model is updated.

- Other call routing back-up functions—some NG911 implementations have backup functions that allow them to answer calls from a location with a consumer-grade Internet connections (e.g. INdigital's Message Evolution consoles) or some other technique that is not part of the i3 standard but enhances the ability of NG911 service up-time. The modelers will have to make assumption regarding these kinds of implementations to characterize outages.
- SIP provider service areas—VoIP providers utilizing SIP to place calls have no defined service area. However, there may be assumptions that can be made that capture the population of callers in an area that could be serviced by VoIP and directly connects to an ESInet. There will have to be further data analysis and thought needed to characterize this issue.

6. CONCLUSIONS AND NEXT STEPS

To date Sandia has developed a communications connectivity model capable of representing Basic 911 and E911. This network model, VoiceNet, visualizes key assets for voice and emergency service call routing. VoiceNet has the necessary data, connectivity definitions, and heuristics to represent E911 but not NG911. Therefore, we reviewed NG911 functional standards, conducted a comparative study of NG911 implementations, and identified key similarities and differences between NG911 implementations. Through the analysis, we identified key assets and data necessary to model NG911 and developed associated heuristics to enable initial modeling of NG911 in VoiceNet. In addition we also identified heuristics that need to be developed and assumptions that need to be made to fill existing data gaps.

This effort provides evidence that NG911 implementations are diverse and transitioning which necessitates the collection of specialized data for each implementation. Determining the impact of disruptions for decision support requires high-fidelity models; however, since there is no central repository detailing particular implementations significant effort would be required to collect the necessary information.

Moreover, the transitional and evolving nature of real-world NG911 implementations leads to the rapid obsolescence of developed models of NG911. While this transitional nature is true with any infrastructure system modeling, the velocity of the changes within NG911 architectures is significant.

The use of IP to support various call routing functions within NG911 should remain fairly constant; however, the connectivity of PSAPs and originating callers to the ESInet is evolving. Telephony providers, data providers, and PSAPs can all make significant changes in their network implementations that will affect the topology and dependencies of the underlying NG911 system resulting in a change in routing and impact of outages.

In addition, NG911 implementations translate between voice and IP traffic. If an emergency call originates from the voice network then the service areas of incumbent wire centers, modeled in VoiceNet, matter a great deal; however, if a call originates from a VoIP provider that is interconnected to an ESInet, then Internet-based routing functions and assets matter. This requires elements and data from Internet and voice network representations depending on which providers service a particular NG911 implementation.

If modeling NG911 implementations for decision-support is desired we recommend starting with an initial model based on available data; for example, information from one of the case studies presented in this document such as the Indiana implementation. To further refine the network modeling structures, additional data will need to be collected. Given the existing dependency of NG911 on E911 assets such as 911 selective routers, modeling of NG911 should begin in VoiceNet, a model of voice networks and E911 services.

Once a particular implementation is modeled, NENA subject matter experts and State or local agencies could verify that the information they provided was captured accurately. An iterative approach of refining the model will increase stakeholders' confidence in the modeling capability and increase the ability of the model to approximate the impact of disruptions for use in crisis action decision support.

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APPENDIX A: COMPILATION OF 50 STATE NG911 TRANSITIONS

Table 2. Compilation of 50 State NG911 Implementation Status[2, 3]

State	State Agency with Oversight	NG911 Status	Notes
Alabama	Statewide 911 board	Preparation activity at the state level	
Alaska	Statewide 911 coordinator within Dept of Military and Veterans' Affairs	Preparation activity at the sub-state level	
Arizona	Arizona Strategic Enterprise Technology (ASET) Office (part of Arizona Department of Administration)	Planning started	
Arkansas	Arkansas Emergency Telephone Service Board 911 Coordinator in Arkansas Department of Emergency Management	Preparation activity at the state level	Preparation activity at the state level through a study of the Legislative Arkansas Blue Ribbon Committee on Local 911 Systems.
California	Public Safety Communications Office 911 Division (within governor's office) Office of Emergency Services	Preparation activity at the sub-state level	
Colorado	Colorado Public Utilities Commission	Planning started	
Connecticut	Division of Statewide Emergency Telecommunications within Department of Emergency Services and Public Protection	Implementation in progress	At state level through pilot projects at 10 different PSAPs throughout the state. In addition to text and video capabilities, system will be able to collect information from vehicle crash notification systems like General Motors' OnStar. Estimated cost for statewide implementation is between $12 million-$22 million.
Delaware	E911 Emergency Service Board	Planning started	
Florida	Florida E911 Board, within the Department of Management Services	Implementation in progress - sub-state level.	Both Palm Beach and Charlotte Counties have launched IP-based 911 systems to allow PSAP to receive high-bandwidth files including photos and video and has text-to-911 capability.

State	State Agency with Oversight	NG911 Status	Notes
Georgia	Georgia Emergency Management Agency 911 Advisory Committee	None or unknown	
Hawaii	Enhanced 911 board, Department of Accounting and General Services	Implementation in progress at state level	
Idaho	Idaho E911 Emergency Communications Commission (within Office of Emergency Management)	Planning started	
Illinois	Illinois State Police Office of the Statewide 911 Administrator Statewide 911 Advisory Board in Department of State Police	Implementation in progress-sub-state level.	13 counties formed the Counties of Southern Illinois association and are now implementing NG 911 in all 17 of their PSAPs. The counties are mainly rural, ranging in population from 8,000 to 63,000. The association leveraged $5.8 million in federal grant money from the Broadband Technology Opportunities Program (BTOP) and Community Oriented Policing Services (COPS).
Indiana	Statewide 911 board, under the state treasurer	Implemented at state level	2 telecom companies, AT&T and INdigital are building IP networks to support NG911. This will provide redundancy so that one of the companies can route all 911 calls if the other company experiences an outage.
Iowa	Department of homeland security and emergency management	Implemented at state level	
Kansas	Kansas 911 coordinating council	Implementation started	3-site pilot program implemented in 2012 and development of statewide GIS database for call location mapping.
Kentucky	Kentucky Office of Homeland Security	Preparation activity at the state level	
Louisiana	N/A	Planning started	
Maine	Emergency Services Communication Bureau, within the PUC & the E911 Council	Implemented at state level	
Maryland	Department of Public Safety and Correctional Services	Planning started	

State	State Agency with Oversight	NG911 Status	Notes
Massachusetts	State 911 Department within the Executive Office of Public Safety and Security State 911 Planning Commission	Implementation in progress at state level	Looking to implement statewide in late 2016 with an estimated price tag of $56 million (covering IP network infrastructure, equipment at two data centers and 250 PSAPs, and training).
Michigan	Emergency 911 service committee, within the department of state police	Preparation activity at the sub-state level	
Minnesota	Department of Public Safety's 911 Program Statewide Emergency Communications Board	Preparation activity at the state level	
Mississippi	Commercial Mobile Radio Service Board	Planning started	
Missouri	Committee on 911 Service Oversight	Implementation in progress - sub-state level	
Montana	Department of Administration; Advisory council	Implementation in progress - sub-state level	
Nebraska	State 911 director, appointed by the Public Service Commission Enhanced Wireless Advisory Board	Planning started	
Nevada	Nevada Public Safety Communications Committee	None or unknown	
New Hampshire	Bureau of Emergency Communications in the Department of Safety Enhanced 911 Commission (membership includes the chair of the PUC or designee and the commissioner of the department of public safety or designee)	Preparation activity at the state level	Has implemented text-to-911 throughout the state (but not other NG 911 features such as picture or video capability).

State	State Agency with Oversight	NG911 Status	Notes
New Jersey	Office of Emergency Telecommunications Services in the Office of Information Technology 911 Commission	Planning started	
New Mexico	Department of Finance and Administration, Local Government Division, E911 Bureau	None or unknown	
New York	Office of Interoperable and Emergency Communications	Preparation activity at the sub-state level	
North Carolina	North Carolina 911 Board	Preparation activity at the state level	
North Dakota	Emergency Services Communications Coordinating Committee	Implementation in progress at state level	North Dakota Association of Counties is working toward implementation on behalf of PSAPs and PSAPs have entered into a joint powers agreement.
Ohio	Ohio 911 Program Office	Implementation in progress - sub-state level.	NG911 rolled out in Morgan County, a rural area with a population of 15,000.
Oklahoma	Oklahoma 9-1-1 Management Authority	None or unknown	
Oregon	Office of Emergency Management	Planning started	
Pennsylvania	Pennsylvania Emergency Management Agency 911 Board	Preparation activity at the sub-state level	
Rhode Island	Rhode Island Enhanced 911 Uniform Emergency Telephone System, Department of Public Safety	Preparation activity at the state level	
South Carolina	Revenue and Fiscal Affairs Office	Planning started	
South Dakota	South Dakota 911 Coordination Board	Implementation in progress at state level	Estimated that all PSAPs will have NG 911 capabilities by 2018.

State	State Agency with Oversight	NG911 Status	Notes
Tennessee	Tennessee Emergency Communications Board of the Department of Commerce and Insurance Tennessee Advisory Commission on Intergovernmental Relations	Implementation in progress at state level	
Texas	Commission on State Emergency Communications (CSEC)	Implementation in progress - sub-state level	
Utah	911 Division	Planning started	
Vermont	Enhanced 911 Board	Implemented at statewide level.	Vermont was the first state to implement an IP network for 911 statewide. As a result, Vermont was able to handle Hurricane Irene in 2011 with no calls lost, even when one PSAP had to be evacuated. Vermont now supports text-to-911 for 98% of the state.
Virginia	911 Services Board Public Safety Communications Division of the Virginia Information Technologies Agency	Implementation in progress at state level	
Washington	E911, Unit of the Emergency Management Division	Preparation activity at the state level	
West Virginia	The Public Service Commission (utilities commission)	None or unknown	
Wisconsin	Minimal authority of Public Service Commission (utilities commission) over 911 surcharges	Planning started	
Wyoming	N/A	Planning started	

APPENDIX B: E911 VOICENET MODEL: HEURISTIC FOR PSAP TO WIRECENTER CONNECTIVITY

PURPOSE

No complete, publically available data set exists for how Public Safety Answering Points are connected to the voice network. Given the fact that this information is needed to develop a comprehensive model/picture of potential ways that communications outages could impact 911 service, NISAC, through the input and help of the National Emergency Number Association (NENA) as well as local PSAPs has developed the following heuristic that specifies how PSAPs are connected to the voice network.

ASSUMPTIONS

- PSAPs are assumed to be functioning under the Enhanced 911 or Basic 911 architecture
- A PSAP is connected to one wire center (WC)
- The PSAP is connected to the WC that services the voice network in the area of the PSAP

HIGH-LEVEL PROCESS DESCRIPTION

The defined process makes use of information that NISAC already has available to it. Note: we have run into examples where this Heuristic does not apply, for those instances we will make use of what PSAPs have told us.
Process:

1. For a given PSAP, find the wire center service area that it is located in.
2. Find the incumbent wire center that services that area. The PSAP is connected to that wire center.
3. Repeat process for all PSAPs nationwide.

PSAP TO WC CONNECTIVITY PSEUDO CODE

Data used:

- polygon: WC Service Areas = (tl_uswcreg_regions)
- points: PSAP = (emer_psap_facilities)
- points: Incumbent WC = (v_incumbent_wc)

Process:

1. For a PSAP with "objectid" = 1 find the WC Service Area that the PSAP is located
2. For the WC Service Area find the Incumbent Wire Center
3. Record the "wc_code" of the Incumbent WC in a new field within the emer_psap_facilities" table named "wc_connection", in an additional field "wc_connectivity_source" in the same table also record "heuristicV1"
4. "objectid"++ and repeat until all PSAPs have an assigned "wc_code"

Output:

- The "emer_psap_facilities" data set will with information on wire center connectivity.

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APPENDIX C: E911 VOICENET MODEL: HEURISTIC FOR PSAP TO 911SR DEPENDENCY

PURPOSE

No complete, publically available data set exists for which 911 Selective Routers (911SRs) route a location's 911 calls. This information is needed to develop a comprehensive model/picture of potential ways that communications outages could impact 911 service. Through the use of data and information from North Carolina[††] [‡‡] and California[§§] NISAC has specified the following heuristic for 911SR routing.

ASSUMPTIONS

- Only one 911SR is assumed to route traffic for a wire center
- A provider's wire center is connected to a provider owned 911SR if available within the state

HIGH-LEVEL PROCESS DESCRIPTION

Physical routing of calls is dependent on the topology of the network. However, despite a network's topology there are logistical factors that drive call routing including equipment capacity, provider policy, and state regulation.

The defined process makes use of information that NISAC already has available to it. We know of instances where the heuristics may not apply (in particular large metropolitan areas where call routing can be highly partitioned in a small geography). In the rare circumstance that data is available to NISAC, we will override the heuristic with the known data.

Process:

1. Determine the "largest provider" for the wire center that "services" a PSAP. The "largest provider" is the owner of most of the switches in that wire center.

2. Find the nearest (geographically) 911SRs (within the state) owned by a wire center serving provider

3. Find the nearest "largest provider's" 911SR

4. If the "largest provider" does not have a 911SR within the state, then assign the nearest 911SR under any provider.

5. Create a record within the PSAP table that specifies the 911SR connection.

[††] "VOLUME 2: Comprehensive Statewide 9-1-1 Plan (Appendices)"

[‡‡] https://arxiv.org/pdf/1609.02353.pdf

[§§] https://primeaccess.att.com/shell.cfm?section=276

6. Repeat process for all incumbent wire centers connected to PSAPs nationwide.

911SR DETAILED STEPS

Data used:

- PSAPs with wire centers
- LERG

Process:

1. Cross reference the LERG to assign an owner (OCN ID) for 911SRs within the wire center database. (Note the WC DB is listed in buildings not switches)
2. For PSAP connected wire centers cross reference switch owners within the LERG.
3. Rank order the owners by number of switches owned at the WC.
4. For the largest provider search for the nearest in-state 911SR owned by that provider
5. If no 911SR exists in state, then search for the next largest provider 911SR
6. Iterate 5 until a 911SR is found. If no 911SR is found then assign the nearest 911SR of any provider.
7. Record the "911SR" of the Incumbent WC in a new field within the emer_psap_facilities" table named "911sr_connection", in an additional field "911sr_connectivity_source" in the same table also record "heuristicV1"

Output:

- The "emer_psap_facilities" data set will with information on 911SR connectivity.

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