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Article

A Cloud-Enabled Communication Strategy for Wildfire Alerts

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SUMMARY

The latest wildfires in California have claimed numerous lives and caused billions of dollars in damages. Inadequate alert systems during these natural disasters have resulted in millions of dollars of avoidable damages and deaths. Misinformed or unaware citizens are the most likely to be injured or die during a natural disaster. The traditional alert system in California consists of Wireless Emergency Alerts (WEAs), which lack location specificity, and sign-up-based technology which is limited by the number of sign ups. Those who do not have phones or have a silence option on their devices are most at risk from the current alert system. In the age of affordable computers, this study analyzes the potential viability of an Internet of Things approach to disaster alert. We developed cloud-enabled crisis connection for disaster alerts (CRISIS-CONNECT) to mitigate problems associated with the current alert system. Preliminary tests demonstrate that the novel CRISIS-CONNECT alert system can perform over high and low data speeds, whereas the existing WEA system does not. We further demonstrate that centralized CRISIS-CONNECT alerts can be sent with greater global positioning system (GPS) precision than WEA. Last, we report that the CRISIS-CONNECT device has a comparable battery life to the iPhone 6s, whether in active or standby mode. Taken together, our data positions CRISIS-CONNECT as a strong alternative to address the shortcomings of the current WEA system.

INTRODUCTION

The 2018 wildfire season in California was responsible for more than 1.5 million acres in burned land and resulted in an estimated 400 billion dollars of economic loss (1, 2). One singular fire in 2018 left over 85 dead, hundreds injured, and millions in panic (3). With the number and intensity of wildfires increasing every year, it is important to evacuate people calmly and efficiently. Unfortunately, this is not the reality. The current alert warning system is inefficient and error prone as there is no standardized system for alerting residents of quickly approaching wildfires. During the Carr Fire in Shasta County, there were several reports of residents dying because they were not given proper warnings about the fire (4). Additionally, residents of Sonoma County and those along the Sacramento River had to be alerted by friends and family. (4). Even when an evacuation notice was issued as in Paradise, California, it came 7.5 hours after the fire had already burnt houses to the ground (5). Knowing about a disaster as early as possible increases survival and decreases chance of injury. The current warning system also leads to millions of dollars of avoidable damage as residents are often given little or no time to prepare before an evacuation.

Current disaster alert systems come on three fronts. The first front is sign-up-based systems. These require an individual to actively sign up for an application on their phone or sign up for an email alert system. In late 2017, one of the more prominent apps, Nixle, had less than 500,000 people signed up for disaster warnings (6). Sign up programs have the inherent flaw of requiring you to enroll. This is very difficult to implement across a state with tens of millions of people. An application may also not be accessible on all platforms and may not work if your ringer or notifications are silenced. Those without access to technology, namely the impoverished and older generations, will not be able to get alerts under the current sign-up-based systems.

Another alert system utilizes the Wireless Emergency Alerts (WEAs) alert infrastructure, which has access to nearly all mobile phones and can send universal text messages. The problem with this is that geographic locations for WEA are calculated by ‘signal sectors’ that are imprecise and blanket entire regions with an alert message (7). Often times, wildfires are only threats to specific communities and using a blanket approach with WEA can result in widespread panic and confusion, making it more difficult for those in danger to evacuate. County officials rarely use WEA because they do not want to create widespread panic. Also, those without phones would not be able to receive this messaging.

The third front, door-to-door warning, is the most successful at making sure people are warned but is not practical over large areas. In many counties, a door-to-door warning was used as a measure to evacuate residents who had not received any alerts about an oncoming wildfire. This system is impractical over large distances, causes confusion, and is highly time-consuming. Rural areas depend nearly entirely on door-to-door warning systems, giving them little time to prepare.

The current warning systems all rely on the county to initiate the warning and alert the right people. This creates 58 different entities with 58 different protocols and warnings. Natural disaster alerts need to centralize warning systems in order to smoothly and efficiently send alerts to specific communities, buildings, or houses. Centralization is important because wildfires do not respect county lines, and a centralized system would be able to alert people as the fire progresses through various counties.

Recent advances in the Internet of Things (IoT) platform and cloud computing make it possible to create a cheap and efficient way to alert millions of homes at once. Our study describes the design and applicability of a novel alert system known as CRISIS-CONNECT and compares it to existing warning systems in place. CRISIS-CONNECT offers centralized communication to a broad range of people (**Figure 1**).

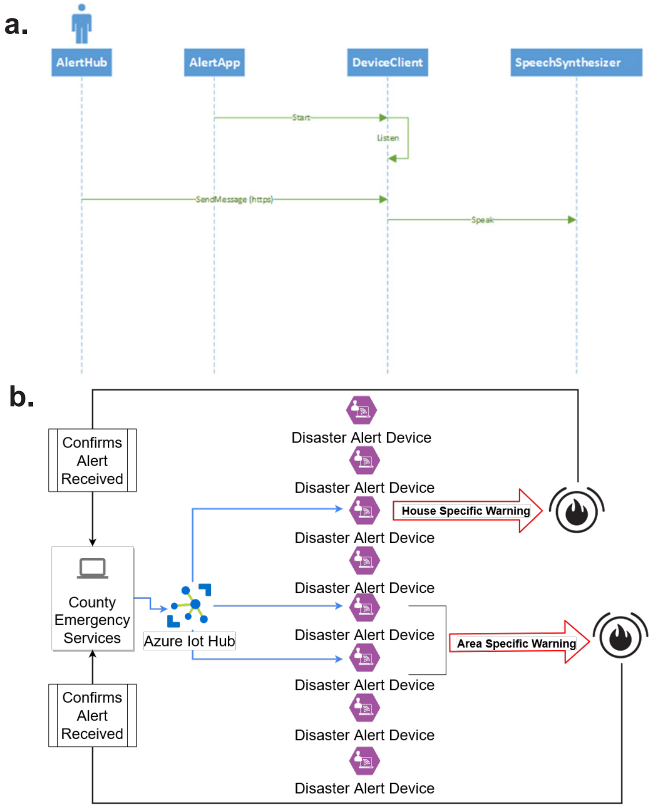

Figure 1: CRISIS-CONNECT application design and system implementation. A) Sequence diagram of the CRISIS-CONNECT application. The Alert Hub is the county office, and the Alert App is the application on an individual device. The Device Client and Speech Synthesizers are parts of the Alert Application. B) High-level schematic of the disaster alert system using the Microsoft Azure.

Internet of Things is a relatively new idea that focuses on creating a network of internet-connected devices to relay some form of information. By combining all of these internet-connected objects under one system, it is possible to execute complex and broad tasks. A common implementation of Internet of Things is the Amazon Alexa smart home set up, which connects internet-enabled devices together to make home life more efficient. In a similar fashion, CRISIS-CONNECT makes disaster warning more efficient.

The design and set up of CRISIS-CONNECT relies on devices to be installed in homes, cars, and commercial buildings, similar to carbon monoxide monitors. For a device to be implemented into the IoT infrastructure and receive alerts, it needs to have a computer, data chip, global positioning system (GPS), and speaker. In this study, we test the CRISIS-CONNECT alert system's performance against the WEA system. We report that CRISIS-CONNECT can transmit audio and visual alerts over a wide range of distances and can function on high and low data speeds, outperforming WEA. Using a location specificity test, we further demonstrate that CRISIS-CONNECT sends alerts with greater GPS precision than WEA. Last, we report that the CRISIS-CONNECT device's battery life is comparable to the iPhone 6s in both active and standby modes. These results support CRISIS-CONNECT as a realistic alternative to address the shortcomings of the current WEA system.

Alamo (12.9 mbps)

Application	Can an alert be sent
Code Red	Yes
FEMA	Yes
CRISIS-CONNECT	Yes

Mt. Diablo (6.4 mbps)

Application	Did message send?
Code Red	"No Internet Connection"
FEMA	"No Internet Connection"
CRISIS-CONNECT	Yes

Round Valley Regional Park (4.2 mbps)

Application	Did message send?
Code Red	"No Internet Connection"
FEMA	"No Internet Connection"
CRISIS-CONNECT	Yes

Table 1: CRISIS-CONNECT has better coverage than prominent smart phone applications such as FEMA and Code Red. The ability to receive alert messages in various locations and data speeds were measured. In areas of low data speeds, sign-up-based applications were not able to send alert messages and maps did not load. However, CRISIS-CONNECT was able to receive the warning message in every trial.

RESULTS

When directly comparing CRISIS-CONNECT to phone-based applications like FEMA and CodeRED, there are several clear advantages to having a CRISIS-CONNECT device in the house. The prototype device has very low computing requirements compared to a phone-based application. This allows for a CRISIS-CONNECT device to have much more reliable connections in rural areas compared to phone applications. In areas of low data speeds like Mt. Diablo and Round Valley Regional Park, where upload speeds were 6.4 mbps and 4.2 mbps respectively, the phone application CodeRED (on an AT&T data plan) and FEMA would not load its map or send notifications **(Table 1)**. The CRISIS-CONNECT prototype device with a cellular data chip from AT&T was able to play the alert within 15 seconds of being sent at Mt. Diablo and within 14 seconds of being sent at Round Valley Regional Park **(Figure 2)**. Rural areas often do not have the data speeds necessary to run data-intensive applications, making a basic CRISIS-CONNECT device ideal. There was a statistically significant difference between data speeds as determined by one-way ANOVA (F(2,45) = 8280.65, p-value

= 1.74 x 10-58) **(Table 2)**.

The current WEA system has a low degree of location specificity, limited to GPS precision on the scale of several square miles. To test CRISIS-CONNECT's GPS precision, four CRISIS- CONNECT prototype devices were spread out along a street, 19 miles away from a county office, roughly 30 meters apart. In 15 repeated trials, a CRISIS-CONNECT alert was sent from the county office hub to one of the four devices, based on its GPS location chip **(Figure 3)**. In all 15 trials, CRISIS-CONNECT alerted only the intended device, demonstrating higher location specificity than WEA.

Battery life is an important aspect to consider during power outages. The prototype CRISIS-CONNECT device powered using a 5,000 mAh battery pack was able to send a signal repeatedly for 3 hours and 15 minutes. On standby mode, the prototype device lasted 4 days and 3 hours. The battery life of a basic CRISIS-CONNECT prototype was compared to an iPhone 6s and performed similarly despite no battery life optimization **(Figure 4).** More battery efficient devices may be able to last weeks or even months.

Last, the CRISIS-CONNECT prototype device includes an audio-based system that remains active unless the device power is turned off. Due to its design, the device always plays at full volume which will ensure that individuals receiving alerts have both audio and visual cues via CRISIS-CONNECT.

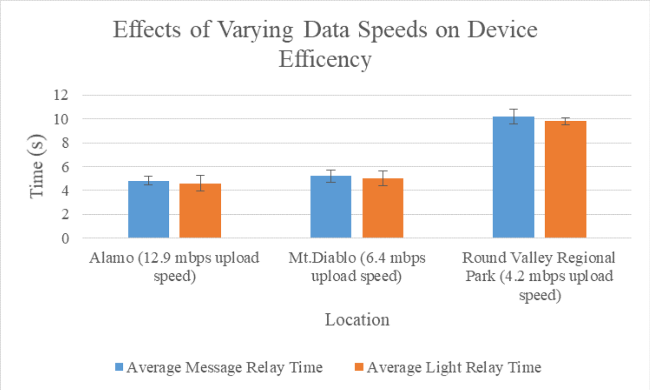

Figure 2: CRISIS-CONNECT transmitted alerts over variable distances and data speeds, outperforming the WEA system. CRISIS-CONNECT devices were placed at Alamo, Mt. Diablo, and Round Valley Regional Park, and alerts were sent from a local county office. The time it took to receive audio and visual alerts in each location was recorded. WEA systems were unable to send alerts to areas with low data speeds (Table 1). One-way ANOVA analysis of data speeds revealed that there was a statistically significant difference between groups for light relay time (F(2,45) = 8280.65, p-value = 1.74 x 10-58) and message relay time (F(2,45) = 4563.99, p-value = 1.09 x 10-52).

DISCUSSION

The results of CRISIS-CONNECT were quite promising. The system has the specificity of a single house and the range of entire cities and counties. It can be used in areas of low data speeds, and it is reliable. Initial results of required data speeds show that a speed of only 4 mbps of upload speed is required for efficient communication, much less than the speed required for alert phone applications. This may be because the disaster alert device is only looking for one signal, far fewer than a phone or a fully operating computer. AT&T cellular data coverage covers 120,517 m2 or 76% of California (8). For areas that do not have cellular data access, disaster alert devices could be connected to Wi-Fi as 100% of Californians have access to mobile broadband service and 95% of Californians have Wi-Fi speeds of over 25 mbps (9). If this disaster alert system proves to continue to work over wide ranges of area and in areas with weak signals, this framework can be expanded to entire counties and states. If implemented, emergency services will be able to send alert signals to residents without causing widespread panic and receive a confirmation when the sound is played on the device. This will reduce misinformation and make evacuations less confusing for residents. The message system is currently a verbal text-to-speech messaging platform.

Light Relay Time						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	269.351	2	134.676	8280.65	1.74236E-58	3.20432
Within Groups	0.73188	45	0.01626			
Total	270.083	47				
Message Relay Time						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	291.886	2	145.943	4563.98	1.09854E-52	3.20432
Within Groups	1.43897	45	0.03198			
Total	293.325	47				

Table 2: An ANOVA test showed there was a large statistical difference based on location and data speed. The test was performed first on the 15 trials of the message relay times and then performed again on the light relay times. F was greater than F crit showing that the null hypothesis should be rejected and that there was a statistical difference based on varying data speeds.

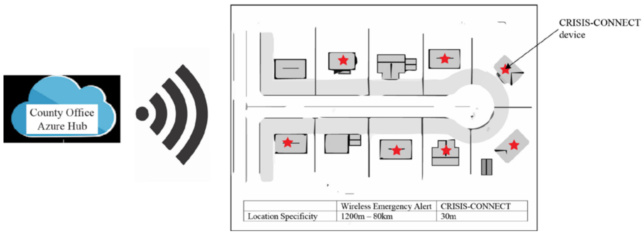

Figure 3: CRISIS-CONNECT had greater location specificity test than the commonly used WEA system. The experiment was designed by placing a CRISIS-CONNECT device 30 meters apart in several houses along a cul-de-sac. An alert was sent from the county office to individual devices and only those specific devices would play the alert. Recorded data on WEA showed a far reduced location specificity compared to CRISIS-CONNECT.

In order to observe reliability, basic Failure Modes & Effects Analysis was performed. One potential failure mode is interrupted internet connectivity, which would result in the IoT technology becoming unusable until internet access is restored. Another failure mode is the bandwidth requirements for the device are greater than the network the device is connected to. This is likely not a major issue because the alert application on the CRISIS-CONNECT devices requires very low data speeds to receive and send messages.

In addition, CRISIS-CONNECT devices may need more visual cues to work effectively. An alert LED panel can easily be added on to devices. The verbal system speech synthesizer reads at 125 words per minute. In the future, a more thorough test should be performed that shows how comprehensible the text-to-speech software is.

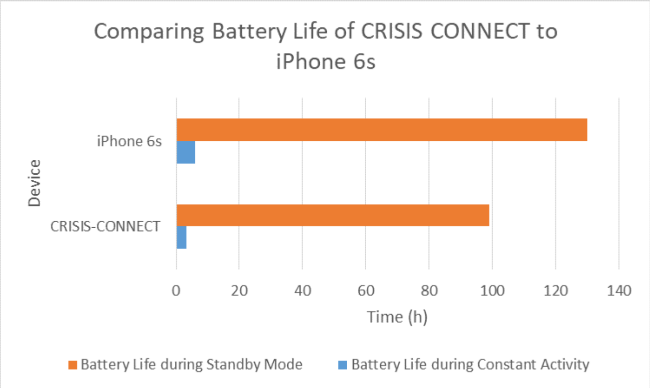

Figure 4: The CRISIS-CONNECT prototype had comparable battery life to that of an iPhone 6s. The battery life was measured in hours. Initially the devices were compared on standby mode and then again during constant activity. The iPhone 6s performed marginally better during constant activity, but lasted considerably longer on standby mode.

The main obstacle for implementation is cost. This specific prototype was close to $100, which is not feasible for large-scale application. However, with scale and reducing unnecessary hardware, a basic CRISIS-CONNECT device can be made for under $15. The great thing is that with four basic pieces (computing system, speaker, cellular data chip/WiFi, and a GPS chip), any device can turn into a CRISIS-CONNECT device. This is obviously far more expensive than a basic alert sign up, but the greater capability to alert individuals will likely result in more property being saved. This device has broad appeal for older generations, rural areas, and will allow authorities to evacuate specific neighborhoods with clear verbal instructions and give residents the time needed to gather essential belongings.

The benefit of Iot technology is that any device can be placed inside the infrastructure and become an alert device. Laptops and phones can come pre-installed with CRISIS-CONNECT software or individuals can download the application. During any disaster or emergency, every device in an area can then receive a message at full volume. CRISIS-CONNECT infrastructure can turn any basic device into an alert device with 30 meters of location specificity. In the future, building code regulation can require an alert device in every house, similar to a carbon monoxide monitor. Devices like the prototype offered here are a cheap and easy way to stay connected during disasters. The end goal is to have CRISIS-CONNECT as one facet of a multi-prong approach to keep people as informed as possible.

This system was created for wildfire alerts, but it can connect directly to mudslides and flood monitoring systems to automatically send messages to evacuation areas within seconds. It is especially useful for fast-moving and hard to predict natural disasters. Wildfires are becoming a normality in California and will likely get progressively worse in the future. It is important to maintain infrastructure to deal with such common disasters and to be able to evacuate residents in a calm and orderly fashion.

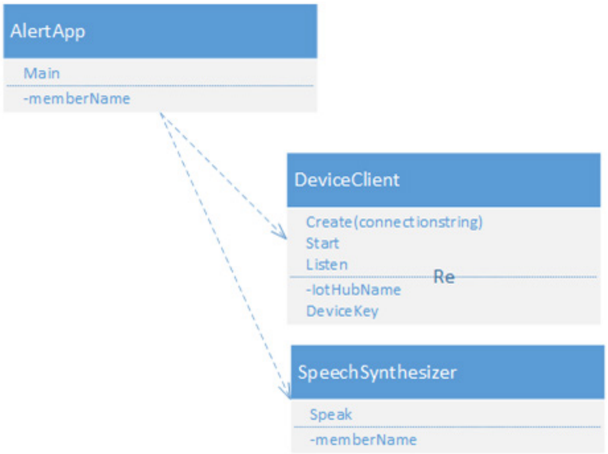

Figure 5: The alert application that controls the CRISIS-CONNECT system has three main classes. The Alert App class calls the Device Client and Speech Synthesizer classes. The Device Client and Speech Synthesizer classes have specific methods that allow the device to start, listen, and play the message.

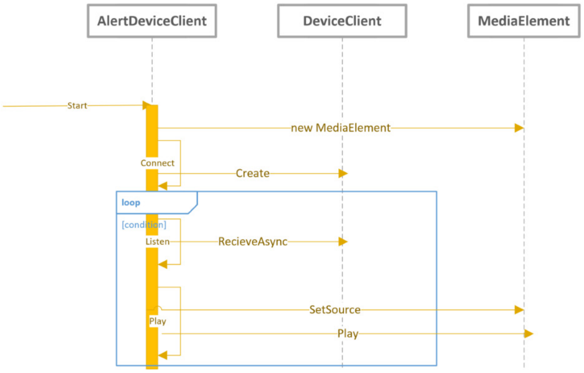

Figure 6: Each class interacts with each other to receive the alert and play the message. The main AlertDeviceClient class has three methods that allows the device to start, listen and play. The DeviceClient class has two methods that connect to the IoT hub and makes the device able to receive a message from the hub. The MediaElement Class has two methods that allow the device to play the message when received and stop after looping.

MATERIALS AND METHODS

CRISIS-CONNECT design

The prototype device presented and tested here was built by utilizing a Raspberry Pi 3 Model B minicomputer, a JBL clip speaker, a small GPS device, and an AT&T data chip. A small LED light was soldered onto the computer. This device has the basic elements of a quality alert device. The computer and cellular data chip allow for connection to the Azure Internet of Things (IoT) Hub, the speaker is able to output audio, and the light is able to flash different colors depending on the input.

Measuring data speeds

The upload and download time were measured using speedtest.net three times at each location.

Measuring response time from initial warning

This test involved two people: one person at the location of the test site, and another person at the county office using the operator application. The two people were on a call; the operator indicated when an alert was sent from the hub, and the person at the test site confirmed when the device lit up and when the device started playing the message. The interval of time from when the operator sent the message to the test site until the time in which it was received was recorded. Each test was conducted at least 15 times. The test sites were chosen strategically. Round Valley Regional Park was chosen for its low data speeds. Mt. Diablo was chosen as it is one of the highest points in the East Bay and a place that has been subjected to wildfires in the past. Alamo was chosen as a third location as it is a residential area.

Location specificity test

A series of identically-built devices was placed along a cul-de-sac in the kitchen of various homes. Based on square footage information available online, this was roughly 30 meters apart. A cul-de-sac provides a good model for a typical wildfire alert scenario. The signal was sent from a local county office that would likely send the alert if there was a wildfire in the region. After being placed along a cul-de-sac, one specific device in the cul-de-sec was sent a warning from the country office several miles away. In 15 separate trials, the singular device was the only one that played the warning.

Battery life testing

A 5,000 mAh battery pack was attached to the raspberry pi via micro USB. The program was placed on a loop, causing the signal to be sent and received until the power of the system was exhausted. The length of time was measured using an iPhone XR timer. To measure the standby time, the time it took for a small LED light on the raspberry pi to turn off was measured. This test also using a 5,000 mAh battery and an iPhone XR timer. The constant activity battery life measurement of the iPhone 6s was performed by continually web surfing over 4G LTE until the phone lost all power. The standby mode was measured by leaving the phone on airplane mode. The length of time was measured using an iPhone XR timer.

Software

The Internet of Things hub allows for a user to send a message to millions of different devices in seconds. The underlying operating system for this system is Windows and the application was built on .NET. The device application must accomplish three tasks. It needs to be able to receive messages, play messages, and constantly listen to messages from the IoT hub. With a plethora of code available, it was a matter of identifying the necessary components to build the application. The code was built using three classes **(Figure 5).** The main AlertDeviceClient class has three methods which allows the device to start, listen, and play. The DeviceClient class has two methods that connect to the IoT hub and make the device able to receive a message from the hub. The MediaElement Class has two methods that allow the device to play the message when received and stop after looping **(Figure 6)**. Azure has an existing operator dashboard platform. It shows every device in the region and, when paired with the alert application built, it can allow a user to alert several million devices at once within seconds. Each device must be registered to the Azure operator dashboard and the packaged application must be installed on the devices. This infrastructure remains secure because the framework uses a cryptographic protocol called Transport Layer Security. This protocol ensures data encryption and integrity and allows the device to validate the identity of the server by validating its digital certificate.

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I would like to dedicate this research to the Do It for Lily Initiative. Remembering Lily in all we do!

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REFERENCES

1. "2018 Fire Season | Welcome to CAL FIRE." *Ca.Gov*, 2018, www.fire.ca.gov/incidents/2018/.
2. Myers, J. "AccuWeather predicts 2018 wildfires will cost California total economic losses of $400 billion." *AccuWeather,* 2018.
3. Lam, K. "Death Toll Drops to 85 at Camp Fire; 11 People Remain Missing." *USA TODAY*, 4 Dec. 2018, www.usatoday.com/story/news/2018/12/03/camp-fire-death-toll-california-deadliest-wildfire/2199035002/. Accessed 13 Nov. 2019.
4. Hart, A. "California Wildfires Reveal Alert System Shortcomings." *Government Technology*, 2018.
5. Krieger, L. "Wildfire alert system failed." *Daily Democrat,* 2018.
6. Evangelista, B. "Signups for Emergency Messaging Service Nixle Rise amid Cellular Outages." *SFGate, San Francisco Chronicle,* 8 Feb. 2018, https://www.sfgate.com/business/article/Sign-ups-for-emergency-messaging-service-Nixle-12267930.php.
7. Bean, Hamilton, et al. "The study of mobile public warning messages: A research review and agenda." *Review of Communication* 15.1 (2015): 60-80.
8. Holmes, C. (2019). "Best Cell Phone Plans & Coverage in California". [online] *Whistleout.com.* Available at: https://www.whistleout.com/CellPhones/Guides/Best-Coverage-

in-California-USA [Accessed 14 Nov. 2019].
9. Reese, N. “Internet Access in California: Stats & Figures.” *Broadband Now*. 16 Oct. 2019. Web. Accessed 12 Nov. 2019. <https://broadbandnow.com/California>