Wireless Emergency Alerts

Geo-Targeting Using Cell Radio Frequency (RF) Propagation Algorithm

Operational Assessment – Field Validation

April 2016

TeleCommunication
Systems, Inc.

TASK LEAD
Dara Ung

RESEARCH STAFF
Vipul Parmar
Fan Wang
N. Vadrevu
Jim Jolley
Rick Ruth

Keith Bhatia
General Manager & VP

Wireless Emergency Alerts: Geo-Targeting Using Cell Radio Frequency (RF) Propagation Algorithm

Operational Assessment–Field Validation

Prepared for
Department of Homeland Security
Science and Technology Directorate
Homeland Security Enterprise and First Responders Group

ACKNOWLEDGEMENTS

TeleCommunication Systems, Inc. (TCS) would like to extend our deep appreciation to the U.S. Department of Homeland Security Science and Technology Directorate for giving the research team the opportunity to work on this exciting project to improve the safety of our families, our communities and our nation. In particular, TCS would like recognize **Denis A. Gusty** and **Laura Barton** for their cooperation and guidance for the success of this research.

TCS also would like to thank our trusting partner carrier, ClearTalk, who gave us the opportunity to utilize its production network to perform the research; in particular we would like to thank **Paul Rauscher** and his team in assisting on the project's logistics and issue resolution.

Table of Contents

List of Figures

EXECUTIVE SUMMARY

TeleCommunication Systems, Inc. (TCS) carried out research and development on constructing an algorithm that utilizes Radio Frequency (RF) cell site propagation footprints. Research focused on using RF coverage area footprints to improve geo-targeting granularity and accuracy for delivery of Wireless Emergency Alert (WEA) messages. This report documents the field testing activities, findings and the analysis of the results that used the enhanced geo-targeting algorithm previously developed for this research.

The WEA standard (J-STD-101) defines two methods that can be used to select cell towers to deliver WEA messages for a given targeted geographical area. The first method calls for the ability to determine the cell towers at the county level of granularity. This level of granularity is a minimum requirement for all mobile carriers that offer the WEA service. The second method is optional and allows the targeted area to be defined by polygons instead of fixed county boundaries and determines if the targeted cell tower physical position (latitude/longitude) is found inside the target area polygon. Both of these methods have been found to be highly inaccurate as the alert target areas become smaller and therefore cannot be used to issue alerts that require target area size to be within a few square miles. This inaccuracy introduces situations known as “over-alert”—when an alert reaches population that is not intended for—or “under-alert”—when the alert does not reach the people in harm’s way.

This research included the modification of WEA software using enhanced geo-targeting algorithms that take into account more than just the physical location of cell towers. The algorithm was tested both in the laboratory and in the live production environment. The outcomes of the research include obtaining the live test results that are keys to validate the lab simulation. The results will also confirm the successful development of tools and software needed to collect the data in the live environment that do not impact real users.

The test results obtained from the field clearly demonstrated the strength and weakness of both the existing and the new enhanced methods. The results show that the enhanced algorithm using cell RF propagation footprints is convincingly superior to any existing method used today. When implemented, the enhanced method developed in this research will provide new benefits to WEA users in several ways, including:

- The ability to target much smaller alert areas down to a square mile regardless of the physical location of the cell towers;
- The ability to use location based Required Monthly Test (RMT), allowing WEA alerts to be tested at chosen live site without impacting the general public;
- Geo-targeting at the cell sector granularity;
- Enhanced reachability to the people in harm’s way;
- The ability to enable other alert categories to be defined because of allowable small alert target area size; and
- A solution that requires no change to the current WEA network.

The key lessons learned in this project consist of understanding the effects of a live environment and how different real-world factors can affect the expected results. These lessons learned are very important because they allow TCS to improve the techniques that will ultimately enhance its solution in the future.

Due to the limitation of the cell broadcast technology, no geo-targeting method can provide 100 percent accuracy. Based on the results obtained, however, the algorithm that uses cell tower RF propagation footprint clearly offers better accuracy than the methods used to date. Although this method will not solve the over-alerting problem within the cell sector level, it will improve the reachability to people in harm's way very effectively. Since the alert target area size can now be defined as small as a square mile, over-alerting can significantly be reduced. Therefore, this method will be suitable for such alerts as a campus emergency, a chemical spill or a road block due to a major accident. These instances would not be possible using the various methods available today.

The cell RF propagation footprint algorithm could be provided as the best-effort solution for cell broadcast technology currently available. The attractiveness of this method is that it does not require any change in the standards and specifications for it to be deployed today. The existing WEA regulatory mandatory requirement for geo-targeting is limited to county-level only. It is therefore recommended that the regulatory requirement be changed to obligate the service providers to offer WEA service with geo-targeting at cell sector level accuracy.

BACKGROUND

Recognizing the Need

Today, the Wireless Emergency Alert (WEA) standard referred to in J-STD-101 [2], defines two methods that can be used to select cell towers to deliver WEA messages for a given targeted geographical area. The first method calls for the ability to determine the cell towers at the county level of granularity. This level of granularity is a minimum requirement for all mobile carriers that offer the WEA service. The second method is optional and allows the targeted area to be defined by polygons instead of fixed county boundaries.

For the first method, based on Federal Information Processing Standard (FIPS) code in counties with very large geographic areas, an alert is sent to all mobile subscribers even though the alert area may impact only a portion of the county, resulting in an “over-alert” condition. Conversely, an uncovered area or “under-alert” condition occurs when a mobile subscriber in harm’s way does not receive an alert because the serving cell tower is physically located outside of the FIPS code defined boundary.

For the second method, since Radio Frequency (RF) cell site propagation is not taken into account, similar over-alert and under-alert conditions will be encountered for the solution that uses only cell tower latitude/longitude (LAT/LON) and polygons as a target area. For example, a cell tower with its RF propagated over the target area while having its LAT/LON point located just outside the targeted area will not be counted as a targeted cell, and thus subscribers in this target area will not receive alerts.

Responding to the Need

TeleCommunication Systems, Inc. (TCS) was contracted by the Department of Homeland Security (DHS) to investigate the feasibility of using enhanced geo-targeting algorithms that take into account more than just the physical location of cell towers. The project was divided in two phases. TCS completed phase 1 in which TCS evaluated the use of predicted cellular RF coverage areas that were included in new WEA geo-targeting algorithms. The research performed by TCS using RF coverage footprints for improved geo-targeting of WEA messages is expected to provide the following benefits:

- Maintain compatibility with the current Commercial Mobile Alert for C Interface message definition;
- Improve existing granularity through the use of the Common Alert Protocol (CAP) alert area polygon and cell tower RF propagation to minimize over-alerting and under-alerting conditions;
- Allow more alerts affecting much smaller target areas such as campus incidents, chemical spills or local fires to be submitted;
- Expand coverage to fill “gaps” in current methods used, further protecting mobile subscribers in a potential emergency situation that would not receive an alert; and
- Enhance the public perception of the WEA service.

To complete the end-to-end study of this research, DHS awarded TCS the second phase of the study to test the results from phase 1 in a live production environment. The readers are recommended to become familiar with the phase 1 *Cell Radio Frequency (RF) Propagation Algorithm Operational Assessment Final Report* [1] as referenced in this document to understand the details of phase 2. Phase 2 consisted of field testing with predicted RF coverage data and actual mobile devices to validate the algorithm's effectiveness for alert delivery accuracy. This report documents the results and the analysis of field testing performed on the live network to compare with the theoretical findings of phase 1, as well as the improvements observed over the existing geo-targeting methods.

I. BASIC TECHINCAL CONCEPTS

The following concepts will be used throughout this document.

Cell Tower and Cell Sector

A cell tower or base station is the access component for air interface between wireless devices and the cellular network. The cell tower uses microwave radio communication. It is composed of several antennas mounted on a tower with electronics in its base. When a text message or a call is placed from/to a cell phone, the cell phone and the cell tower communicate bi-directionally over a dedicated RF range. A cell tower generally has three antennas. Each antenna represents a sector, also referred to as cell sector. Each antenna covers one-third, or 120 degrees, of the cell tower coverage. Therefore, with three antennas, all 360 degrees of tower area is covered to transmit and receive signals to and from the mobile devices in that area. Figure 1 illustrates a sectored antenna pattern of a cell tower.

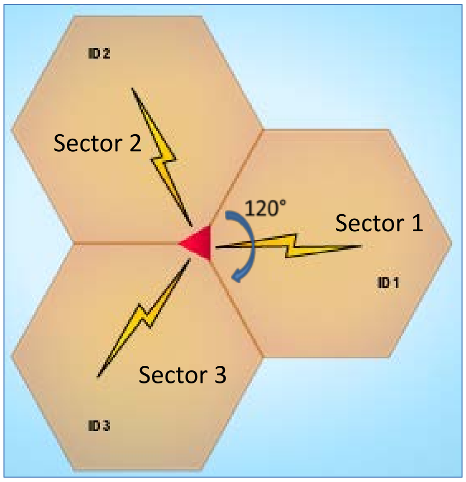

Figure 1 - Cell Tower with Three Sectors

RF Propagation Footprints

Each antenna in the sector propagates an RF signal covering an area that extends outward as far as the power of that antenna and other environmental factors allow. The geographical limit (range) of the RF signal that is detectable by a mobile device defines the footprint boundary of the coverage.

To generate the RF footprint model, commercially-of-the-shelf cell site planning software is used. This software takes radio parameters such as cell tower power, frequency, antenna characteristics and terrain data as inputs to generate a predicted RF propagation footprint polygon for every cell sector. The generated polygons are then used by TCS's WEA geo-targeting *poly-in-poly algorithm* (see definition below).

To process WEA alerts using RF footprints, all the generated RF propagation footprints are stored in a Relational Database Management System (RDBMS) that can support spatial data records.

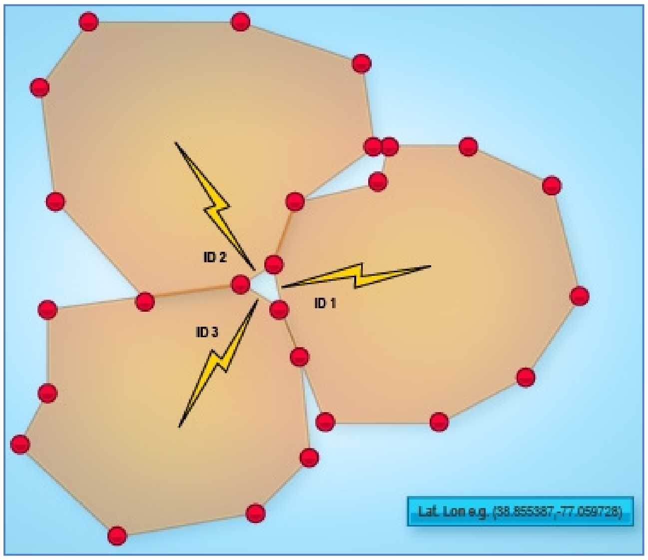

Figure 2 - Sample LAT/LON Plot Approximation of Cell Sectors RF Coverage

For simplicity, the illustration above indicates that each sector propagates an RF signal covering an area represented by a hexagon (i.e., cell sector). To represent the footprint so that it can be stored and processed in an RDBMS, the coverage map is approximated using RF analysis software to generate LAT/LON plots of the signal coverage in the form of polygons. Each node of the cell sector polygons is stored as a sequence of LAT/LON coordinates as illustrated in Figure 2. The nodes of each polygon are represented as spatial data and stored in the RDBMS for processing.

In reality, cell sector coverage footprints vary in shape and size depending on many factors. These factors include antenna azimuth, height, tilt, power, signal frequency, and human-made and natural obstacles like terrain, water and physical structures. Figure 3 represents an example of a generated RF propagation footprint of an actual cell tower. The areas shaded with light green color belong to the same cell tower Wellton with three cell sectors labeled as Sector 1, Sector 2 and Sector 3, and outlined by white boundary traces.

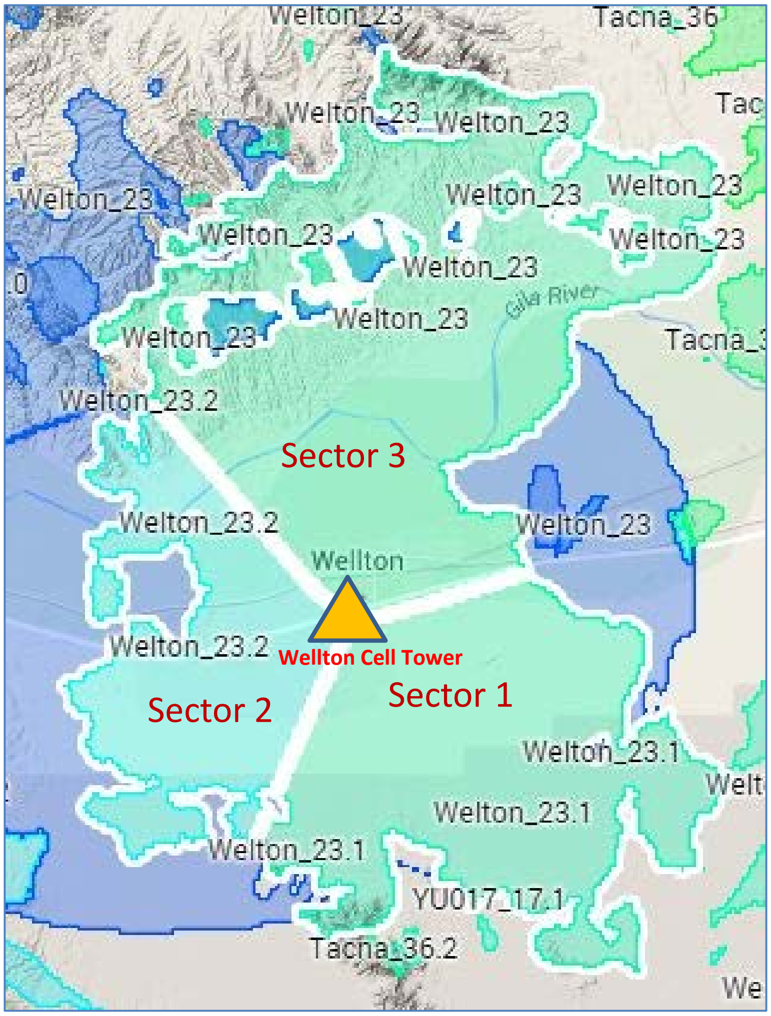

Figure 3 - RF Footprint Model

Device Tuning to Cell Tower

When a mobile device is turned on, it scans for the signal propagated by cell tower antennas (cell sectors) and tunes to the one that has the strongest signal. As the device moves from one location to another, it would "hang on" to that tuned cell sector until its signal strength drops below a service quality threshold; at this point, the mobile device will rescan for a better cell sector. This means that in many cases, a mobile device is still tuned to a cell tower far away even though it is physically much closer to another cell tower.

Paging or Control Channel

The paging or the control channel is the air interface path used by the cell tower to establish a communication link between the antenna and the mobile device. The control channel is used to perform call set up and to keep track of the mobile device whereabouts. Cell broadcast and short messages are sent to the mobile device over the control channel.

Cell Broadcast

Cell broadcast is a mobile technology that allows messages (currently up to 15 pages of up to 93 characters per page) to be broadcast to all mobile devices within a designated geographical area. The broadcast range can vary from a single cell sector to the entire network. Cell broadcast messages are delivered over dedicated channels to which the mobile device can tune to, much the same way as a radio or TV station broadcasts its signal to radio or TV devices. <u>When the message is broadcast to a cell sector, the sector antenna will attempt to broadcast the message to all mobile devices that are successfully tuned to that antenna.</u>

Cell broadcast is designed for simultaneous delivery of messages to multiple users in a specified area. Whereas the Short Message Service is a one-to-one service, cell broadcast is a one-to-many geographically targeted service. Cell broadcast technology has been adopted by WEA service to deliver emergency alerts to the mobile devices in the United States.

Point-in-Poly Algorithm (Dynamic)

Point-in-poly is an algorithm used in a geo-targeting function to determine if a physical object, based on its LAT/LON point, is found inside a polygon defined by a set of LAT/LON points. In WEA, the physical object would be a cell tower with its physical LAT/LON point, and the polygon is the alert geo-targeting area. This algorithm is called ***Dynamic*** *geo-targeting* in this document.

Poly-in-Poly Algorithm (Dynamic Plus)

The poly-in-poly is an algorithm used in a geo-targeting function to determine if a *target polygon* defined by a set of LAT/LON points intersects, touches or is inside an *object polygon*. In WEA, the object polygon is the RF propagation model of a cell sector, and the target polygon is the alert geo-targeting area. This algorithm is used to determine what coverages of the cell sectors intersect, touch or are inside an alert target area. Those cell sectors that meet any of these conditions are the cell sectors to which the emergency alert would be sent. This algorithm is called ***Dynamic Plus*** *geo-targeting* in this document.

Alert Target Area

An alert target area is a geographical area defined by the alert origination authority that consists of a polygon with a set of LAT/LON points as vertices where an emergency alert is intended to be sent. The alert target area varies in size from a several hundred yards to several hundred miles with varying shapes from a circle to rectangle. Figure 4 below depicts a sample of alert target areas drawn over the town of Yuma, Arizona, and its vicinity. Polygons labeled 1 to 4 are alert target areas.

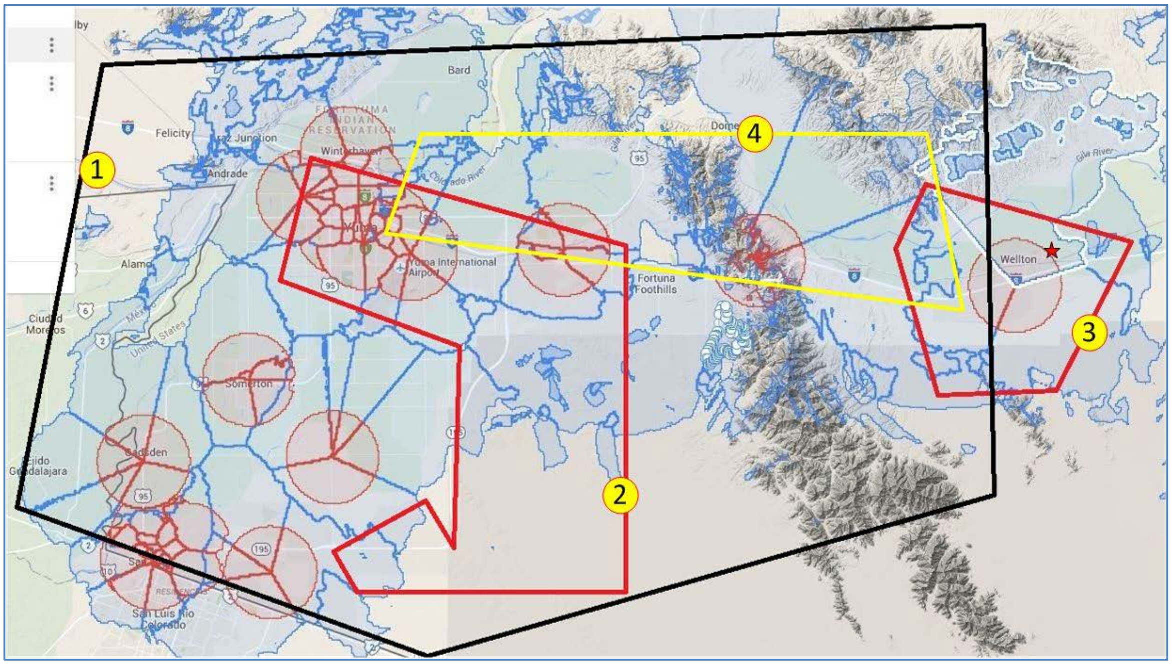

Figure 4 - Alert Target Areas Example

II. GEO-TARGETING ALGORITHMS

Geo-targeting algorithms deployed today provide the ability to determine the cell towers situated inside a county (basic requirement) or a defined polygon (optional requirement). Using only cell tower LAT/LON as a means to determine if the cell tower is candidate to receive broadcast alerts can introduce over-alert and under-alert situations. This gap condition can be addressed by taking into account the predicted cell site RF coverage footprint. Figure 5 conceptually illustrates the geo-targeting methods comparison.

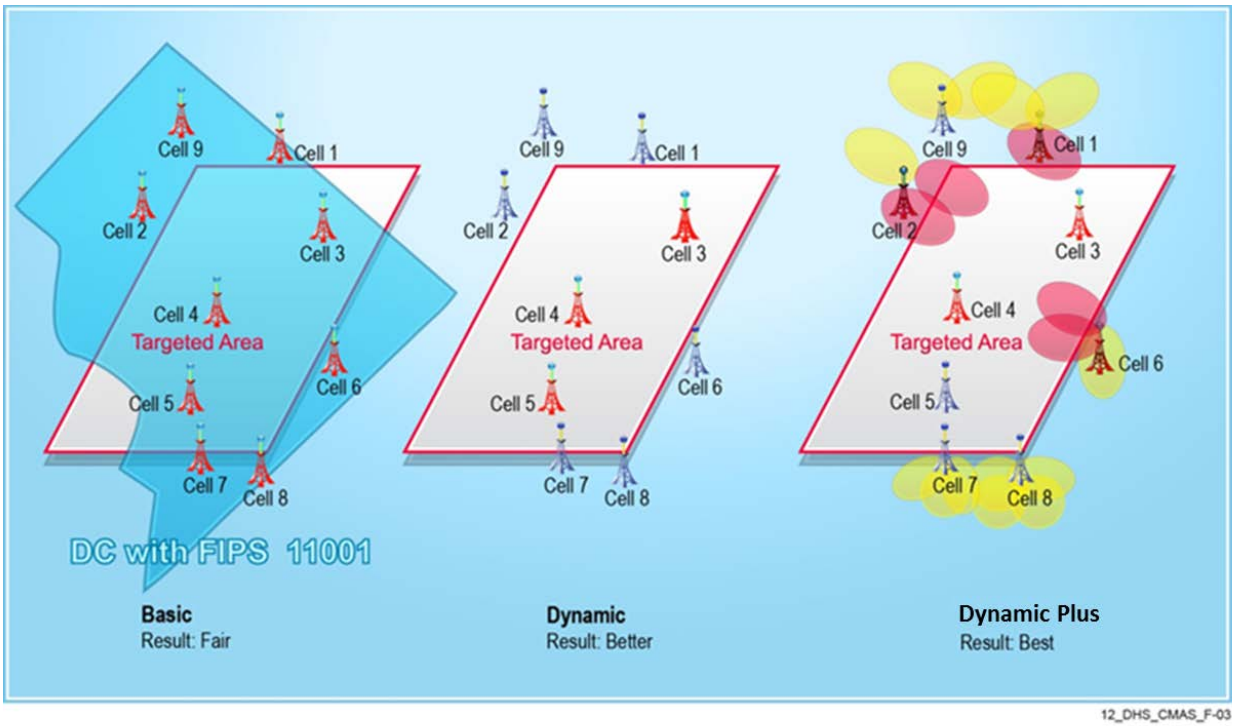

Figure 5 - Geo-targeting Methods Comparison

As shown in Figure 5, today's "Basic" algorithm results in all cell towers (shown in red) that bleed well beyond the desired target area to the entire county, despite the fact that the desired targeted area (represented by parallelograms) touches only part of the county (designated by the FIPS code). A better approach is to use the point-in-polygon algorithm labeled as "Dynamic." In this method, the Dynamic polygon data sets (parallelograms) can be compared against the stored cell site coordinates, which results in cell towers 3, 4 and 5 being alerted. Since the Dynamic algorithm does not take into consideration the RF propagation of each cell tower, however, cell towers 1, 2 and 6 are not targeted and therefore subscribers who are roaming in those cells at that moment will miss the alert. This is due to the fact that their tower LAT/LON location are physically located outside the targeted boundary while their RF signals, shown in Figure 5 as yellow and red ellipses, may propagate into the targeted area. The algorithm using RF footprint referred to here as "Dynamic Plus," which is used in this research, solves this under-alert case. Cell sectors belonging to cell towers 1, 2, 3, 4, 5 and 6 have their RF footprint propagate over the alert target area. The result of execution of this algorithm will show that cell towers 1, 2, 3, 4, 5 and 6 are the ones that will receive the alerts.

III. ALGORITHM VALIDATION SCENARIO

Validation of the enhanced algorithm developed in the phase 1 effort consisted of using the predicted cell tower RF propagation model to exercise the algorithm and observing the effect when WEA test alerts are submitted to the test handsets in the live environment. WEA test alerts were submitted to a target area defined by a polygon as illustrated in the call flow of Figure 6. The targeted area polygon was defined for an area having known cell tower RF coverage.

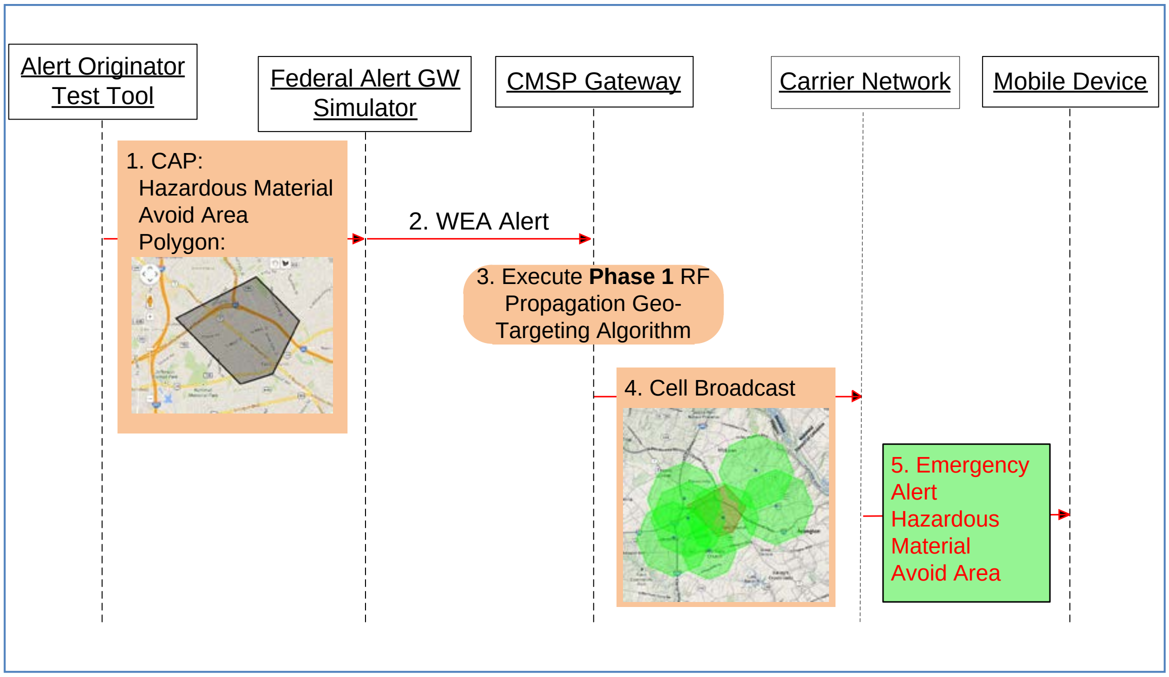

Figure 6 - WEA Call Flow Used in Field Testing

1. The Alert Originator tool is used to create the alert message and define the area to be targeted based on the CAP 1.2 standard [5]. The alert target area is defined by drawing a polygon over the map where the alert is targeted.
2. The alert message is submitted and received at the Federal Alert Gateway simulator. The Federal Alert Gateway simulator validates the message then converts the CAP message to the J-STD-101 “C” interface message and sends it the Commercial Mobile Service Provider (CMSP) Gateway.
3. Upon receiving the “C” interface message, the CMSP Gateway executes the enhanced geo-targeting by comparing the target area polygon to the cell tower RF propagation polygons previously imported in the database.
4. The results of the execution outputs a list of the cell sectors whose RF object polygon touches or overlaps the targeted area polygon. The list of the cell sectors is sent to the carrier’s radio network.
5. The carrier broadcasts the alert to all the mobile devices currently tuned to those cell towers.

IV. TESTING ENVIRONMENTS

Selected Test Site

Following several discussions with TCS carrier customers, the town of Yuma, Arizona, was selected as the field test site for the research. The site was chosen for its size, the number of available towers, the size of population and accessibility of roads and terrain. Figure 7 shows a map of Yuma and its vicinity.

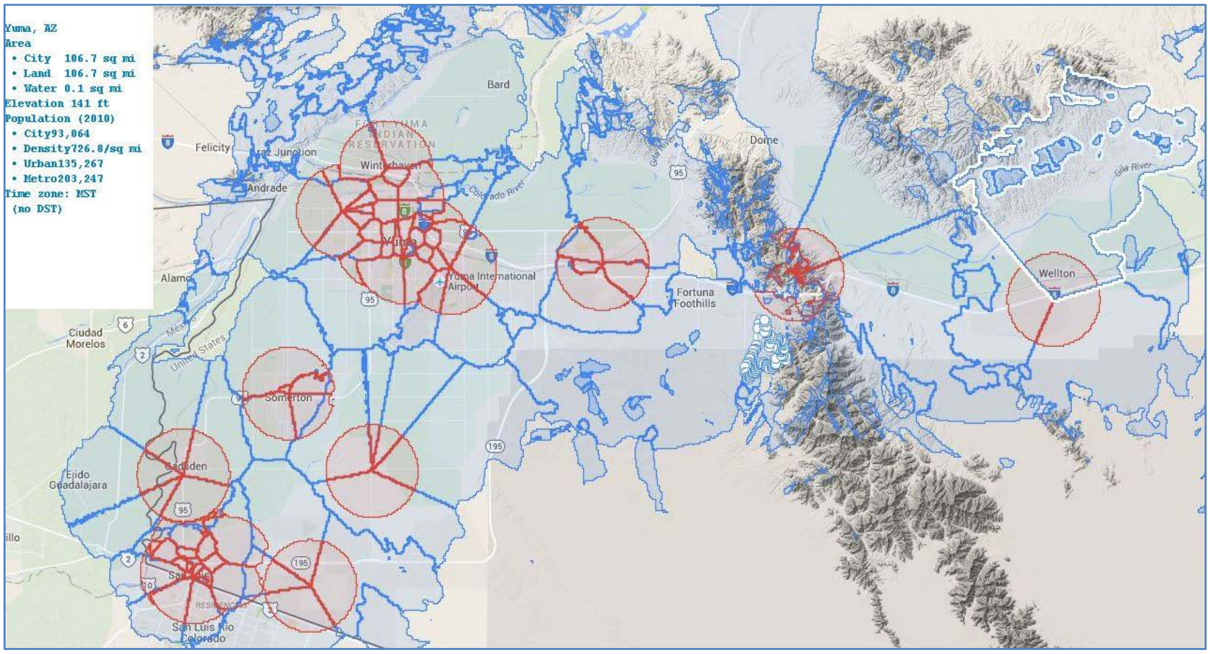

Figure 7 - Map of Yuma and Vicinity

Yuma has a population of 93,064 (census 2010) and a surface area of 106.7 square miles. Note, however, that the test areas conducted stretch beyond the city itself and cover the towns of San Luis and Wellton with populations of approximately 31,000 and 3,000, respectively. The total covered test area was approximately 985 square miles.

Cell Towers and Mobile Switching Center

The site consists of 18 cell towers with a total of 71 cell sectors. Most cell towers have four sectors per tower. The cell towers are shown on Figure 7 represented by red circles with the tower LAT/LON reference point at the center of the circles. The coverage range of the cell towers varies from a few miles to approximately 15 miles in radius. The cellular technology used is Code Division Multiple Access (CDMA). All of the cell towers are connected to the Mobile Switching Center (MSC) located in El Centro, California. In CDMA, a broadcast message is sent from the Cell Broadcast Center (CBC) to the MSC using

ANSI-41[1] based message called Short Message Delivery Point to Point (SMDPP). Once the MSC receives the message from the CBC, it sends the message to the cell sectors indicated by the CBC in the SMDPP message.

Mobile Devices

Since the testing was conducted in the live environment where the same network was used by the public, it was required that test messages did not alert the public. To prevent this from happening, special test handsets were used. To accomplish this goal, the RMT-capable handsets were used because the RMT messages do not normally alert on regular handsets. Two RMT-capable mobile devices were available for testing. A third-party app was installed on the devices to capture signal strength information, cell sector ID, time stamps and LAT/LON location of the handsets. This information was used for post-test analysis.

Cell RF Footprint Polygons Generation

The cell sector RF propagation footprint data was generated using a third-party software (deciBel Planner). This modeling tool generates RF footprints for each cell sector in terms of polygons, as explained earlier under the Basic Technical Concepts section. All 71 cell sector RF footprint polygons were generated and imported into the database to be accessed by the algorithm. Figure 8 below is the plot of the cell RF propagation footprint of the cell towers in the test site.

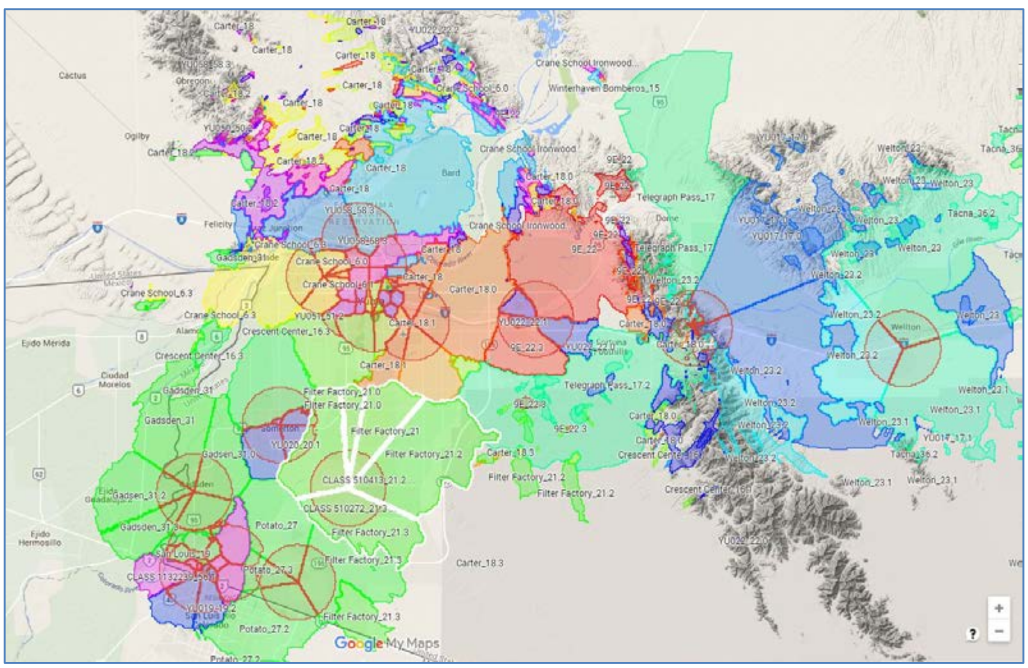

Figure 8 - RF Propagation Footprint Plot for Test Site

[1] ANSI-41 is a United States based mobile cellular telecommunications system standard to support mobility management by enabling the networking of switches

V. TESTING STRATEGY

Lab Environment

The lab was set up so that the alert could be submitted from within the TCS lab or securely from any public location via a TCS controlled environment that terminated to the live production network. Figure 9 shows the lab setup for the field test. This setup allowed the alert to be submitted via a portal from the Internet by using an Internet browser from any public Internet connection. The authorized user needed to first access the TCS lab network via a virtual private network (VPN) portal. The alert message could then be created and submitted to the WEA gateway, which in turn generated the cell broadcast message and sent it to the carrier over the SS7/SIGTRAN connection. The broadcast message arrived at the MSC which then broadcast it to the targeted cell sectors.

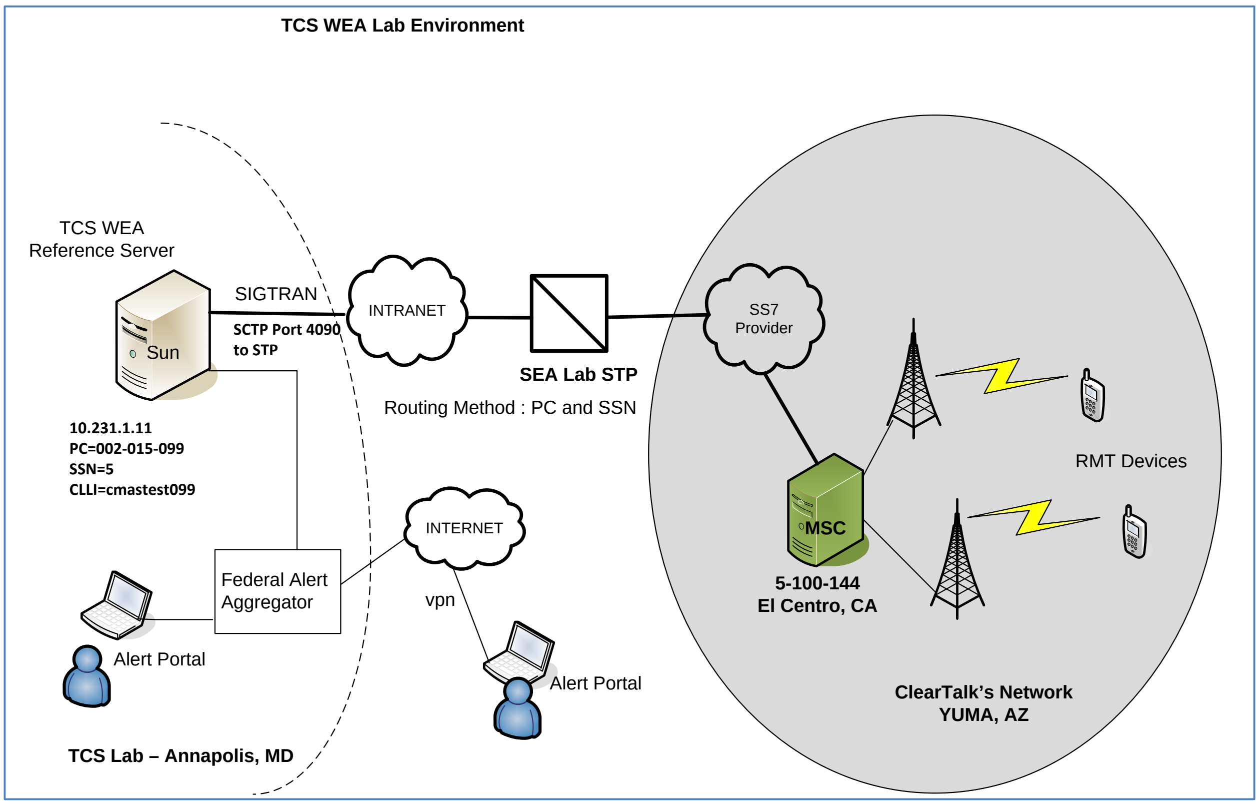

Figure 9 - Lab Set Up

Handset with Test Alert Capability

Since the testing was conducted in the live environment where the same network was being used by the public, it was necessary that test messages did not alert the public. To prevent this from happening, special test handsets were used. The J-STD-101 standard defines a test message called the RMT. In general, only cellular operators should have access to handsets capable of RMT. However, it has been observed that some devices sold to the public also have test alert capability, but with the feature turned off by default. By working with a partnering carrier, TCS was able to identify two handsets which were used for this research study.

RMT Message Modification

The RMT message defined by the J-STD-101 does not contain location information. Consequently, when the RMT message is submitted, it is sent to every cell tower in the carrier network. For the purpose of this project, alerting every tower would not be acceptable. To prevent this from happening, software changes were made to the TCS WEA components, namely the Alert Originator Portal, the Federal Alert Gateway simulator, the CMSP Gateway and the CBC, to add the location information element to the RMT message so that the test alerts were only broadcast to the targeted cell sectors.

Test Objectives

The objectives of testing the enhanced geo-targeting with RF footprints algorithm in the real environment consisted of:

1. Collecting alert reception on the mobile devices on all identified test points for both Dynamic and Dynamic Plus methods;
2. Verifying the receipt of the RMT message on the RMT mobile devices in the cells resulting from the execution of the algorithms in the field; and
3. Recording data with the goal to study any improvement of the Dynamic Plus method using the RF footprint algorithm over the standard Dynamic geo-targeting algorithm that is only based on LAT/LON of the cell tower.

To collect sufficient test data for the study, testers were physically located at the chosen site for each defined target area during the time of the alert submission. Figure 10 is an illustration of a typical defined target area where a tester would be located to validate the reception (or lack thereof).

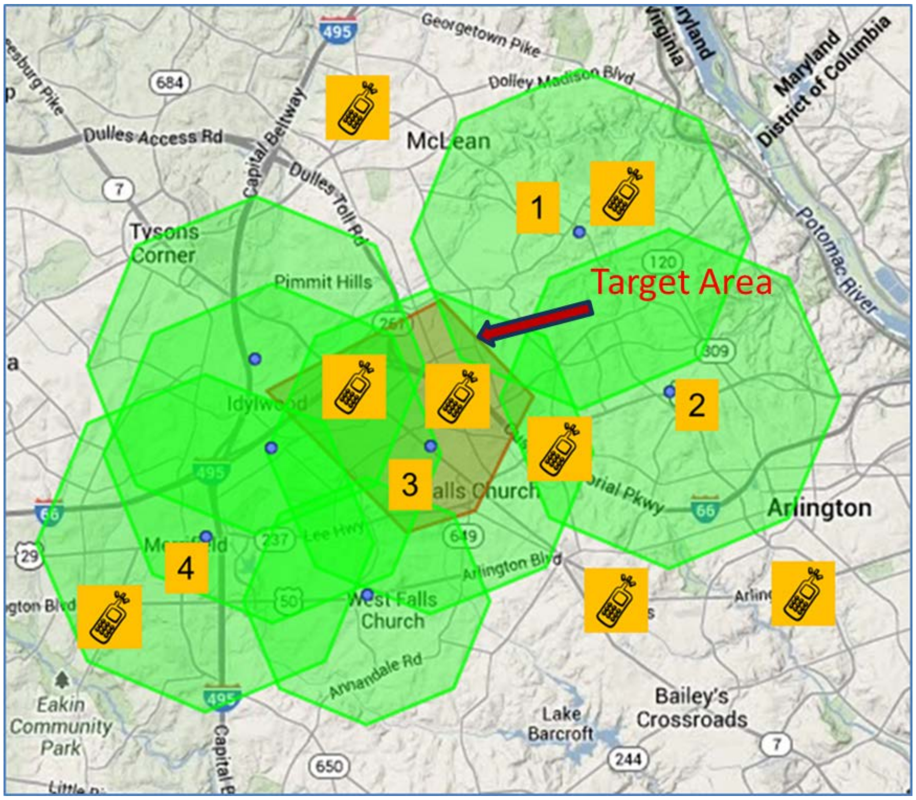

Figure 10 - Data Collection for a Typical Target Area

In Figure 10, the target area is shown with a polygon indicated by the arrow with the affected cell towers in green. Assuming, for the purpose of illustration, that cell towers numbered 1 to 4 are the cell towers to which the mobile devices are tuned. Testers, indicated by cellular phone icons, are located in various locations relative to the target area, both inside and outside of the target polygon. Testers should receive the alerts at the locations where the cell tower RF signal coverage is expected, and they should not receive the alerts where there is no coverage. The selection of the test locations included:

- Near the center of the target area physical location;
- At the border (just inside or just outside) of the target area; and
- Outside of the RF footprint coverage.

Test Execution Procedure

Validating the alert reception and collecting the test results required a minimum team of two test engineers. One field tester was physically located at the known geographical location (test point) at the time of the test alert submission. Another engineer performed the alert submission using the alert portal. The test team coordinated the execution of the test over a voice conference call so that the field engineers knew the exact time at which the alert should be received, or not received, on the mobile devices.

The steps performed for each alert submission for each test point is as follows:

1. The alert originator draws the target area on the map using the Alert Portal Originator tool.
2. The alert originator configures the method used as Dynamic geo-targeting method.
3. The field engineer drives to the desired test point on the map.
4. The field engineer has two mobile devices turned on and ready for reception.
5. The alert originator submits the alert.
6. The mobile devices should alert the reception within 10 seconds of submission.
7. The engineers record the result for the method selected.
8. The alert originator configures the method used as Dynamic Plus geo-targeting <u>with RF footprint.</u>
9. Steps 3 to 8 are repeated.

The test was repeated for different locations throughout the test areas where the cell tower RF footprints are known to propagate. Figure 11 shows the target areas where the alerts were sent, Figure 12 illustrates the associated test points for those target areas and Figure 13 shows additional polygons and test points that were conducted during field testing.

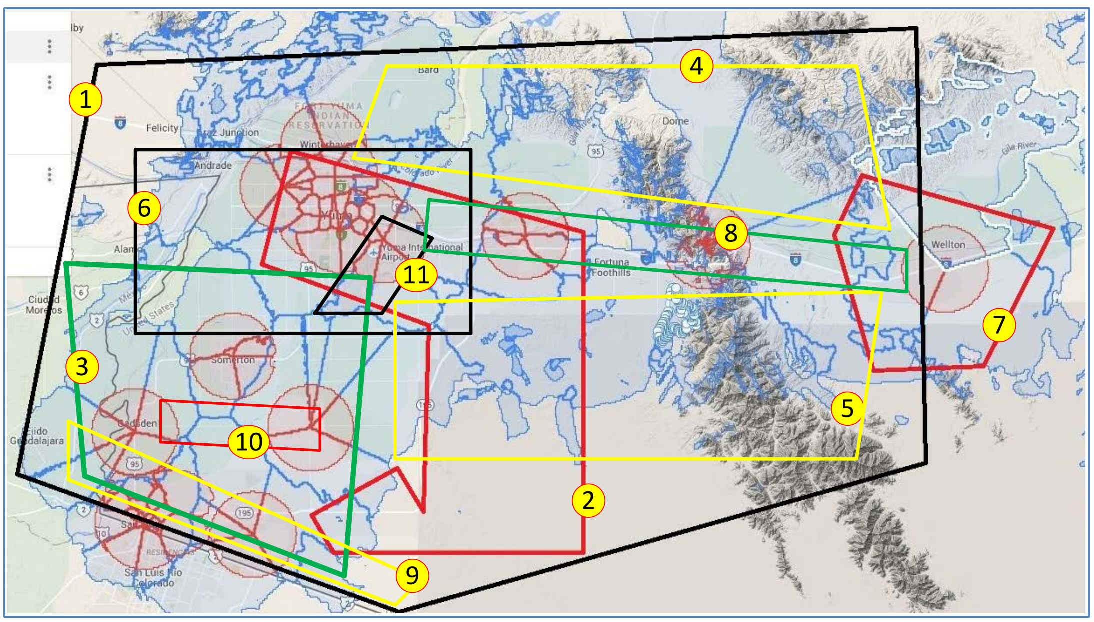

Figure 11 - Testing Target Areas

only.

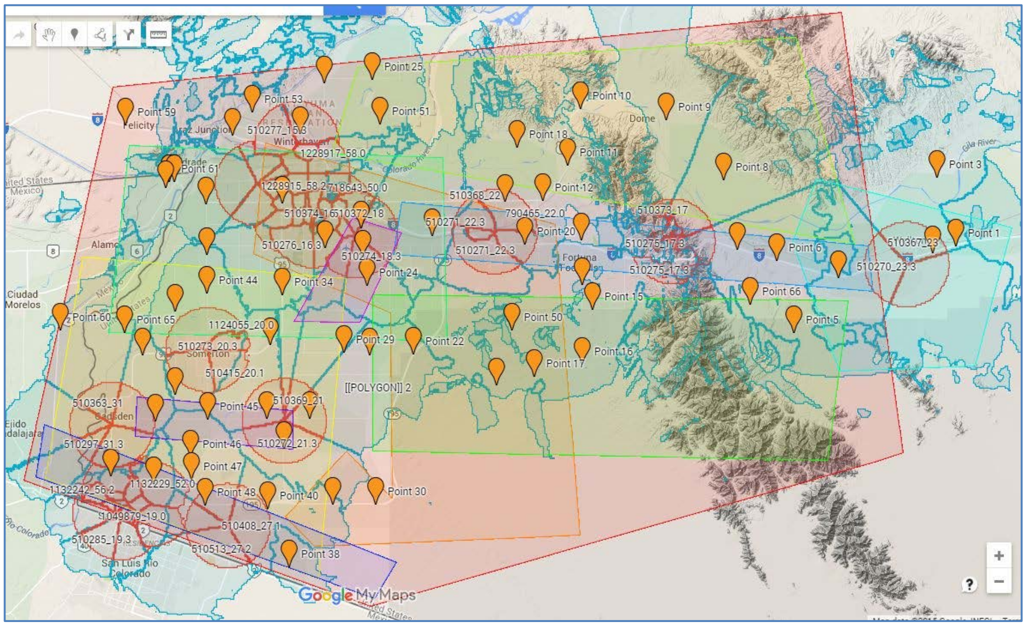

Figure 12 - Test Points Overlay

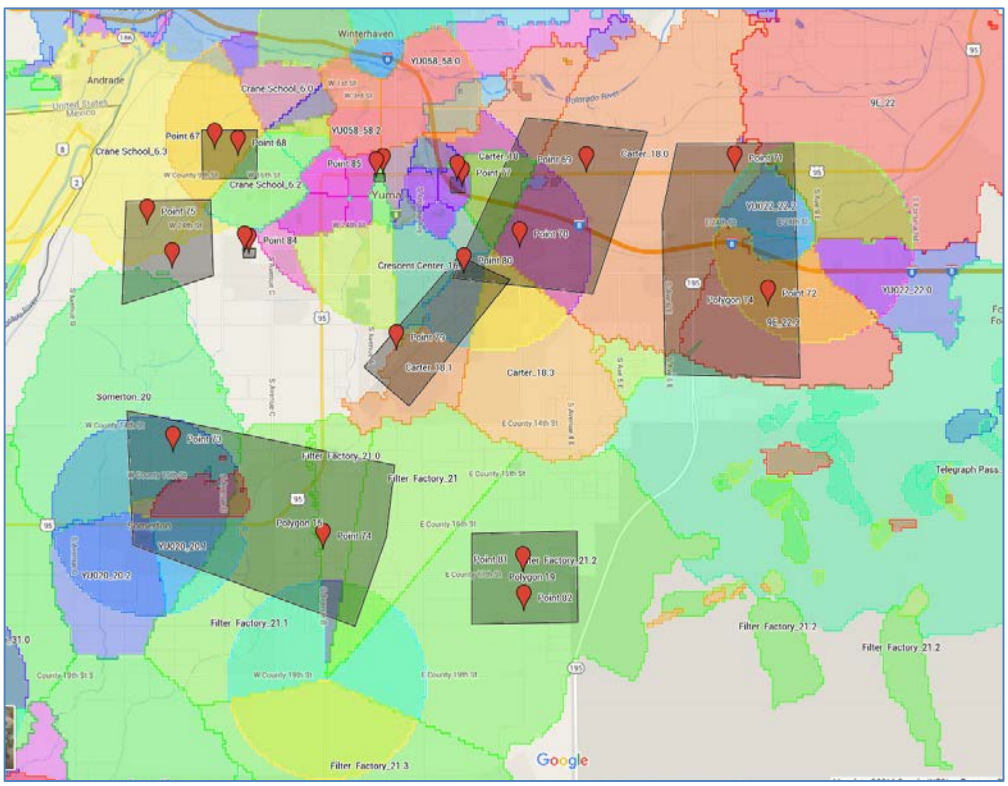

Figure 13 - Additional Test Points

Figure 11 and Figure 12 focus on larger target areas with many test points purposely located outside the target areas to study the results associated with over-alerting scenarios. Figure 13 focuses more on smaller target areas (shaded polygons in gray) with test points (in red) located inside the target areas only.

VI. TEST RESULTS AND OBSERVATIONS

A total of 21 alert target areas were defined for the field testing with a total of 86 test points. An average of four test points were conducted for each target area. Since each test point had two alert submissions, one for the Dynamic geo-targeting method and one for the Dynamic geo-targeting with RF footprint method, a total of 172 tests were submitted. Figure 14 shows a sample of the results captured and sorted by test targeted area polygon.

Test Point Number	Target Area Polygon	Time	Mobile Cell ID	Mobile Cell Sector	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	No of Devices	Test Case Result	Note
55	1	12/9/2015 15:49	31/20	0/2	32.596288	-114.7618103	Dynamic Plus	Y	2	Success	
55	1	12/9/2015 15:50	31/20	0/2	32.596288	-114.7618103	Dynamic	N		fail	missing page?
42	1	12/9/2015 16:47	??		32.697466	-114.7109985	Dynamic Plus	Y	1	Success	
42	1	12/9/2015 16:47	??		32.697466	-114.7109985	Dynamic	y	1	Success	
64	3	12/9/2015 11:26	34	0	32.514105	-114.7868729	Dynamic Plus	Y	1	Success	There is no sector 0, may be this means sector 1
64	3	12/9/2015 11:32	34	0	32.514105	-114.7868729	Dynamic	N		fail	
58	3	12/9/2015 11:47	19	1	32.509038	-114.7525406	Dynamic Plus	Y	2	Success	
58	3	12/9/2015 11:48	19	1	32.509038	-114.7525406	Dynamic	N		fail	
48	3	12/9/2015 12:00	19	1	32.494705	-114.7116852	Dynamic Plus	Y	1	Success	
48	3	12/9/2015 12:01	19	1	32.494705	-114.7116852	Dynamic	N		fail	
46	3	12/9/2015 14:30	19/31	1	32.526987	-114.7233582	Dynamic Plus	Y	1	Success	
46	3	12/9/2015 14:31	19/31	1	32.526987	-114.7233582	Dynamic	N		fail	
55	3	12/9/2015 15:47	31/20	0/2	32.596288	-114.7618103	Dynamic Plus	Y	1	Success	
55	3	12/9/2015 15:48	31/20	0/2	32.596288	-114.7618103	Dynamic	N		fail	missing page?
54	3	12/9/2015 16:06	21/20	0/3	32.625208	-114.7357178	Dynamic Plus	Y	1	Success	
54	3	12/9/2015 16:07	21/20	0/3	32.625208	-114.7357178	Dynamic	Y	2	Success	
44	3	12/9/2015 16:16	21	0	32.63764	-114.7103119	Dynamic Plus	Y	1	Success	
44	3	12/9/2015 16:17	21	0	32.63764	-114.7103119	Dynamic	N		fail	
43	3	12/9/2015 16:33	??		32.663657	-114.7103119	Dynamic Plus	N		Success	
43	3	12/9/2015 16:35	??		32.663657	-114.7103119	Dynamic	N		Success	
44	6	12/9/2015 16:18	21	0	32.63764	-114.7103119	Dynamic Plus	Y	1	Success	
44	6	12/9/2015 16:19	21	0	32.63764	-114.7103119	Dynamic	Y	1	Success	
43	6	12/9/2015 16:29	??		32.663657	-114.7103119	Dynamic Plus	Y	2	Success	
43	6	12/9/2015 16:32	??		32.663657	-114.7103119	Dynamic	N		fail	missing page?
42	6	12/9/2015 16:45	??		32.697466	-114.7109985	Dynamic Plus	Y	2	Success	
42	6	12/9/2015 16:45	??		32.697466	-114.7109985	Dynamic	Y	1	Success	
64	9	12/9/2015 11:34	34	0	32.514105	-114.7868729	Dynamic Plus	Y	1	Success	
64	9	12/9/2015 11:35	34	0	32.514105	-114.7868729	Dynamic	N		fail	
58	9	12/9/2015 11:44	19	1	32.509038	-114.7525406	Dynamic Plus	Y	2	Success	
58	9	12/9/2015 11:46	19	1	32.509038	-114.7525406	Dynamic	N		fail	
48	9	12/9/2015 12:02	19	1	32.494705	-114.7116852	Dynamic Plus	Y	2	Success	
48	9	12/9/2015 12:03	19	1	32.494705	-114.7116852	Dynamic	Y	1	Success	

Figure 14 - Sample of Test Results Log

The “Test Point Number” column is the ID of the location of the mobile device where the test was made as shown by the indicated “Handset LAT/LON.” The “Mobile Cell ID” and “Mobile Cell Sector” are, respectively, the cell tower and sector reported by the devices at the time of testing (if available). “Geo-targeting Type” indicates which method was used, either Dynamic or Dynamic Plus. The Dynamic Plus method is the enhanced geo-targeting algorithm using the RF propagation footprints. The “Alert Received?” column indicates if the mobile device received the alert (Y) or not (N) for the test. “No of

Devices" indicates whether both devices, one device, or no devices received the alert. The "Test Case Result" records a fail or a success.

A **Fail** indicates one of the following scenarios:

- The mobile device was inside the target area but no alert was received 15 seconds after the alert submission. This result occurred because of an "under-alerting" condition, the device was tuned to a very distant tower, or the device simply missed the cell broadcast page.
- The mobile device was outside the target area but still received the alert. This represents a case of an "over-alerting" condition.
- There was no coverage (no signal, or signal strength was too low) at the test point. In this case the result was inconclusive.

A **Success** indicates one of the following scenarios:

- The mobile device was inside the target area and it received the alert within 15 seconds of its submission.
- The mobile device was outside the alert area and it did NOT receive the alert after 15 seconds of alert submission.

The following are the results recorded for the test target area polygons defined above with alert tests submitted at the indicated test points.

<u>Target Area 1</u>

The objective of this test target area was to determine the behavior of the alert reception for an area that covered the entire city of Yuma and its vicinity. This target area was the largest of all test polygons that covered 861 square miles with 117 miles of perimeter. Figure 15 shows the test alert target area in blue with the test point locations where the alerts were submitted. The test points with results collected for this polygon are indicated by balloon-shaped markers with white circles around them. Note that the test points for this polygon were intentionally selected toward the border of the polygon because of the likelihood of receiving alerts at the center of the polygon is nearly 100 percent for both geo-targeting methods and therefore will not provide much added value to the study.

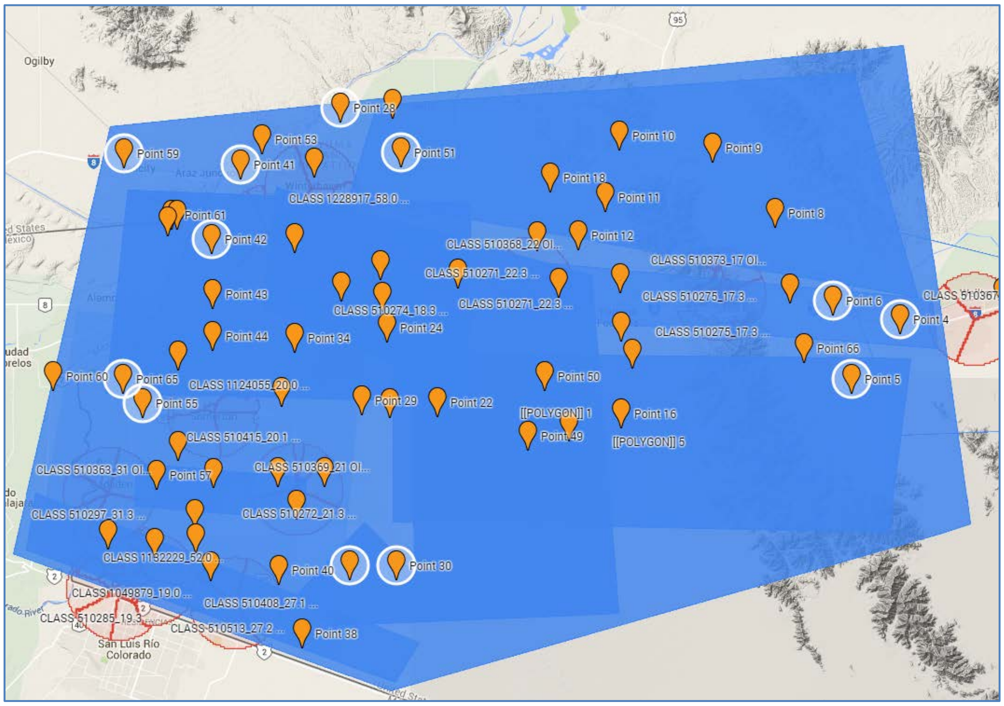

Figure 15 - Target Area 1 with Test Points

The test results of target area 1 are shown in Figure 16. As expected, both geo-targeting methods show similar results; all of the cell towers' LAT/LON were found inside the target polygon. The results show that both methods performed equally well.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
4	1	32.6483367	-114.2040825	Dynamic	N	Fail	
31	1	32.4949948	-114.6097183	Dynamic	N	fail	
59	1	32.7506114	-114.7758865	Dynamic	N	Fail	No Signal
5	1	32.6108934	-114.2399597	Dynamic	Y	Success	
6	1	32.6594655	-114.2538643	Dynamic	Y	Success	
28	1	32.7791926	-114.6164131	Dynamic	Y	Success	
30	1	32.4949948	-114.5750427	Dynamic	Y	success	
41	1	32.7442587	-114.6900558	Dynamic	Y	Success	
42	1	32.6974663	-114.7109985	Dynamic	y	Success	
51	1	32.7514776	-114.5712662	Dynamic	Y	Success	
55	1	32.5962877	-114.7618103	Dynamic	Y	Success	
65	1	32.611038	-114.7764015	Dynamic	Y	Success	Yuma phone got it.
4	1	32.6483367	-114.2040825	Dynamic Plus	N	Fail	
5	1	32.6108934	-114.2399597	Dynamic Plus	N	Fail	1 mile away from the point, due to bad spot.
59	1	32.7506114	-114.7758865	Dynamic Plus	N	Fail	No Signal
6	1	32.6594655	-114.2538643	Dynamic Plus	Y	Success	Happened after multiple attempts
28	1	32.7791926	-114.6164131	Dynamic Plus	Y	Success	
30	1	32.4949948	-114.5750427	Dynamic Plus	Y	success	

31	1	32.4949948	-114.6097183	Dynamic Plus	Y	success	
41	1	32.7442587	-114.6900558	Dynamic Plus	Y	Success	
42	1	32.6974663	-114.7109985	Dynamic Plus	Y	Success	
51	1	32.7514776	-114.5712662	Dynamic Plus	Y	Success	
55	1	32.5962877	-114.7618103	Dynamic Plus	Y	Success	
65	1	32.611038	-114.7764015	Dynamic Plus	Y	Success	Missed page at first attempt. Got at second attempt.

Figure 16 - Target Area 1 Test Results

<u>Target Area 2</u>

This target area shown in blue with white boundary lines covered the city of Yuma and focused on the most populated area. This test polygon included 180 square miles and 71.2 miles of perimeter. The test points are shown in balloon-shaped markers with white circles around them. Note that a number of test points were conducted outside the target area to collect over-alerting scenarios.

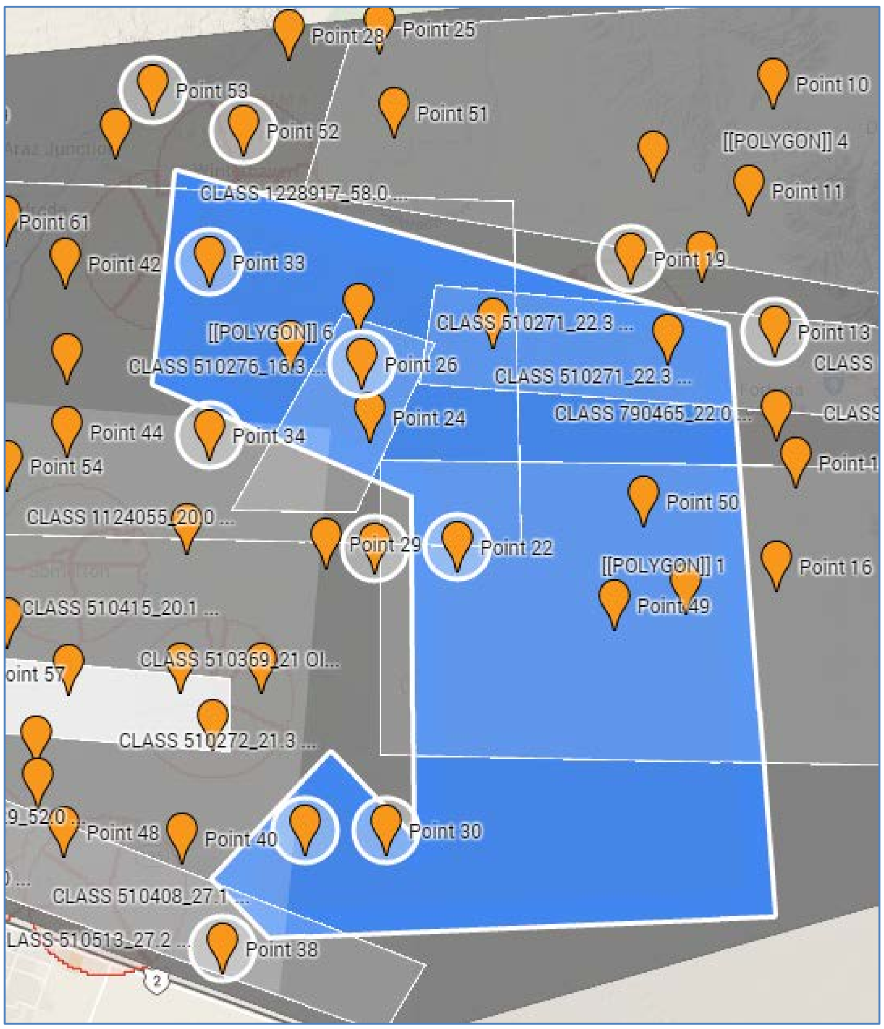

Figure 17 - Target Area 2 with Test Points

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
30	2	32.4949948	-114.57504	Dynamic	N	Fail	
31	2	32.4949948	-114.60972	Dynamic	N	Fail	
53	2	32.7597064	-114.67358	Dynamic	Y	Fail	Over-alert. Device is outside the alert area
13	2	32.6731939	-114.41008	Dynamic	N	Success	Device is outside the alert area
19	2	32.6991998	-114.47119	Dynamic	N	Success	Device is outside the alert area
22	2	32.5968662	-114.54449	Dynamic	Y	success	
23	2	32.5962877	-114.57985	Dynamic	N	success	Device is outside the alert area
26	2	32.6616333	-114.58569	Dynamic	Y	success	Yuma phone got it.
33	2	32.6986219	-114.64989	Dynamic	Y	success	
34	2	32.6361947	-114.65023	Dynamic	N	Success	Device is outside the alert area
38	2	32.4529971	-114.64474	Dynamic	N	success	Device is outside the alert area
52	2	32.745125	-114.6353	Dynamic	N	Success	Device is outside the alert area
30	2	32.4949948	-114.57504	Dynamic Plus	N	Fail	
34	2	32.6361947	-114.65023	Dynamic Plus	Y	Fail	over-alert. Device is outside the alert area
53	2	32.7597064	-114.67358	Dynamic Plus	Y	Fail	over-alert. Device is outside the alert area
38	2	32.4529971	-114.64474	Dynamic Plus	N	success	Device is outside the alert area
13	2	32.6731939	-114.41008	Dynamic Plus	N	Success	Device is outside the alert area
19	2	32.6991998	-114.47119	Dynamic Plus	N	Success	Device is outside the alert area
22	2	32.5968662	-114.54449	Dynamic Plus	Y	success	0.5 mile North from spot.
23	2	32.5962877	-114.57985	Dynamic Plus	N	success	Device is outside the alert area
26	2	32.6616333	-114.58569	Dynamic Plus	Y	success	0.5 miles South of the spot.
31	2	32.4949948	-114.60972	Dynamic Plus	Y	success	Yuma phone got it.
33	2	32.6986219	-114.64989	Dynamic Plus	Y	success	
52	2	32.745125	-114.6353	Dynamic Plus	N	Success	Device is outside the alert area

Figure 18 - Target Area 2 Test Results

The test results of target area 2 (Figure 17) are captured in Figure 18. For this target area, once again the Dynamic method performed equally well with Dynamic Plus. The type of failures were different because several test points were conducted outside the target area to detect over-alert scenarios. As can be seen from the results, the Dynamic Plus method encountered two failures due to over-alert tests; the alerts were received on the mobile device while it was outside the target area. Dynamic Plus missed one alert; the Dynamic method had one over-alert but missed two alerts.

Target Area 3

This target area covered the southern part of the Yuma area. This area also focused on a populous area. This test polygon included 158 square miles and 50.6 miles of perimeter.

Figure 19 - Target Area 3 with Test Points

The target area is shaded in blue with a white boundary line. The test points of interest are indicated by orange balloon-shaped markers with white circles around them. There are 17 test points identified and the test results are shown below.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
64	3	32.5141045	-114.78687	Dynamic	N	fail	
58	3	32.5090379	-114.75254	Dynamic	N	fail	
48	3	32.4947052	-114.71169	Dynamic	N	fail	
46	3	32.5269868	-114.72336	Dynamic	N	fail	
38	3	32.4529971	-114.64474	Dynamic	N	fail	
43	3	32.6636565	-114.71031	Dynamic	N	Success	outside of target area
44	3	32.6376402	-114.71031	Dynamic	Y	Success	
54	3	32.6252076	-114.73572	Dynamic	Y	Success	Elcentro phone got it.
55	3	32.5962877	-114.76181	Dynamic	Y	Success	
56	3	32.5696732	-114.73537	Dynamic	Y	Success	
57	3	32.551322	-114.75173	Dynamic	Y	Success	Elcentro phone got it.
45	3	32.5523117	-114.7098	Dynamic	Y	Success	Yuma phone got it.
47	3	32.5123674	-114.72233	Dynamic	Y	Success	0.5 mile North from spot.
31	3	32.4949948	-114.60972	Dynamic	N	success	

39	3	32.6029401	-114.6595	Dynamic	Y	success	
40	3	32.492286	-114.66163	Dynamic	Y	success	
65	3	32.611038	-114.7764	Dynamic	Y	Success	
39	3	32.6029401	-114.6595	Dynamic Plus	N	fail	
38	3	32.4529971	-114.64474	Dynamic Plus	N	fail	Couldn't make any calls
31	3	32.4949948	-114.60972	Dynamic Plus	Y	fail	Overalert- Yuma phone got it. Signal strength is very low.
64	3	32.5141045	-114.78687	Dynamic Plus	Y	Success	
58	3	32.5090379	-114.75254	Dynamic Plus	Y	Success	
48	3	32.4947052	-114.71169	Dynamic Plus	Y	Success	
46	3	32.5269868	-114.72336	Dynamic Plus	Y	Success	
43	3	32.6636565	-114.71031	Dynamic Plus	N	Success	outside of target area
44	3	32.6376402	-114.71031	Dynamic Plus	Y	Success	
54	3	32.6252076	-114.73572	Dynamic Plus	Y	Success	Elcentro phone got it.
55	3	32.5962877	-114.76181	Dynamic Plus	Y	Success	
56	3	32.5696732	-114.73537	Dynamic Plus	Y	Success	Elcentro phone got it.
57	3	32.551322	-114.75173	Dynamic Plus	Y	Success	
45	3	32.5523117	-114.7098	Dynamic Plus	Y	Success	Elcentro phone got it.
47	3	32.5123674	-114.72233	Dynamic Plus	Y	Success	0.5 mile North from spot.
40	3	32.492286	-114.66163	Dynamic Plus	Y	success	
65	3	32.611038	-114.7764	Dynamic Plus	Y	Success	

Figure 20 - Target Area 3 Test Results

Points 31 and 43 are outside of the target area. Test point 31 failed for Dynamic Plus because the alert was received outside the target area (over-alert). For this target area, the Dynamic method missed five alerts; the Dynamic Plus method missed two alerts. Overall, Dynamic Plus method experienced an 82 percent success rate while the Dynamic method experienced a 71 percent success rate.

<u>Target Area 4</u>

This target area covered the northern part of the Yuma area. This less populated area had no cell towers located inside the target polygon (in blue). The test points are marked by the orange markers with white circles around them. This target area polygon included 153 square miles and 59.6 miles of perimeter.

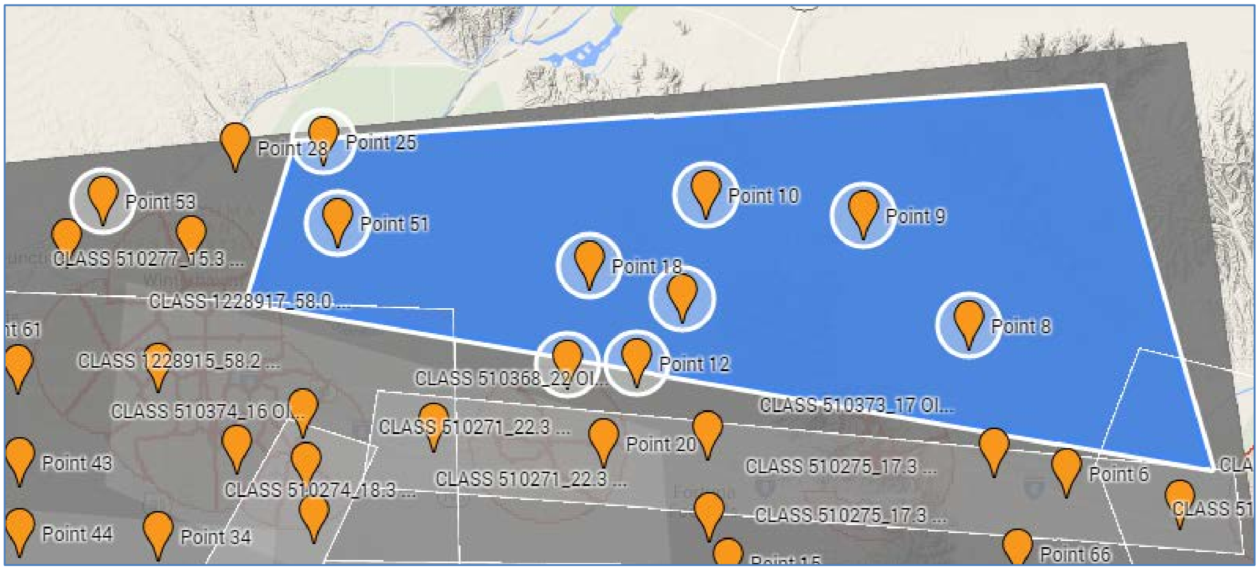

Figure 21 - Target Area 4 with Test Points

Figure 22 (below) captures the test results.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
8	4	32.7139331	-114.2964363	Dynamic	N	Fail	
9	4	32.7544011	-114.3422699	Dynamic	N	Fail	
10	4	32.7621604	-114.4109344	Dynamic	N	fail	
11	4	32.7236095	-114.4214058	Dynamic	N	fail	
18	4	32.7360285	-114.4617462	Dynamic	N	fail	
25	4	32.7815018	-114.5781326	Dynamic	N	Fail	
51	4	32.7514776	-114.5712662	Dynamic	N	Fail	
12	4	32.7003554	-114.4411469	Dynamic	N	Success	Device is outside the alert area
19	4	32.6991998	-114.4711876	Dynamic	N	Success	Device is outside the alert area
53	4	32.7597064	-114.6735764	Dynamic	N	Success	Device is outside the alert area
12	4	32.7003554	-114.4411469	Dynamic Plus	Y	fail	over-alert
51	4	32.7514776	-114.5712662	Dynamic Plus	N	Fail	missing paged?
53	4	32.7597064	-114.6735764	Dynamic Plus	Y	Fail	over-alert
8	4	32.7139331	-114.2964363	Dynamic Plus	Y	Success	
9	4	32.7544011	-114.3422699	Dynamic Plus	Y	Success	
10	4	32.7621604	-114.4109344	Dynamic Plus	Y	Success	
11	4	32.7236095	-114.4214058	Dynamic Plus	Y	Success	
18	4	32.7360285	-114.4617462	Dynamic Plus	Y	Success	
19	4	32.6991998	-114.4711876	Dynamic Plus	N	Success	Device is outside the alert area
25	4	32.7815018	-114.5781326	Dynamic Plus	Y	Success	

Figure 22 - Target Area 4 Test Results

As expected, because no cell tower was located inside the target polygon, none of the alerts were received on the mobile devices at those test points for Dynamic geo-targeting method. On the other

hand, for Dynamic Plus, every test alert was received by the mobile devices for the test points inside the target area. Over-alerting cases were observed for Dynamic Plus for those test points (12, 53) that were located outside the target area, however.

Target Area 5

This target area covered the southeast part of the Yuma area. This less populated area had no cell towers inside the target polygon (in blue). The test points are marked by the orange markers with white circles around them. This target area polygon included 162 square miles and 58.5 miles of perimeter. There were seven test points for this area with points 14 and 24 located outside the alert area; point 23 was located at the border.

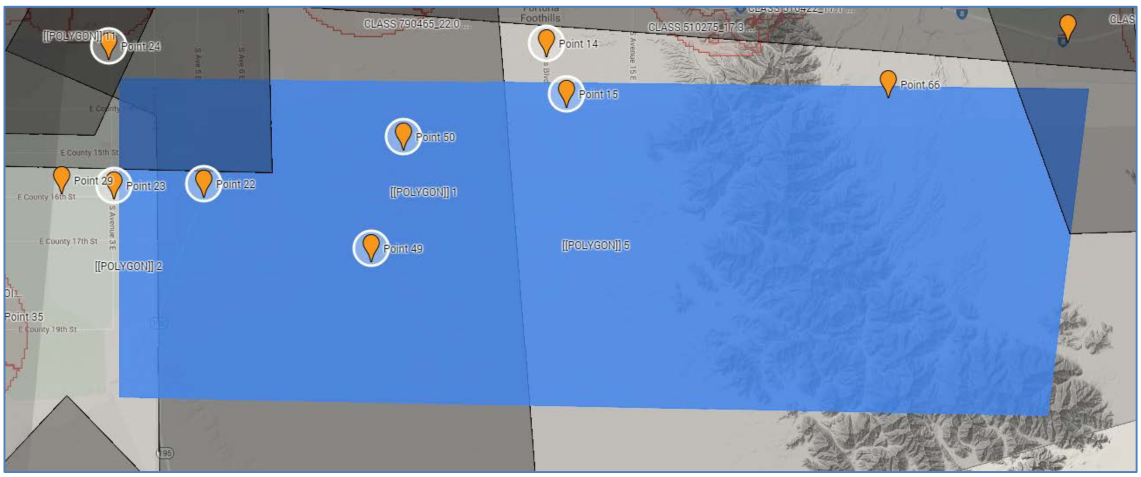

Figure 23 - Target Area 5 with Test Points

The test results are shown in Figure 24.

Test Point Number	Target Area Polygon	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
15	5	32.6266533	-114.4016647	Dynamic	N	fail	
22	5	32.5968662	-114.544487	Dynamic	N	fail	
49	5	32.5754597	-114.4783974	Dynamic	N	Fail	
50	5	32.612484	-114.4658661	Dynamic	N	Fail	
14	5	32.6434223	-114.4097328	Dynamic	N	Success	outside
23	5	32.5962877	-114.5798492	Dynamic	N	success	outside
24	5	32.642555	-114.5819092	Dynamic	N	success	outside
14	5	32.6434223	-114.4097328	Dynamic Plus	Y	fail	over alert
15	5	32.6266533	-114.4016647	Dynamic Plus	Y	Success	
22	5	32.5968662	-114.544487	Dynamic Plus	Y	success	
23	5	32.5962877	-114.5798492	Dynamic Plus	N	success	outside border
24	5	32.642555	-114.5819092	Dynamic Plus	N	success	outside
49	5	32.5754597	-114.4783974	Dynamic Plus	Y	Success	
50	5	32.612484	-114.4658661	Dynamic Plus	Y	Success	

Figure 24 - Target Area 5 Test Results

Since there were no cell towers located inside the target area, no alerts were received on the devices at the test points for Dynamic geo-targeting, which is similar to target area 4. For Dynamic Plus, all of the alerts were received on the devices for the test points inside the alert area. There were three test points (14, 23 and 24) located outside the target area, but only one test point (14) failed the test (over-alert). Test points 23 and 24 did not receive the alerts.

Target Area 6

Figure 25 depicts target area 6 in blue. The rectangular shape covered the northern part of central Yuma where dense population was expected. The majority of cell towers were concentrated in this target area. The 15 test points are marked by the orange markers with white circles around them. This target area polygon included 132 square miles and 47.9 miles of perimeter. Test points 39, 41, 51, 52 and 53 were located outside the alert area.

Figure 25 - Target Area 6 with Test Points

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
44	6	32.6376402	-114.7103119	Dynamic	N	fail	
65	6	32.611038	-114.7764015	Dynamic	N	Fail	
27	6	32.681823	-114.587054	Dynamic	Y	Success	
32	6	32.6685698	-114.6152115	Dynamic	Y	Success	
34	6	32.6361947	-114.6502304	Dynamic	Y	Success	

42	6	32.6974663	-114.7109985	Dynamic	Y	Success	
43	6	32.6636565	-114.7103119	Dynamic	Y	Success	
54	6	32.6252076	-114.7357178	Dynamic	Y	Success	
39	6	32.6029401	-114.6595001	Dynamic	N	success	
33	6	32.6986219	-114.6498871	Dynamic	Y	success	
26	6	32.6616333	-114.5856857	Dynamic	Y	success	
41	6	32.7442587	-114.6900558	Dynamic	N	Success	
53	6	32.7597064	-114.6735764	Dynamic	N	Success	Device is outside the alert area
52	6	32.745125	-114.6352959	Dynamic	N	Success	Device is outside the alert area
51	6	32.7514776	-114.5712662	Dynamic	N	Success	Device is outside the alert area
27	6	32.681823	-114.587054	Dynamic Plus	N	Fail	
65	6	32.611038	-114.7764015	Dynamic Plus	N	Fail	right at the border of target area
53	6	32.7597064	-114.6735764	Dynamic Plus	Y	Fail	over-alert
32	6	32.6685698	-114.6152115	Dynamic Plus	Y	Success	
34	6	32.6361947	-114.6502304	Dynamic Plus	Y	Success	
42	6	32.6974663	-114.7109985	Dynamic Plus	Y	Success	
43	6	32.6636565	-114.7103119	Dynamic Plus	Y	Success	
44	6	32.6376402	-114.7103119	Dynamic Plus	Y	Success	
54	6	32.6252076	-114.7357178	Dynamic Plus	Y	Success	
39	6	32.6029401	-114.6595001	Dynamic Plus	N	success	Device is outside the alert area
33	6	32.6986219	-114.6498871	Dynamic Plus	Y	success	
26	6	32.6616333	-114.5856857	Dynamic Plus	Y	success	
41	6	32.7442587	-114.6900558	Dynamic Plus	N	Success	
52	6	32.745125	-114.6352959	Dynamic Plus	N	Success	Device is outside the alert area
51	6	32.7514776	-114.5712662	Dynamic Plus	N	Success	Device is outside the alert area

Figure 26 - Target Area 6 Test Results

Figure 26 shows the results of the test performed for target area 6. The success rate for the Dynamic method in this case was 87 percent and that of Dynamic Plus was 80 percent. It is interesting to note that even though there were five test points located outside the target area, only one point (53) experienced an over-alert failure case. Once again, the over-alert failure was attributed to the Dynamic Plus method. Both methods failed to receive two alerts.

Target Area 7

This target area, shown on Figure 27, covered a remote Yuma area that featured only one cell tower within the target area polygon (in blue). The test points are marked by the orange markers with white circles around them. This target area polygon included 66.8 square miles and 32.1 miles of perimeter. There were five test points for this area with points 3 and 6 located outside the alert area.

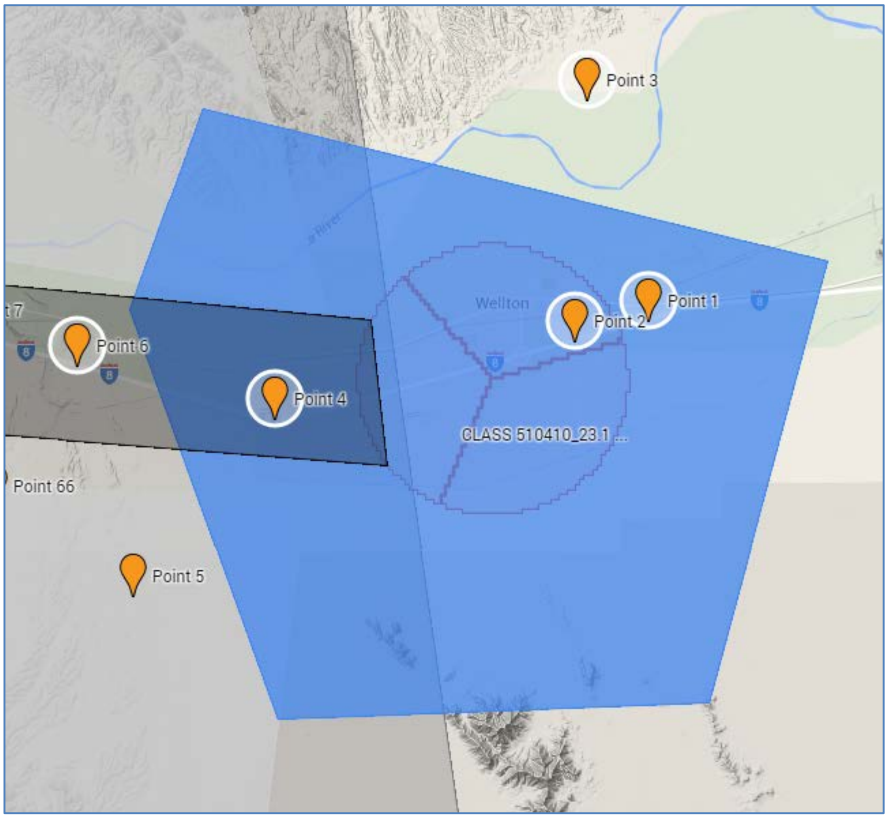

Figure 27 - Target Area 7 with Test Points

The test results are shown in Figure 28 below.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
3	7	32.7159551	-114.1254616	Dynamic	Y	Fail	over-alert
6	7	32.6594655	-114.2538643	Dynamic	Y	Fail	over-alert
1	7	32.75910574	-114.8471887	Dynamic	Y	Success	
2	7	32.6648126	-114.1286802	Dynamic	Y	Success	
4	7	32.6483367	-114.2040825	Dynamic	Y	Success	
3	7	32.7159551	-114.1254616	Dynamic Plus	Y	Fail	over-alert
6	7	32.6594655	-114.2538643	Dynamic Plus	Y	Fail	over-alert
1	7	32.75910574	-114.8471887	Dynamic Plus	Y	Success	
2	7	32.6648126	-114.1286802	Dynamic Plus	Y	Success	
4	7	32.6483367	-114.2040825	Dynamic Plus	Y	Success	

Figure 28 - Target Area 7 Test Results

The above results show that both geo-targeting methods provided the same result. This is due to the fact that the target area contained the cell tower (number 23) to which both the devices were tuned to at the indicated test points. The test points outside the alert area experienced the same over-alert condition for both methods since the same cell tower RF signal spread beyond the alert area.

Target Area 8

This target area shown on Figure 29 covered an area along Interstate 8 with two cell towers (17 and 22) situated inside the target polygon. The test points are marked by the orange markers with white circles around them. This target area polygon included 51.2 square miles and 49.1 miles of perimeter. There were nine test points for this area with points 12 and 19 located outside the alert area.

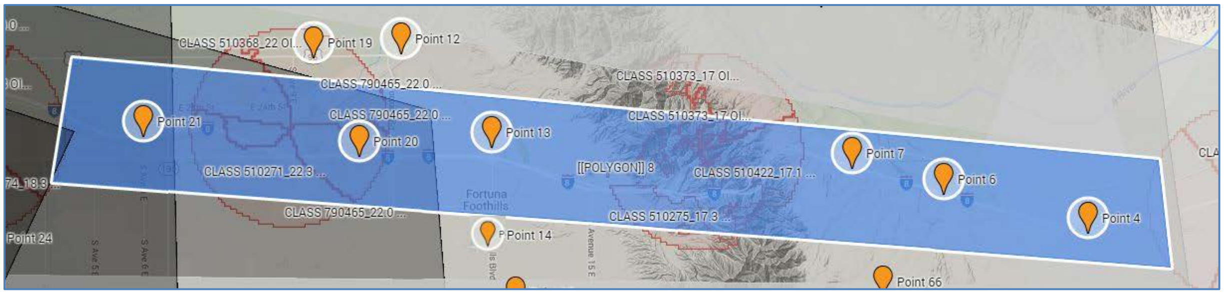

Figure 29 - Target Area 8 with Test Points

The results of the test are shown in Figure 30 below.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
4	8	32.6483367	-114.2040825	Dynamic	N	fail	tuned to cell outside alert area
12	8	32.7003554	-114.4411469	Dynamic	Y	fail	over alert
14	8	32.6434223	-114.4097328	Dynamic	Y	fail	over alert
6	8	32.6594655	-114.2538643	Dynamic	Y	Success	
7	8	32.6672692	-114.28545	Dynamic	Y	Success	
13	8	32.6731939	-114.4100761	Dynamic	Y	Success	
20	8	32.6704484	-114.4555664	Dynamic	Y	Success	
21	8	32.6763728	-114.5300674	Dynamic	Y	Success	
4	8	32.6483367	-114.2040825	Dynamic Plus	N	fail	tuned to cell outside alert area
14	8	32.6434223	-114.4097328	Dynamic Plus	Y	fail	over alert
6	8	32.6594655	-114.2538643	Dynamic Plus	Y	Success	
7	8	32.6672692	-114.28545	Dynamic Plus	Y	Success	
12	8	32.7003554	-114.4411469	Dynamic Plus	Y	Success	over alert
13	8	32.6731939	-114.4100761	Dynamic Plus	Y	Success	
20	8	32.6704484	-114.4555664	Dynamic Plus	Y	Success	
21	8	32.6763728	-114.5300674	Dynamic Plus	Y	Success	

Figure 30 - Target Area 8 Test Results

The outcome of this test is very similar to target area 7; the mobile devices were tuned to the two cell towers that were located inside the target polygon at those test points. Both methods show the same over-alert condition for test points 12, 14 and 19. This is due to the fact that the mobile devices were tuned to the same cell tower (22), which was inside the target polygon. Test point number 4 failed to receive alerts for both methods because the mobile devices were tuned to a cell tower where both its RF footprint coverage and cell tower LAT/LON were located outside the alert target area.

Target Area 9

This target area shown on Figure 31 covered an area along the Mexican border with several cell towers situated inside the target polygon (in blue). The test points are marked by the orange markers with white circles around them. This target area polygon included 34.4 square miles and 39.1 miles of perimeter. There were five test points for this area with point 40 located outside the alert area.

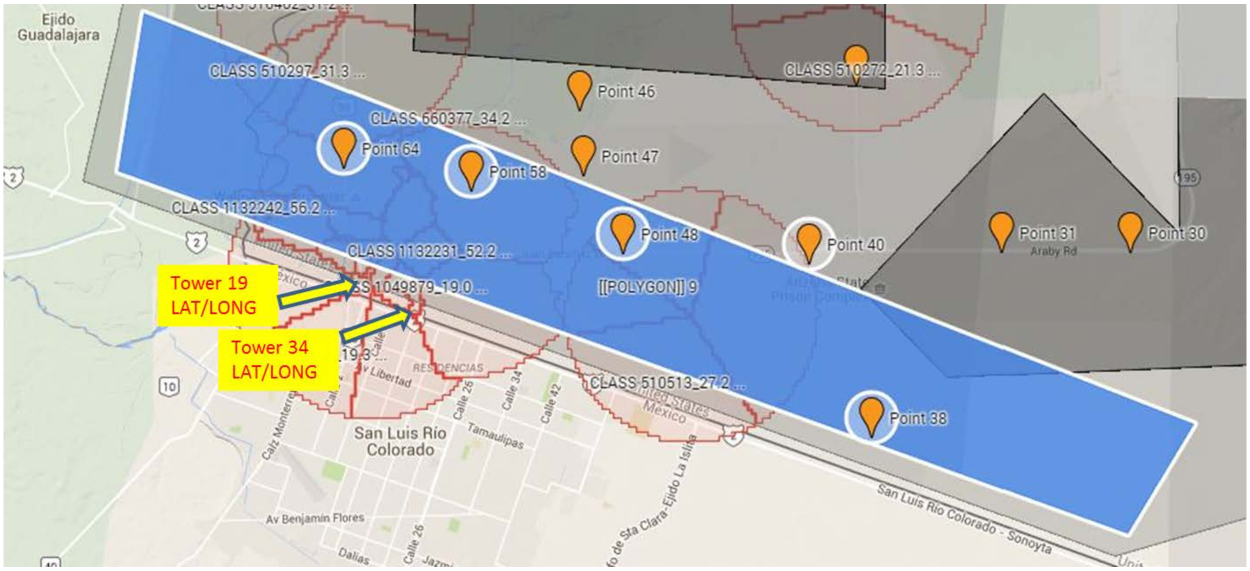

Figure 31 - Target Area 9 with Test Points

The test results for target area 9 are shown in Figure 32 below.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
40	9	32.492286	-114.661626	Dynamic	Y	fail	over-alert
58	9	32.5090379	-114.7525406	Dynamic	N	fail	
64	9	32.5141045	-114.7868729	Dynamic	N	fail	
38	9	32.4529971	-114.6447372	Dynamic	Y	success	
48	9	32.4947052	-114.7116852	Dynamic	Y	Success	
47	9	32.5123674	-114.7223282	Dynamic	N	Success	0.5 mile North from spot.
40	9	32.492286	-114.661626	Dynamic Plus	Y	fail	over alert
38	9	32.4529971	-114.6447372	Dynamic Plus	Y	success	
48	9	32.4947052	-114.7116852	Dynamic Plus	Y	Success	
58	9	32.5090379	-114.7525406	Dynamic Plus	Y	Success	
64	9	32.5141045	-114.7868729	Dynamic Plus	Y	Success	
47	9	32.5123674	-114.7223282	Dynamic Plus	N	Success	0.5 mile North from spot.

Figure 32 - Target Area 9 Test Results

The results show similar outcomes between the two methods. Both methods failed on test point 40 because they received the alert even though the test point was outside the target area (over-alert). The

Dynamic method failed on two other cases for test points 58 and 64; both test points did not receive the alerts. This was due to the fact that the mobile devices were tuned to cell towers 19 and 34 whose physical LAT/LONs resided outside the target polygon (thus the result of the algorithm execution did not contain cell towers 19 and 34). For points 58 and 64, the Dynamic Plus method showed successful results because the RF footprints of towers 19 and 34 intersected with the target polygon.

<u>Target Area 10</u>

This target area shown on Figure 33 represented a less dense area with one cell tower (21) LAT/LON inside the alert target polygon. The test points are marked by the orange markers with white circles around them. This small target area polygon included only 13.9 square miles and 18.6 miles of perimeter. There were seven test points for this area with three test points (35, 46 and 56) located outside the alert area.

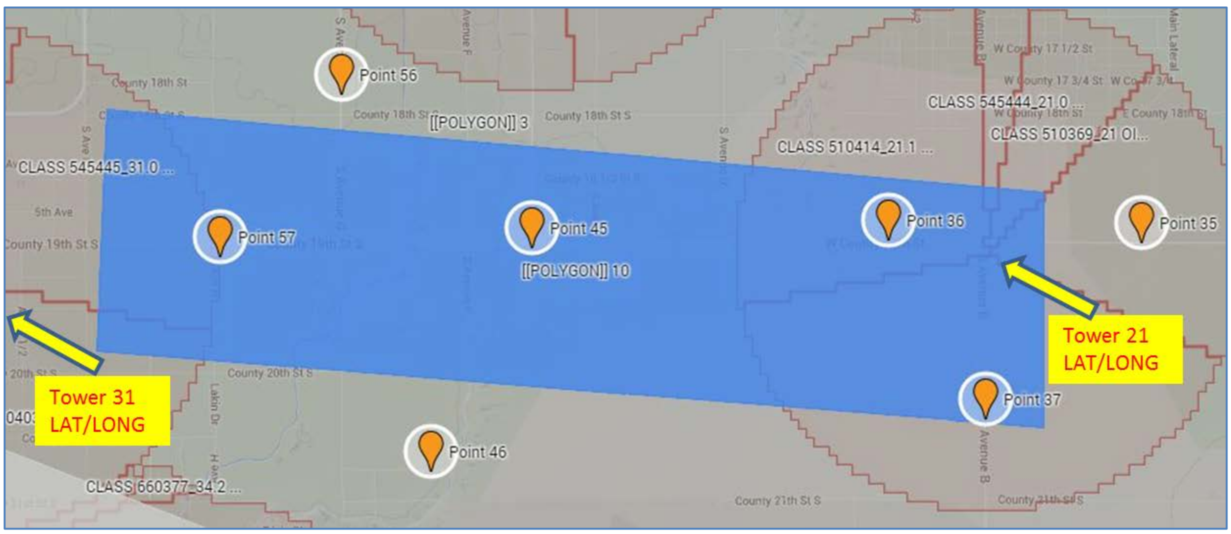

Figure 33 - Target Area 10 with Test Points

The results of the field test are shown in Figure 34.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
35	10	32.5528905	-114.6279144	Dynamic	Y	fail	over-alert
57	10	32.551322	-114.751734	Dynamic	N	fail	
57	10	32.551322	-114.751734	Dynamic	N	fail	
45	10	32.5523117	-114.7097969	Dynamic	N	fail	
36	10	32.5531799	-114.6619034	Dynamic	Y	success	
37	10	32.5329207	-114.6488571	Dynamic	Y	success	
45	10	32.5523117	-114.7097969	Dynamic	Y	Success	
46	10	32.5269868	-114.7233582	Dynamic	N	Success	
56	10	32.5696732	-114.7353745	Dynamic	N	Success	
35	10	32.5528905	-114.6279144	Dynamic Plus	Y	fail	over-alert

46	10	32.5269868	-114.7233582	Dynamic Plus	Y	fail	over-alert, border
56	10	32.5696732	-114.7353745	Dynamic Plus	Y	fail	over alert, border
36	10	32.5531799	-114.6619034	Dynamic Plus	Y	success	
37	10	32.5329207	-114.6488571	Dynamic Plus	Y	success	
45	10	32.5523117	-114.7097969	Dynamic Plus	Y	Success	
57	10	32.551322	-114.751734	Dynamic Plus	Y	Success	
57	10	32.551322	-114.751734	Dynamic Plus	Y	Success	
45	10	32.5523117	-114.7097969	Dynamic Plus	Y	Success	Elcentro phone got it.

Figure 34 - Target Area 10 Test Results

The location of target area 10 was favorable for the Dynamic method. First, the results show that Dynamic Plus produced more over-alert conditions than the Dynamic algorithm. All of the failed tests for Dynamic Plus method were attributed to over-alerting cases. Second, since the cell tower (21) LAT/LON point resided inside the target polygon, mobile devices located at the test points inside the polygon tuned to that cell tower and received the alerts. The Dynamic method, however, missed the alert at points 45 and 57. While at point 57, the mobile device was tuned to cell tower 31, whose tower LAT/LON resides outside the target polygon.

Target Area 11

This target area shown on Figure 35 was another small polygon with one cell tower (18) LAT/LON inside the alert target polygon. The test points are marked by the orange markers with white circles around them. This target area polygon included 13.3 square miles and 15.8 miles of perimeter. There were four test points for this area with two test points (32 and 34) located outside the alert area.

Figure 35 - Target Area 11 with Test Points

Figure 36 shows the test results of target area 11.

Test Point Number	Target Area	Handset Lat	Handset Lon	Geo-targeting Type	Alert Received?	Test Case Result	Note
24	11	32.642555	-114.5819092	Dynamic	Y	success	
26	11	32.6616333	-114.5856857	Dynamic	Y	success	
27	11	32.681823	-114.587054	Dynamic	Y	Success	
34	11	32.6361947	-114.6502304	Dynamic	N	Success	
24	11	32.642555	-114.5819092	Dynamic Plus	N	fail	missing page
34	11	32.6361947	-114.6502304	Dynamic Plus	Y	fail	over-alert
26	11	32.6616333	-114.5856857	Dynamic Plus	Y	success	0.6 miles from actual point
27	11	32.681823	-114.587054	Dynamic Plus	Y	Success	

Figure 36 - Target Area 11 Test Results

As can be observed, Dynamic Plus had an over-alert condition at test point 34 whose location was outside the target polygon. In this case, however, for the Dynamic method, only the mobile devices that were tuned to any sector of cell tower 18 received the alert. Test point 24 failed for Dynamic Plus due to a “missing page.” This can happen in cell broadcast because it is a one-way communication and there is

no retry when the device misses a page on the control channel. This missing page may occur because the page is sent and repeated within only a particular timeslot on the control channel. If the device is not monitoring at that particular time, it may miss that page. It is also possible that the device is in the process of tuning to another cell tower because the current signal falls below the quality threshold.

<u>Target Areas 12 to 20</u>

The testing of target areas 12 to 20 focused on much smaller alert areas that ranged from 15 square miles down to as small as 30 acres (1307K ft^2) – the size of an elementary school area. Figure 37 shows the map of central Yuma with different target areas shown in grey. Each polygon had two test points inside the target area. The results are shown in Figure 38.

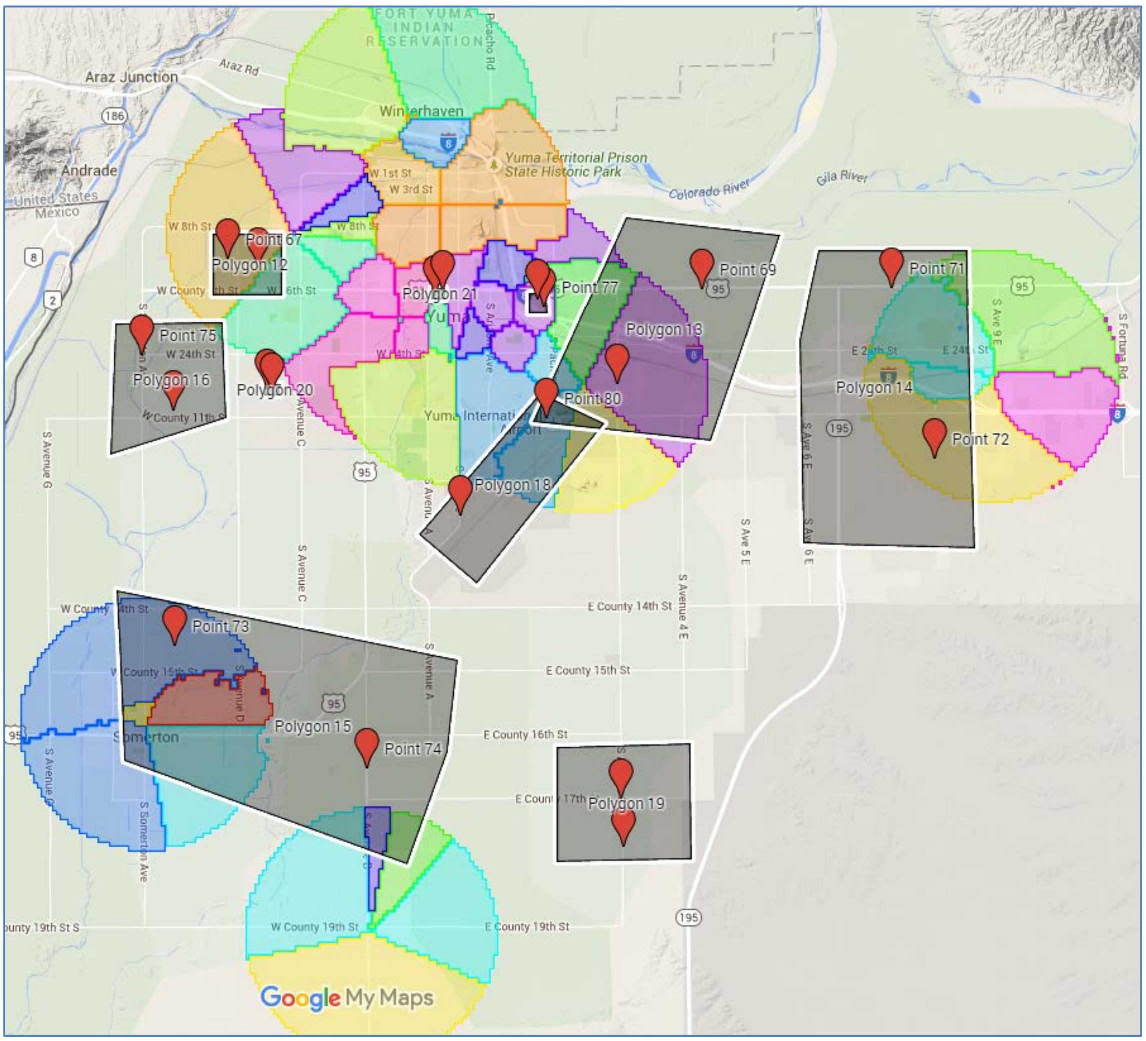

Figure 37 - Target Areas 12 to 20 with Test Points

Test Point Number	Target Area Polygon	Polygon Size (Sq. miles)	Time	Handset Lat	Handset Lon	Geo-targeting Type	Test Case Result	Note
67	20	0.0471	12/15/2015 16:17	32.6760115	-114.6766341	Dynamic	Fail	
68	20	0.0471	12/15/2015 16:24	32.6753613	-114.6752608	Dynamic	Fail	
69	17	0.0915	12/15/2015 11:49	32.6949653	-114.6015751	Dynamic	Fail	
71	17	0.0915	12/16/2015 11:52	32.6966085	-114.6030772	Dynamic	Fail	
72	12	1.04	12/15/2015 16:41	32.7057723	-114.6873093	Dynamic	Fail	
74	12	1.04	12/15/2015 16:47	32.7038584	-114.6790695	Dynamic	Fail	
75	16	3.19	12/15/2015 16:31	32.6838139	-114.7105694	Dynamic	Fail	
76	16	3.19	12/15/2015 16:04	32.6710986	-114.7019434	Dynamic	Fail	
77	18	3.55	12/15/2015 13:40	32.6471443	-114.6242666	Dynamic	Fail	
78	18	3.55	12/15/2015 13:26	32.669491	-114.6008778	Dynamic	Fail	
79	19	3.9	12/15/2015 13:58	32.5824752	-114.5804501	Dynamic	Fail	
80	19	3.9	12/15/2015 14:07	32.5713369	-114.5799351	Dynamic	Fail	
81	13	8.92	12/15/2015 12:09	32.6989831	-114.5584774	Dynamic	Fail	
82	13	8.92	12/15/2015 13:14	32.6772397	-114.5816517	Dynamic	success	
83	14	12.4	12/15/2015 12:19	32.6993442	-114.5068932	Dynamic	Fail	
84	14	12.4	12/15/2015 12:42	32.6600436	-114.4954777	Dynamic	Fail	
70	15	15.5	12/15/2015 14:29	32.5892733	-114.6497154	Dynamic	Fail	
73	15	15.5	12/15/2015 14:46	32.6175447	-114.701643	Dynamic	success	
76	20	0.0471	12/15/2015 16:15	32.6760115	-114.6766341	Dynamic Plus	Fail	Mesquite Elementary. 350 feets away, private area. No coverage
81	20	0.0471	12/15/2015 16:23	32.6753613	-114.6752608	Dynamic Plus	Fail	No coverage
82	17	0.0915	12/15/2015 11:49	32.6949653	-114.6015751	Dynamic Plus	success	Hotels
83	17	0.0915	12/16/2015 11:51	32.6966085	-114.6030772	Dynamic Plus	success	Received at second attempt
84	12	1.04	12/15/2015 16:40	32.7057723	-114.6873093	Dynamic Plus	success	Hospital
67	12	1.04	12/15/2015 16:46	32.7038584	-114.6790695	Dynamic Plus	success	
68	16	3.19	12/15/2015 16:03	32.6710986	-114.7019434	Dynamic Plus	Fail	handsets camped to other cells
69	16	3.19	12/15/2015 16:30	32.6838139	-114.7105694	Dynamic Plus	success	
70	18	3.55	12/15/2015 13:39	32.6471443	-114.6242666	Dynamic Plus	success	
71	18	3.55	12/15/2015 13:25	32.669491	-114.6008778	Dynamic Plus	success	Airport
72	19	3.9	12/15/2015 13:57	32.5824752	-114.5804501	Dynamic Plus	Fail	Target Area is small for this less dense area the handsets are still camped to cells far away
73	19	3.9	12/15/2015 14:06	32.5713369	-114.5799351	Dynamic Plus	Fail	
74	13	8.92	12/15/2015 12:09	32.6989831	-114.5584774	Dynamic Plus	success	
75	13	8.92	12/15/2015 13:12	32.6772397	-114.5816517	Dynamic Plus	success	
77	14	12.4	12/15/2015 12:18	32.6993442	-114.5068932	Dynamic Plus	success	
78	14	12.4	12/15/2015 12:41	32.6600436	-114.4954777	Dynamic Plus	success	
79	15	15.5	12/15/2015 14:45	32.6175447	-114.701643	Dynamic Plus	success	

Test Point Number	Target Area Polygon	Polygon Size (Sq. miles)	Time	Handset Lat	Handset Lon	Geo-targeting Type	Test Case Result	Note
80	15	15.5	12/15/2015 14:28	32.5892733	-114.6497154	Dynamic Plus	success	

Figure 38 - Test Results for Small Target Areas (12 to 20)

There were a total of 36 test alerts sent to the nine target areas. Each target area had two test points and two alerts sent to each test point, one for each geo-targeting type. Therefore, each geo-targeting type received and processed a total of 18 alerts. For the Dynamic method, 16 out of the 18 alerts failed to deliver to the mobile devices (89 percent failure rate). Only two alerts were received on the mobile devices for test point 70 that was targeted at polygon 13, and test point 73 that was targeted at polygon 15. Through closer examination of polygons 13 and 15, one can observe that both target polygons had cell towers 18 and 20 LAT/LON's, respectively, located inside them. On the other hand, the Dynamic Plus method had 13 successes out of 18 tests. Further observation indicates that the failed test cases were for the target areas that were very small and where the area was sparse (few or no cell towers nearby; more analysis on this later). An interesting example where Dynamic Plus exhibited a clear advantage over the Dynamic method was where the area was more densely populated (thus with more cell towers) with a very small target area. Figure 39 shows such a scenario with target area 17 and test points 77 and 78.

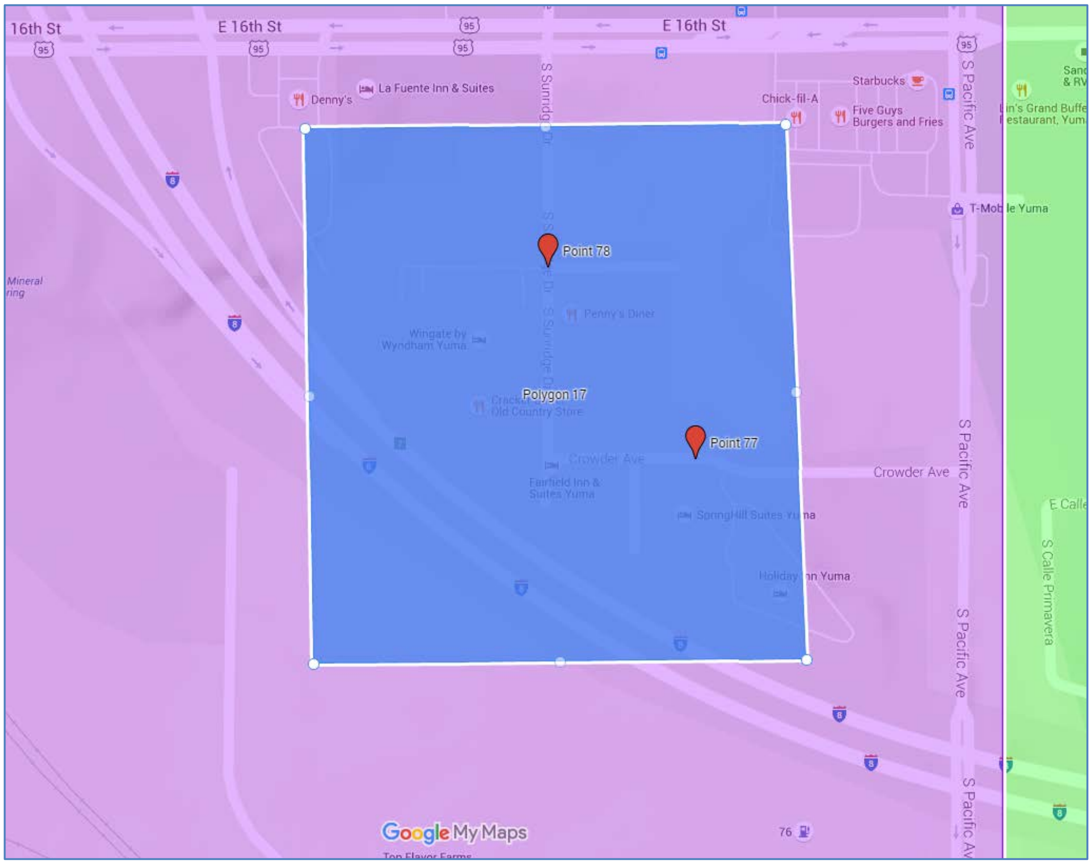

Figure 39 - Dynamic Method Always Fails Scenario

The target area included an area of 58.6 acres and 1.21 miles of perimeter (roughly 440 x 440 yards) that covered a few blocks of several hotel properties. This scenario demonstrates how the Dynamic method will always fail or cannot be used since there is no physical cell tower LAT/LON situated inside the target area polygon. Similar cases are shown in target areas 12 and 18. Target area 12 covers only one square mile surrounding the Yuma hospital and target area 18 covers the Yuma airport area of 3.5 square miles.

VII. RESULTS ANALYSIS

General Observation of Results

Based upon the gathered results of the field testing, the outcomes depend on several factors including the size of target alert area, number of cell towers covered, cell tower location relative to target area, locations of the mobile devices and several other environmental factors. The field testing results, however, are comparable to the ones conducted in the lab simulated environment with a few exceptions, such as missing page cases and mobile device tuning behavior. Overall, the Dynamic Plus method is convincingly superior to the Dynamic geo-targeting method, especially when the size of the target areas becomes smaller. The Dynamic Plus method reaches many more subscribers than the Dynamic method, but with the drawback of producing over-alerting cases. Figure 40 shows the summary of field test results sorted by target area size for both geo-targeting methods. Before providing more detailed analysis of this table, a few factors that may affect the test result are discussed in the following paragraphs.

Geo-Targeting Method	Target Area Polygon	Polygon Size (Sq. Miles)	Number of Desired Outcomes	Number of Over-Alerts	Number of Under Alerts (missing alerts)	Total Number of Tests	Success Ratio	Over-Alert Ratio	Missing Alert Ratio
Dynamic	1	861	9	0	3	12	75%	0%	25%
Dynamic	2	180	9	1	2	11	82%	9%	18%
Dynamic	5	163	3	0	4	7	43%	0%	57%
Dynamic	3	158	12	0	5	17	71%	0%	29%
Dynamic	4	153	3	0	7	10	30%	0%	70%
Dynamic	6	132	13	0	2	15	87%	0%	13%
Dynamic	7	66.8	3	2	0	5	60%	40%	0%
Dynamic	8	51.2	5	3	1	8	63%	38%	13%
Dynamic	9	34.4	3	1	2	6	50%	17%	33%
Dynamic	10	13.9	5	1	3	9	56%	11%	33%
Dynamic	11	13.3	4	0	0	4	100%	0%	0%
Dynamic Small Areas	Average of 9 Polygons	**5.40**	**2**	**0**	**16**	**18**	11%	N/A	89%
Total			**71**	**8**	**45**	**122**	58%	7%	37%
Dynamic Plus	1	861	9	0	3	12	75%	0%	25%
Dynamic Plus	2	180	9	2	1	11	82%	18%	9%
Dynamic Plus	5	163	6	1	0	7	86%	14%	0%
Dynamic Plus	3	158	14	1	2	17	82%	6%	12%
Dynamic Plus	4	153	7	2	0	10	70%	20%	0%
Dynamic Plus	6	132	12	1	2	15	80%	7%	13%
Dynamic Plus	7	66.8	3	2	0	5	60%	40%	0%
Dynamic Plus	8	51.2	6	2	1	8	75%	25%	13%
Dynamic Plus	9	34.4	5	1	0	6	83%	17%	0%
Dynamic Plus	10	13.9	6	3	0	9	67%	33%	0%

Geo-Targeting Method	Target Area Polygon	Polygon Size (Sq. Miles)	Number of Desired Outcomes	Number of Over-Alerts	Number of Under Alerts (missing alerts)	Total Number of Tests	Success Ratio	Over-Alert Ratio	Missing Alert Ratio
Dynamic Plus	11	13.3	2	2	1	4	50%	50%	25%
Dynamic Plus Small Areas	Average of 9 Polygons	**5.40**	**13**	**0**	**5**	18	72%	N/A	28%
Total			**92**	**17**	**15**	**122**	75%	14%	12%

Figure 40 - Summary of Field Test Results by Size of Target Area

Missing Pages

Missing pages may cause the test result to be inconclusive for either geo-targeting method. For example, in the case of the over-alert test scenario where the mobile device is located outside the target area polygon, a successful test occurs when the device does not receive the alert when the alert is submitted to that target area. If the device does not receive the alert following its submission, does the case pass or is the device missing a page? A missing page can occur due to the nature of radio cell broadcast technology. Since cell broadcast technology is designed for unidirectional communication (fire and forget), there is no confirmation from the mobile device or retry when the device misses a page. This happens because the page is sent within a particular timeslot on the control channel and the device is not monitoring or is not synchronized at that particular time. It is also possible that the device is in the process of tuning to another cell tower because the current signal falls below the quality threshold. For this reason, two devices were used side by side for testing to reduce the likelihood of inconclusive results. Sometimes during testing, none of the devices received the alert. In that case, the same test was repeated to ensure that it was not a missing page scenario.

Live Versus Lab Testing Deviation

The cell tower predicted RF propagation data is an approximation modeled by the software based on the cell tower parameters (emitting power, frequency, altitude, sector bearing, etc.) and environmental characteristics (natural or man-made obstacles, terrains, etc.). In real life, however, since the communication medium is the air, it may fluctuate due to many other physical environmental factors that are too complex or cannot be predicted mathematically (interference due to other signals, earth's atmospheric fluctuations, signal reflection and propagation delay, to name a few). These factors challenge the validation of the presence or absence of the alert reception on the field. The problem will manifest itself particularly when testing is performed at the border of the predicted RF signal coverage or when the size of the target area polygon becomes very small. Therefore, the margin of error may be large when testing is performed under these conditions.

The resulting effect of this real-world factor was observed on the mobile device behavior in the field. Of particular interest is how a mobile device tunes to the cell sector antenna and how it switches to another sector antenna as it moves from place to place. One of the main tasks of the mobile device is to ensure that it has the best possible signal strength with a cell tower at all time. As such, it needs to

monitor and periodically scan for the best possible signal that it receives from a few to several neighboring cell towers. In the predicted cell RF propagation model, the mobile behavior criteria is not taken into consideration as it calculates the propagation based on the cell tower parameters only. To illustrate this point, Figure 41 shows the picture of a cell RF propagation model predicted by the RF propagation software with the actual mobile device tuning to different cell sectors.

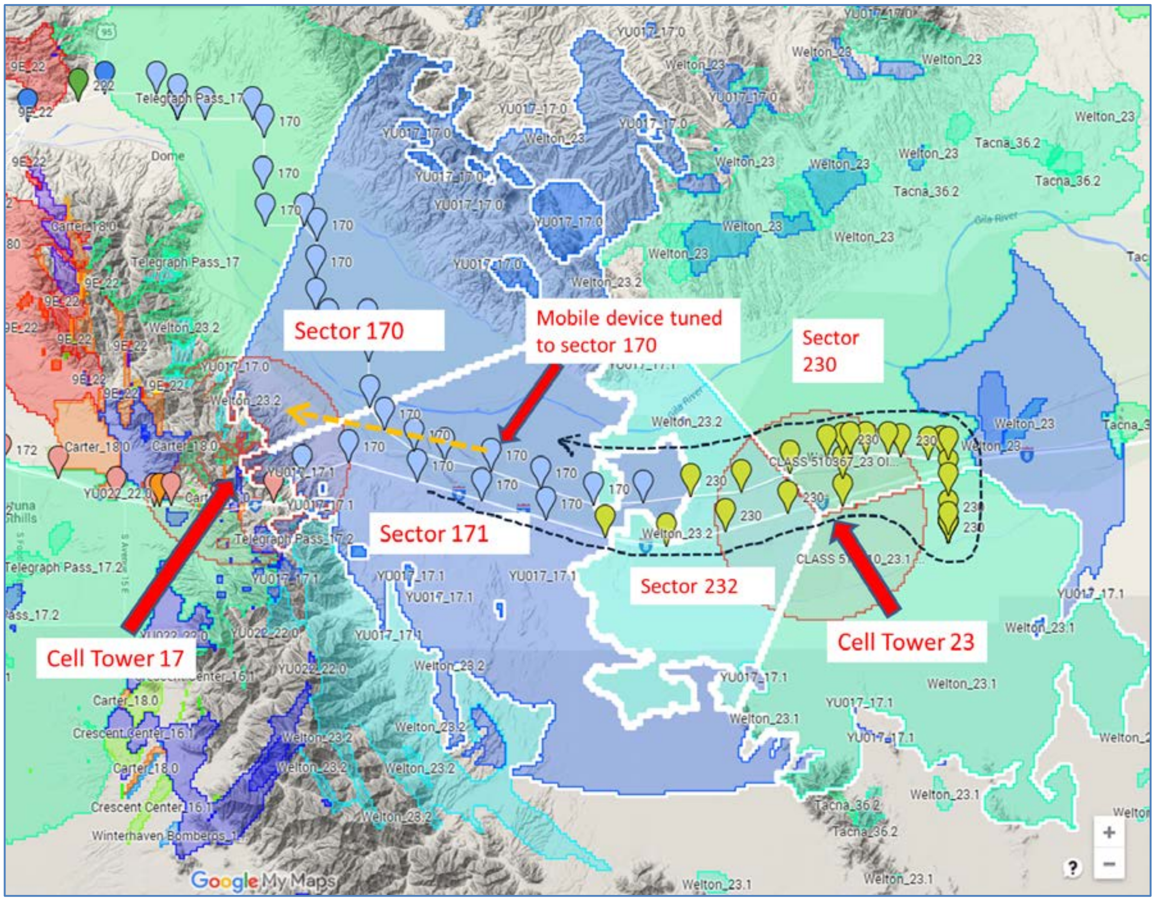

Figure 41 - Cell RF Propagation Model with Actual Device Reading

There were two cell towers (17 and 23) shown in Figure 41 with cell sectors as indicated. The RF propagation model shows cell sector coverage in sky blue and turquoise colors bordered by the white lines that separate sectors 170, 171, 230 and 232. The mobile device readings of the sector to which it was tuned are shown with the balloon markers in blue and yellow-green with a number (e.g., 170, 230) next to it, while moving in the direction of the dark blue dashed arrow. Following the movement of the mobile device from left to right, one can see that the device switched from cell sector 170 to sector 230 as it moved away from tower 17 and closer to tower 23. However, while physically located in sector 232, the handset was actually tuned to sector 230 which is the antenna further away with its bearing in the other direction. This behavior repeated when the device was located in sector 171 but was actually tuned to the antenna of sector 170. This shows that the theoretical assumption that all devices were tuned to the cell RF coverage shown on the map is not always the case. This affects the results of some of the test cases with a similar scenario. Using the same scenario shown in Figure 41, assuming that the

target area is shown in the red rectangle as in Figure 42, the device would likely miss the alert if the alert were to target to this target area at that time.

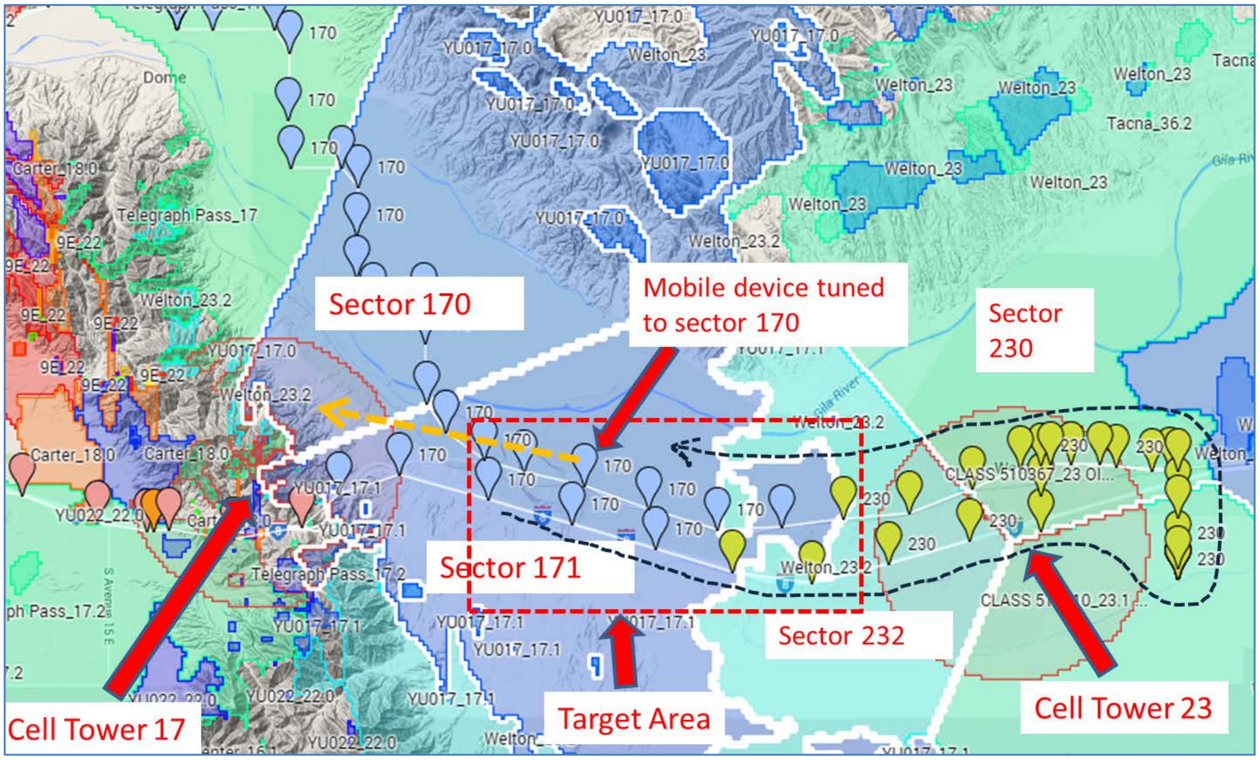

Figure 42 - Failed Geo-Targeting Due to Device Tuning to Different Cell Sector

The reason why the mobile device would miss the alert can further be explained as follows. The execution of the Dynamic Plus algorithm will return cell sectors 171 and 232 as targeted cell sectors because their RF propagation polygons overlap with the target area. Therefore, the alert is broadcast to antennas 171 and 232. Since the device is actually tuned to either 170 or 230, however, it would not receive the alert because no alert is being broadcast to sectors 170 and 230. Thus in the case of when the mobile device is moving while the alert is being sent to a small target area, this unfavorable situation is likely to happen.

Over-Alerting for Dynamic Plus Algorithm

As can be observed from the results presented in this document, another drawback of the geo-targeting algorithm using the cell RF propagation model is over-alerting. Because the algorithm identifies the candidate cell sectors based on their RF propagation polygon intersection with the target polygon, it is expected that the outcome of the intersections will result in more cell sectors to be targeted. To illustrate this point, consider Figure 43 below.

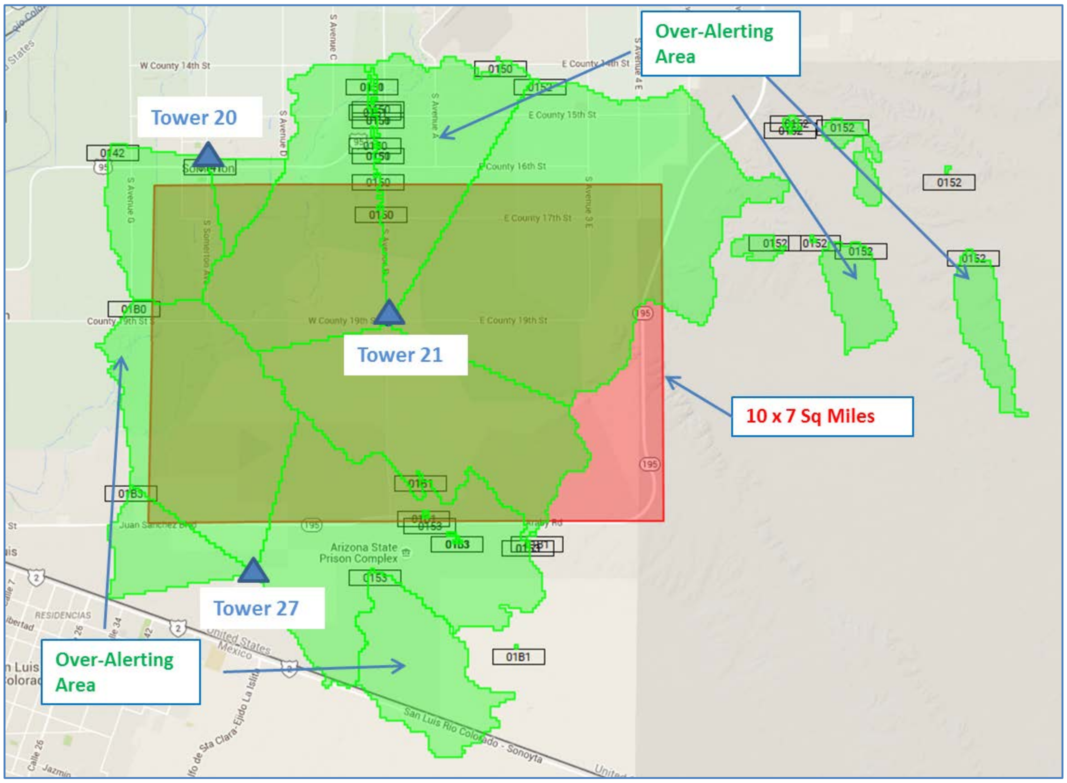

Figure 43 - Over-Alerting Map of Southern Yuma, Arizona

The target area polygon (area 10x7 mi^2) is represented by the rectangle in red and the cell sector RF propagation affected by the target area is shown in green. The Dynamic Plus algorithm identifies all the cell sectors whose RF propagation polygons overlap or touch the target area. In this example, a total of nine cell sectors were identified. Cell tower 20 results in two sectors, cell tower 21 with four sectors and cell tower 27 with three sectors identified. Note that cell towers 20 and 27 reside outside the target area, but some of their cell sector RF coverage resides in the alert target area. Therefore, all nine cell sectors will be targeted, including those with part of the coverage that extend beyond the target area. Since the smallest granularity that the cell broadcast technology can target is the cell sector, emergency alerts will be sent to the entire cell sector coverage resulting from the algorithm output. Therefore, all of the subscribers whose devices are tuned to those cell sectors will receive the alert, including those that are physically outside the target area. It is important to note that because the granularity of the Dynamic Plus method is at cell sector level, the maximum over-alerting area does not exceed the size of a cell sector. Consequently, for a larger target polygon that covers tens of cell sites or more, the amount of over-alerting becomes less of an issue.

Polygon Size Limit for Dynamic Plus Algorithm

Referring to Figure 37 and Figure 38, the test results of a small target area, it is observed that there is a limit to how small an alert target area can be for the algorithm to be effective. As the target area becomes very small (e.g., target area 20), the likelihood of missing an alert is very high. Note that the minimum granularity of this algorithm is the cell sector. As the size of the polygon approaches the size of a cell sector, the likelihood of having mobile devices that are still tuned to the cell sector in question is

low. As shown in the example of Figure 42, when the target area becomes too small, the mobile device is most likely tuned to another cell sector outside the target area and therefore will not receive the alert.

Dynamic and Dynamic Plus Method Comparison

Besides the caveats mentioned above in this section, live field testing concurs, for the most part, with the lab environment results of phase 1. The live production results clearly show improvement in terms of alert accuracy, as well as the ability to target small alert areas, in using the cell RF propagation geo-targeting (Dynamic Plus) method over the cell tower location (Dynamic) method. The main advantage of the Dynamic Plus over the Dynamic method is in the size of the alert area polygon. When the size of the polygons are large (e.g., the size of the entire city or larger) both methods behave comparatively in the result. The exception is at the border of the polygon where the Dynamic Plus method is more accurate than the Dynamic method due to the fact that it is based on cell sector granularity and not the entire cell tower (as with the Dynamic method). As the target area polygon gets smaller, the likelihood of the target area containing the cell tower becomes less. The result of the execution of the Dynamic algorithm would show fewer cell towers to broadcast to, and ultimately fewer subscribers will receive the alerts. On the contrary, the Dynamic Plus algorithm does not have this limitation since it does not rely on cell tower location. Instead it takes into consideration cell tower RF propagation coverage, thus resulting in affected cell sectors. This was evident during the testing of small target area polygons 12 to 20, as shown in Figure 37 and Figure 38. For those small polygons, the Dynamic method failed to deliver the alerts 89 percent of the time, while the Dynamic Plus missed the alerts 28 percent of the time. For this sample, the Dynamic Plus performed 6.5 times better than the Dynamic method. In the case of Figure 39, the Dynamic method failed 100 percent of the time.

Once again, Figure 40 shows the summary of field test results for both methods sorted in the decreasing order of polygon size. The *Number of Desired Outcomes* shows the number of successful alert deliveries for both when the alert was expected to be received inside the target area and NOT received outside the target area. The *Number of Over-Alerts* signifies the occurrence when the alerts were received outside the intended target area. The *Number of Under-Alerts* refers to the alerts that were NOT received (missing alerts) while the mobile device was located inside the target area. The *Missing Alerts Ratio* is the percentage of missing alerts over the total alerts submitted. For the *Number of Desired Outcomes,* the Dynamic Plus method performed consistently better than the Dynamic method for the same test. Surprisingly, the overall improvement of the Dynamic Plus method is only about 30 percent better than that of the Dynamic method. This ratio includes the failed cases for over-alerts where Dynamic Plus scored poorly compared to Dynamic, however. As previously discussed, the effect of cell RF propagation polygon intersection with the alert target area produces more cell sectors to be targeted. The test shows that the Dynamic Plus method produced 14 percent of over-alerts for all alerts submitted whereas the Dynamic method produced 7 percent. Finally, the most important data is the *Number of Under-Alerts.* Once again, the Dynamic Plus method performed far better than that of the Dynamic method. The overall under-performance of Dynamic to Dynamic Plus is 45 to 15, or three times worse. Again, when the alert target area is small, less than several square miles, the likelihood of missing alerts in the Dynamic method is high, as shown in Figure 38. The Dynamic method missed all of the

alerts for all target areas smaller than four square miles in a less dense area (rural area with few cell towers). While it might be a nuisance to receive alerts that are not relevant to the recipients, it is critical that the people who are exposed to imminent danger be alerted consistently.

VIII. KEY FINDINGS AND LESSONS LEARNED

Successes

One key success in this research consists of obtaining the live test results that validate and adjust the findings and assumptions from the lab environment. Another success is the successful development of tools and software needed to collect the data. The test results obtained from the field clearly demonstrated the strength and weakness of both the Dynamic and Dynamic Plus geo-targeting methods. As expected from the phase 1 study, the results show that the Dynamic Plus method is convincingly superior to the Dynamic method. When implemented, the Dynamic Plus method will provide new benefits to WEA users in several ways which include:

- Targeting much smaller alert areas down to a square mile regardless of the physical location of the cell towers;
- Using location based RMT, allowing WEA alerts to be tested at chosen live sites without impacting the general public;
- Geo-targeting at the cell sector granularity;
- Enhancing reachability to the people in harm's way;
- Enabling other alert categories to be submitted to the public because alert target area size can now be reduced significantly; and
- Providing a solution that requires no change to the current WEA network.

The key lessons learned in this project consist of understanding the effects of live environments and how different real-world factors can affect the expected results. These lessons learned are very important because they allow TCS to improve the techniques that will ultimately enhance its solution in the future. Several key lessons learned include:

- How mobile device behavior deviated from the theoretical assumption, as explained in Figure 41 and Figure 42;
- How the size of different alert target areas affected the test results;
- The smallest definable limit for the alert target area; and
- The drawbacks of over-alerting and missing pages.

Remaining Issues

While conducting live tests provided positive results that confirmed the phase 1 study findings, the experiment also helped to uncover several interesting issues that were not expected when the study was conducted in the lab environment. From field testing, several issues remained unsolved due to the variables that exist in real-world environments and the limitations of cell broadcast technology. As previously mentioned in this report, these issues include:

- Using air interface as a communication medium;
- Missing pages due to mobile device and antenna synchronization;
- Unpredictability of mobile device behavior (e.g., tuning to cell towers much farther than a nearby tower);
- Target area polygon size limit; and
- Over-alerting.

As stated in the phase 1 report, generating the cell tower propagation footprints could be another potential issue for commercial service providers. To generate the cell tower coverage footprints for WEA use, additional tools and efforts are needed. A compromise to this is to use a simplified model where the cell tower RF footprints can be approximated (calculated) using the expected cell coverage radius, sector beam direction and beam width. These parameters are readily available for all carriers during cell planning. This will allow the cell sector RF polygon to be generated in the form of a circular sector, which should be acceptable for sector level geo-targeting.

At the time of this writing, using cell RF propagation for geo-targeting is clearly superior to any existing method deployed today for WEA service. But because of the remaining issues mentioned above, additional research is needed to further improve end-user experience. One possible improvement is the use of mobile device based applications to avoid the possibility of over-alerting cases. Using mobile device based applications, however, will require changes to both the CMSP node and the air interface specifications for WEA.

IX. RECOMMENDATIONS

Although no geo-targeting method can provide 100 percent accuracy, the algorithm that uses cell tower RF propagation clearly provides better accuracy than the methods used to date. Given economic, administrative and political constraints, certain concessions need to be made to provide a service to the public which can be considered a “best-effort solution.” While this method will not solve the over-alerting problem within the cell sector level, it will improve the reachability to people in harm’s way effectively. Because the alert target area size can now be defined as small as a square mile, over-alerting can significantly be reduced. Therefore, this method will be suitable for alerts such as a campus emergency, a chemical spill or a road block due to a major accident. These instances would not be possible using the methods available today.

The RF propagation footprint algorithm could be provided as the best-effort solution for cell broadcast technology available today. The attractiveness of this method is that it does not require any change in the standards and specifications for it to be deployed today. Today’s WEA regulatory requirement for geo-targeting is limited to the county-level only, however. It is therefore recommended that the requirement be changed to obligate service providers to offer WEA service with geo-targeting at cell sector level accuracy.

Given the limitations discussed in this document, further improvement can still be made, perhaps in cooperation with mobile device application developers or manufacturers. The Dynamic Plus method allows a very small area to be targeted and can identify exactly the list of cell sectors affected by this area. Cell sectors, however, can be quite large and can extend for several miles in rural areas. As the test results show in this report, over-alerting can therefore extend for miles. To avoid this problem, intelligence in the mobile device is needed. A GPS capable mobile device knows its own location. Thus, if the target area LAT/LONs can be conveyed to the mobile device over the cell broadcast message, the mobile device would be able to determine if it is located inside the target area and subsequently notify the user. Otherwise no alert will be triggered on the device. Such combined technology would provide the best possible result and is recommended as a subject of future experiment.

APPENDIX A – Acronyms List

CAP	Common Alert Protocol
CBC	Cell Broadcast Center
CMSP	Commercial Mobile Service Provider
DHS	Department of Homeland Security
FIPS	Federal Information Processing Standard
LAT/LON	Latitude/Longitude
RDBMS	Relational Database Management System
RMT	Required Monthly Test
RF	Radio Frequency
SIGTRAN	Signaling Transport Protocol
SS7	Signaling System Number 7 Protocol
TCS	TeleCommunication Systems, Inc.
VPN	Virtual Private Network
WEA	Wireless Emergency Alert

APPENDIX B – References

[1] *Cell Radio Frequency (RF) Propagation Algorithm Operational Assessment, Jun 2014, US DHS S&T http://www.firstresponder.gov/TechnologyDocuments/TCS%20Final%20Report-WEA.pdf*

[2] *J-STD-101: Joint ATIS/TIA CMAS Federal Alert Gateway to CMSP Gateway Interface Specification*

[3] *FCC First Report & Order FCC 07-214*

[4] *FCC Second Report & Order And Further Notice Of Proposed Rulemaking* FCC 08-16

[5] *Common Alerting Protocol Version 1.2 Public Review Draft 03 02 March 2010 https://docs.oasis-open.org/emergency/cap/v1.2/pr03/CAP-v1.2-PR03.pdf*