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Wireless Emergency Alerts

Cell Radio Frequency (RF) Propagation Algorithm
Operational Assessment

First Responders Group
June 2014



Homeland
Security

Science and Technology

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Prepared for the US Department of Homeland Security, Contract Number HSHQDC-14-C-B0003

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EXECUTIVE SUMMARY

TeleCommunication Systems, Inc. (TCS) carried out research and development on constructing algorithms that utilize 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) alert messages.

Today, 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.

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 “gap” 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.

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

TCS’s research investigated the feasibility of using enhanced geo-targeting algorithms that take into account more than just the physical location of cell towers. TCS’s combined experience with WEA and E911 services allowed it to successfully design, implement, and test the algorithm that uses cell RF propagation using Commercial Off-The-Shelf software. Results prove that if commercially implemented, the following benefits to the public can be expected:

- Maintain compatibility with the current standardized message definition
- Optimize existing granularity to prevent “over-alerting” and “alert fatigue”
- Improve coverage to fill potential “gaps” further protecting the public from life-threatening events
- Enhance the public perception of the WEA service

BACKGROUND

Recognizing the Need

Today, the mandatory geo-targeting granularity of Wireless Emergency Alert (WEA) messages is defined at the county and county-equivalent level by a Federal Information Processing Standard (FIPS) code value contained in the Common Alert Protocol (CAP) message. Alert originators, such as the National Weather Service (NWS), generate WEA messages. In layman's terms, wireless carrier cell tower(s) geographically located within the designated alert county (FIPS code¹) transmit WEA messages.

Geo-targeting performed on a FIPS code level solely based on the cell tower latitude/longitude (LAT/LON) can provide potential undesirable effects. In counties with very large geographic areas, an alert would be sent to all mobile subscribers in the entire region even though the alert area may theoretically impact only a portion of the county. The result of this instance is an undesirable "over-alert" condition.

Conversely, an uncovered area or "gap" condition may also occur 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. This scenario exists due to cellular Radio Frequency (RF) emissions propagating independently of FIPS code political boundary information. Therefore, it is not uncommon that cell towers provide RF coverage that overlap multiple FIPS codes (i.e., one cell tower's RF signal propagates into more than one county).

An optional enhancement to this basic mandatory requirement is to redefine the geo-targeting area based on a polygon or a circle. Since geo-targeting does not take into consideration cell tower RF propagation data, many cell towers would be overlooked. This is due to their physical locations outside the target area, while their RF propagation touches or overlaps it.

Responding to the Need

The U.S. Department of Homeland Security (DHS) contracted TeleCommunication Systems, Inc. (TCS) to investigate the feasibility of using enhanced geo-targeting algorithms that account for more than just the physical location of cell towers. TCS evaluated the use of predicted cellular RF coverage areas that were included in new WEA geo-targeting algorithms. TCS expected the research using RF coverage footprints for improved geo-targeting of WEA messages to provide the following benefits:

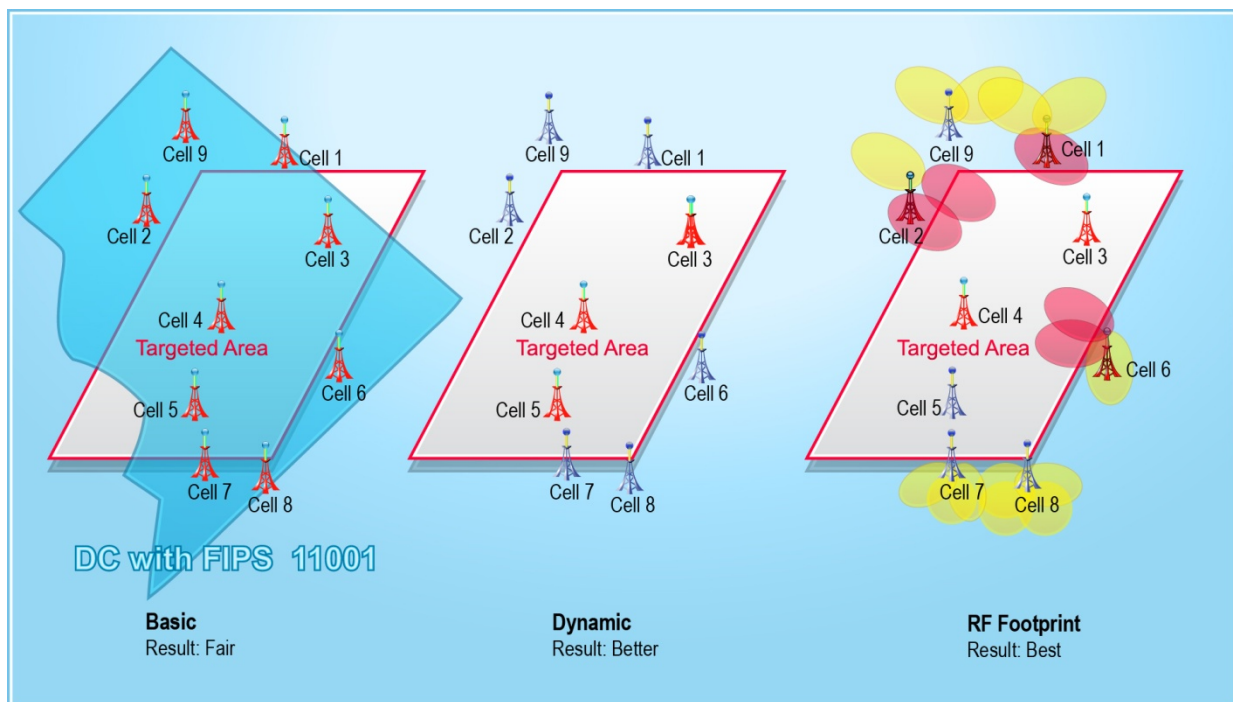
- Maintain compatibility with the current CAP message definition

¹ Refer to FIPS PUB 6-4 "COUNTIES AND EQUIVALENT ENTITIES OF THE UNITED STATES, ITS POSSESSIONS, AND ASSOCIATED AREAS". Note that in the case of Virginia, this includes many independent cities.

- Improve existing granularity by using the CAP alert area polygon and cell tower RF propagation to reduce the probability of over-alerting and under-alerting conditions
- Expand coverage to fill gaps in current methods used, further protecting mobile subscribers that would not receive an alert in a potential emergency situation
- Enhance the public perception of the WEA service

GEO-TARGETING CHALLENGES

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 targeted to broadcast the 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 1 conceptually illustrates the geo-targeting methods comparison.



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Figure 1 - Geo-targeting Methods Comparison

As shown in the above illustration, today's "Basic" algorithm results in all cell towers (shown in red) found within an area to be alerted, despite the targeted area consisting of only part of the FIPS code. By using the point-in-polygon algorithm approach labeled as "Dynamic," the dynamic polygon data sets can be compared against the stored cell site coordinates, which results in Cells 3, 4, and 5 being alerted. Since the point-in-polygon algorithm does not take into consideration the RF propagation of each cell tower, however, Cells 1, 2, and 6 are missed. This is due to the fact that they are physically located

outside the targeted boundary while their RF signals, shown in Figure 1 as yellow and red ellipses, may propagate into the targeted area. The “RF Footprint” is the most accurate algorithm. “RF Footprint” propagates the RF to Cells 1, 2, 3, 4, 5, and 6. This report documents the results of research determining the feasibility of the RF footprint geo-targeting method, as illustrated in Figure 1, to improve the accuracy of WEA message broadcast.

To process WEA alerts using RF footprints, all the RF propagation footprints need to be generated and stored in a Relational Database Management System (RDBMS) that can support spatial data records. Each cell tower typically features three directional antennas aimed in three different directions. 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. Each of these directional antennas is also known as a sector. Thus, each cell tower has three sectors that propagate signals to the mobile devices. Figure 2 illustrates a sectorized antenna pattern of a cell tower.

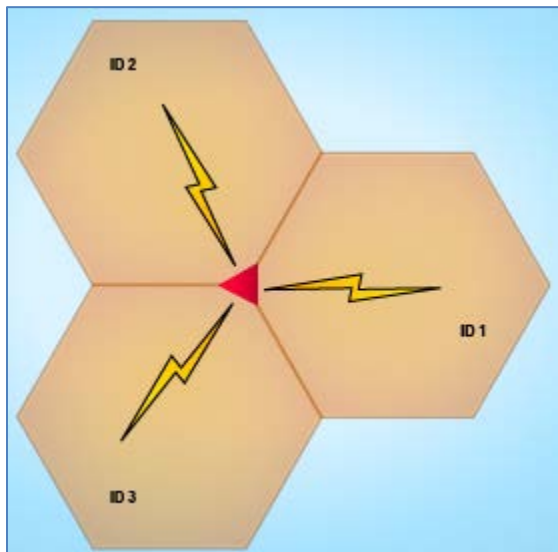


Figure 2 - Sectorized Antenna Pattern of a Cell Tower

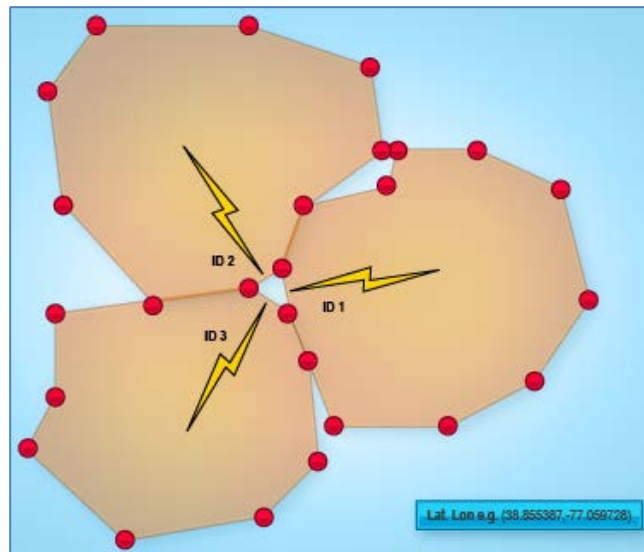


Figure 3 - Sample LAT/LON Plot Approximation of Cell Sectors RF Coverage

For simplicity, the illustration above indicates that each sector propagates an RF signal covering an area represented by a hexagon (i.e., cell). In reality, cell sector coverage footprints vary in shape and size depending on many factors. These factors include antenna azimuth, height, tilt, power, and human-made and natural obstacles like terrain, water, and physical structures. 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 indicated in Figure 3.

The nodes of each polygon are represented as spatial data and stored in the RDBMS for future processing. A high performance RDBMS and Spatial Data Engine (SDE) software is required due to the large amount of spatial data required and the constraint to process them in near real-time. The SDE

software uses a data structure that supports spatial operations. For example, these operations include a query for a point inside and/or outside a polygon, or a query to determine if a polygon touches or is inside another polygon. To represent the RF footprint in a RDBMS, a relational data record is created as shown in Figure 4.

site_id	Cell ID	FIPS	County	State	Site LAT	Site LON	MSC Address	Polygon
DC123	1.1	11001	DC	DC	38.857962	-77.054277	8-13-192	7
DC123	1.2	11001	DC	DC	38.857962	-77.054277	8-13-192	8
DC123	1.3	11001	DC	DC	38.857962	-77.054277	8-13-192	9

Polygon	Latitude	Longitude
7	38.855387	-77.059728
	38.856761	-77.058955
	38.856889	-77.057282
	38.858219	-77.056595
	38.857962	-77.054277
	38.857018	-77.053248
	38.855258	-77.053119
	38.853542	-77.054492
	38.852726	-77.057239

Figure 4 - Database Record Representation of the RF Coverage Approximation

The above example only represents one sector of a cell tower. A typical Tier 1 carrier supports hundreds of thousands of cell sites, resulting in large quantities of data. To compute the geo-targeting for an alert querying with this magnitude of data, an SDE must use a very efficient algorithm to meet the performance requirement. Many Commercial Off-The-Shelf (COTS) SDE software packages available in the market today can implement the algorithm discussed in this section. TCS investigated the following COTS software packages as part of the selection process:

- Esri ArcGIS
- Oracle DB GIS
- PostgreSQL DB GIS (PostGIS)

Following the investigation and comparison among different technologies, TCS selected PostGIS due to cost, usage simplicity, ease of integration, and performance.

MODEL AND ALGORITHM DEVELOPMENT

Cell RF Footprint Polygons Generation

In a production environment, the actual cell RF footprint data, as illustrated in Figure 4, would be generated by the carrier and imported into the database to be accessed by the algorithm. This research sought to determine the feasibility of using an effective algorithm to compare alert area polygons to the existing cell RF propagation polygons to determine which cells should broadcast the alert. As such, the research does *not* focus on how to accurately predict the RF propagation of the cell tower itself.

The secondary goal of this project was to model a system as close as possible to an actual location based on carrier cell tower data. Given that actual RF propagation data was not readily available for research, TCS generated the cell RF polygons using a mathematical model to approximate the coverage of a cell tower based on its power output and frequency. The following section describes the detail of this formulation.

Cell RF Footprint Polygon Modeling

TCS's approach used the Friis transmission equation. This equation is derived from the fundamental theory of signal transmission known as Free Space Path Loss (FSPL) theory and antenna gain rule. FSPL states that the power degradation of a transmitter is proportional to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. In other words, to keep the frequency constant, one needs to increase the transmission power by four times to double the distance of signal coverage, or nine times the power to triple the signal coverage. The FSPL formula is given below:

$$\begin{aligned} \text{FSPL} &= \left(\frac{4\pi d}{\lambda} \right)^2 \\ &= \left(\frac{4\pi d f}{c} \right)^2 \end{aligned}$$

Where:

- λ is the signal wavelength (in meters)
- f is the signal frequency (in hertz)
- d is the distance from the transmitter (in meters)
- c is the speed of light in a vacuum, 2.99792458×10^8 meters per second

Friis equation states that, given two antennas, the ratio of power available at the input of the receiving antenna (P_r) to output power to the transmitting antenna (P_t), is given by:

$$\frac{P_r}{P_t} = G_t G_r \left(\frac{\lambda}{4\pi R} \right)^2$$

G_t and G_r are antenna gains of the transmitter and receiver respectively, and R is the distance between the transmitter and the receiver. Thus, the factor in the parenthesis is just the inverse of FSPL. This can be pictorially illustrated as in Figure 5 below.

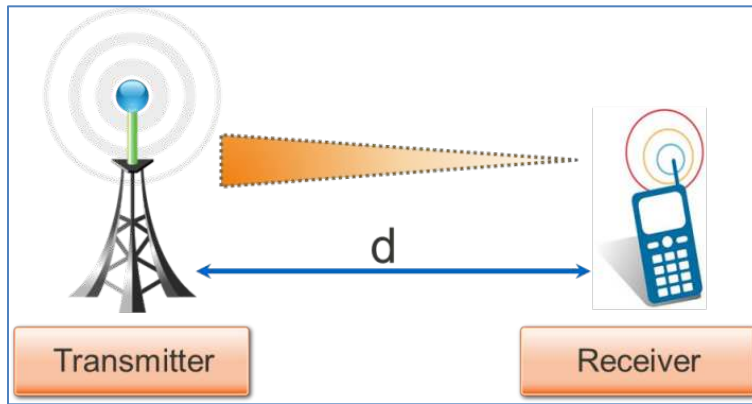


Figure 5 - Pictorial Representation of Signal Range

Re-arranging the above two formulas:

$$\text{FSPL} = \left(\frac{4\pi d f}{c} \right)^2 = \frac{P_t}{P_r} G_t G_r$$

Solving for (d):

$$d = \frac{c \cdot \sqrt{P_t / P_r (G_t G_r)}}{4\pi f}$$

Therefore, the above equation allows the determination of how far a signal can reach a cell phone knowing the power of the transmitter (P_t), expected power received at the cell phone (P_r), the frequency on which the cell phone is operated (f), and assumed antenna gain constants (G_t , G_r).

After determining how far a signal from a tower can reach a mobile device with the distance d , the next task is to generate the polygon LAT/LON for each cell. For simplicity, only one polygon is assumed for each cell tower. Figure 6 illustrates the generated polygon.

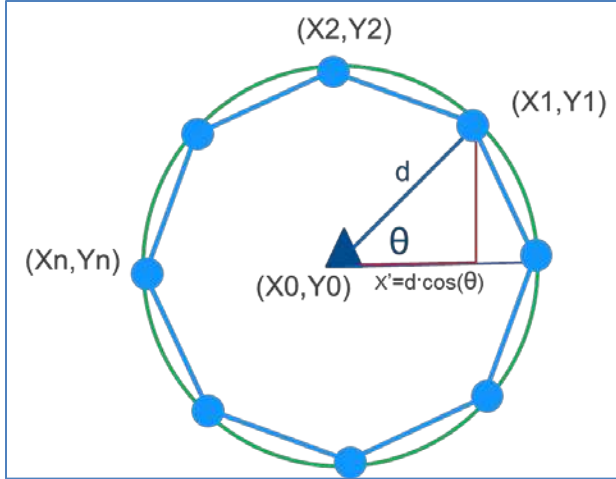


Figure 6 - Coordinates Generation Based on (X0,Y0), d, and Bearing

The goal is to generate a polygon in a shape of an octagon. To do so, all the LAT/LON coordinates (X, Y) points shown above must be generated. On a Cartesian plane, given a point of origin (X0,Y0), a bearing in degree θ , and a distance d , a destination point (X1,Y1) can be determined as follows:

- $X1 = X0 + d \cdot \cos(\theta)$
- $Y1 = Y0 + d \cdot \sin(\theta)$

Thus, by repeating the same formula in changing θ for every 45 degrees, all eight points of the octagon will be determined. Note that a Cartesian coordinate system represents a flat, two dimensional plane, whereas the LAT/LON points of the earth uses the geographic coordinate system. The same idea can be applied using the Haversine² formula to determine a destination LAT/LON point on the earth with radius R , however. Given an origin point with a distance d , and a bearing θ :

- $\phi2 = \text{asin}(\sin(\phi1) \cdot \cos(d/R) + \cos(\phi1) \cdot \sin(d/R) \cdot \cos(\theta))$
- $\lambda2 = \lambda1 + \text{atan2}(\sin(\theta) \cdot \sin(d/R) \cdot \cos(\phi1), \cos(d/R) - \sin(\phi1) \cdot \sin(\phi2))$

Where:

- $\phi1$ = origin latitude, $\lambda1$ = origin longitude
- $\phi2$ = destination latitude, $\lambda2$ = destination longitude
- R = earth's radius

Technical Data Collection

As mentioned previously, RF polygons generation requires actual cell tower data inputs with cell ID, power, frequency, and base station LAT/LON. Figure 7 below is an example of such data.

² Derivation omitted for simplicity.

CELL SECTORID	CELLSITEID	SECTOR ID	LATITUDE	LONGITUDE	t_power	t_height	Frequency (Mhz)	CITY	STATE	ZIP	antenna azimuth
01CC	204	1	35.90456	-90.614075	50	280	750	Jonesboro	AR	72401	330
02CC	204	2	35.90456	-90.614075	50	280	750	Jonesboro	AR	72401	110
03CC	204	3	35.90456	-90.614075	51	280	750	Jonesboro	AR	72401	220
01CD	205	1	35.85285	-90.673219	49	225	750	Jonesboro	AR	72401	0
02CD	205	2	35.85285	-90.673219	51	225	750	Jonesboro	AR	72401	90
03CD	205	3	35.85285	-90.673219	51	225	750	Jonesboro	AR	72401	260
01CE	206	1	35.83986	-90.701875	49	120	750	Jonesboro	AR	72401	0
02CE	206	2	35.83986	-90.701875	50	120	750	Jonesboro	AR	72401	120
03CE	206	3	35.83986	-90.701875	51	120	750	Jonesboro	AR	72401	260
01CF	207	1	35.8983	-90.6994	51	250	750	Jonesboro	AR	72401	60
02CF	207	2	35.8983	-90.6994	51	250	750	Jonesboro	AR	72401	180
03CF	207	3	35.8983	-90.6994	51	250	750	Jonesboro	AR	72401	300
01D0	208	1	35.8194	-90.750622	49	170	750	Jonesboro	AR	72401	0
02D0	208	2	35.8194	-90.750622	49	170	750	Jonesboro	AR	72401	70
03D0	208	3	35.8194	-90.750622	50	170	750	Jonesboro	AR	72401	200
01D1	209	1	35.79734	-90.716494	51	185	750	Jonesboro	AR	72401	0
02D1	209	2	35.79734	-90.716494	50	185	750	Jonesboro	AR	72401	90
03D1	209	3	35.79734	-90.716494	49	185	750	Jonesboro	AR	72401	240
01D2	210	1	35.81755	-90.680083	51	110	750	Jonesboro	AR	72401	60
02D2	210	2	35.81755	-90.680083	51	110	750	Jonesboro	AR	72401	160
03D2	210	3	35.81755	-90.680083	51	110	750	Jonesboro	AR	72401	290
01D3	211	1	35.75267	-90.684608	51	175	750	Jonesboro	AR	72401	340
02D3	211	2	35.75267	-90.684608	51	175	750	Jonesboro	AR	72401	130
03D3	211	3	35.75267	-90.684608	49	175	750	Jonesboro	AR	72401	270

Figure 7 - Sample of Actual Cell RF Data

Figure 8 is a sample polygons plot using the project's polygons generator program based on the data shown in Figure 7.

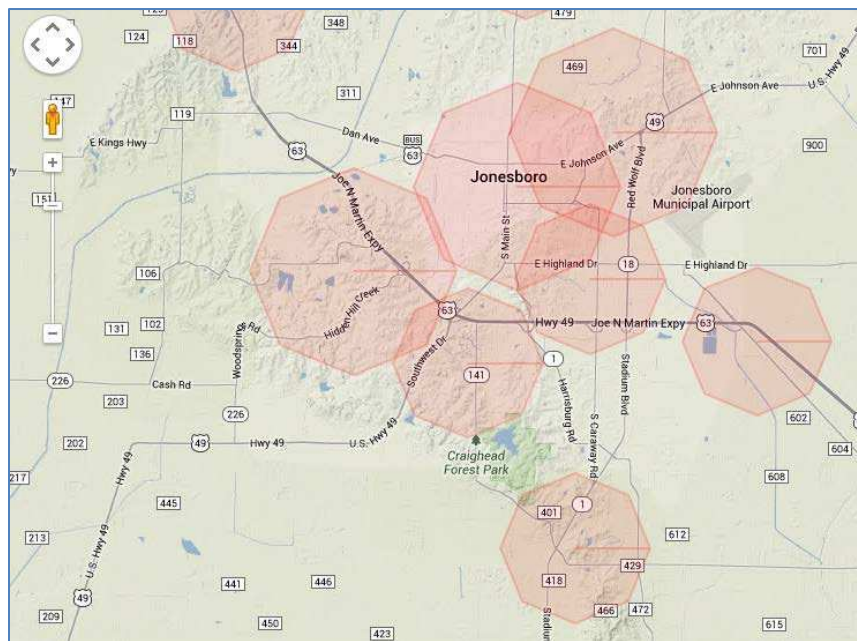


Figure 8 - Generated Cell RF Propagation Polygons

Algorithm Design

Database Schema Population

As previously noted, Figure 4 shows the data structure designed to represent cell RF coverage footprints, which represents a record for one cell tower. As a next step, the project team loaded all of the polygons generated, as shown under Figure 8, into the database for each cell tower. TCS selected a national carrier with roughly 10,000 cell polygons populated in the database. The following Figure 9 depicts a sample of the actual cell RF coverage footprint polygons populated in the database. Note that FIPS, county, and state are not shown for readability.

cell_site		latitude	longitude	MSC Address	Polygon
site_id	sector_id				
Jonesboro	98479	36.060033	-90.439783	141-59-5	POLYGON((-90.41748891 36.06003189,-90.42401817 36.07277473,-90.43978119 36.07805298,-90.45554421 36.07277473,-90.46207347 36.06003189,-90.45554421 36.04728905,-90.43978119 36.0420108,-90.42401817 36.04728905,-90.41748891 36.06003189))
Jonesboro	98481	36.031622	-90.516703	141-59-5	POLYGON((-90.48581005 36.03162384,-90.49485772 36.04928813,-90.51670074 36.05660491,-90.53854377 36.04928813,-90.54759144 36.03162384,-90.53854377 36.01395955,-90.51670074 36.00664277,-90.49485772 36.01395955,-90.48581005 36.03162384))
Jonesboro	98483	35.970875	-90.553675	141-59-5	POLYGON((-90.5316251 35.97087479,-90.53808272 35.98349208,-90.55367279 35.98871833,-90.56926286 35.98349208,-90.57572048 35.97087479,-90.56926286 35.9582575,-90.55367279 35.95303124,-90.53808272 35.9582575,-90.5316251 35.97087479))
Jonesboro	98485	35.904561	-90.614075	141-59-5	POLYGON((-90.5920455 35.90456009,-90.59849771 35.91717738,-90.61407471 35.92240363,-90.62965171 35.91717738,-90.63610391 35.90456009,-90.62965171 35.8919428,-90.61407471 35.88671655,-90.59849771 35.8919428,-90.5920455 35.90456009))
Jonesboro	98487	35.852853	-90.673219	141-59-5	POLYGON((-90.64239688 35.85285187,-90.65142411 35.87051615,-90.67321777 35.87783294,-90.69501144 35.87051615,-90.70403867 35.85285187,-90.69501144 35.83518758,-90.67321777 35.82787079,-90.65142411 35.83518758,-90.64239688 35.85285187))
Jonesboro	98489	35.839864	-90.701875	141-59-5	POLYGON((-90.67105793 35.83986282,-90.68008368 35.85752711,-90.70187378 35.8648439,-90.72366388 35.85752711,-90.73268963 35.83986282,-90.72366388 35.82219854,-90.70187378 35.81488175,-90.68008368 35.82219854,-90.67105793 35.83986282))
Jonesboro	98491	35.8983	-90.6994	141-59-5	POLYGON((-90.67715522 35.89830017,-90.68367111 35.91104301,-90.69940186 35.91632126,-90.71513261 35.91104301,-90.7216485 35.89830017,-90.71513261 35.88555733,-90.69940186 35.88027908,-90.68367111 35.88555733,-90.67715522 35.89830017))
Jonesboro	98493	35.8194	-90.750622	141-59-5	POLYGON((-90.7198177 35.81940079,-90.72884113 35.83706507,-90.75062561 35.84438186,-90.77241009 35.83706507,-90.78143352 35.81940079,-90.77241009 35.8017365,-90.75062561 35.79441971,-90.72884113 35.8017365,-90.7198177 35.81940079))
Jonesboro	98495	35.797336	-90.716494	141-59-5	POLYGON((-90.69427336 35.79733658,-90.70078096 35.81007941,-90.7164917 35.81535767,-90.73220243 35.81007941,-90.73871003 35.79733658,-90.73220243 35.78459374,-90.7164917 35.77931549,-90.70078096 35.78459374,-90.69427336 35.79733658))
Jonesboro	98497	35.817547	-90.680083	141-59-5	POLYGON((-90.65786024 35.81754684,-90.66436949 35.83028968,-90.68008423 35.83556794,-90.69579896 35.83028968,-90.70230822 35.81754684,-90.69579896 35.80480401,-90.68008423 35.79952575,-90.66436949 35.80480401,-90.65786024 35.81754684))

Figure 9 - Sample of Generated Cell RF Propagation Polygons

Spatial Data Query Algorithm

After generating the model and necessary inputs for geo-targeting using RF coverage footprint plots, the project team then developed the algorithm itself. The core of the algorithm consists of a function to determine the intersections of polygons of the alert targeted areas and the cell RF coverage footprints. This function would need to be inserted to the existing WEA code inside the WEA Commercial Mobile Service Provider (CMSP) gateway at the point where geo-targeting is performed.

As stated earlier, TCS chose PostGIS as the COTS SDE to perform spatial data query in determining the polygon over polygon intersection. PostGIS provides a function called `ST_Intersects` (*Polygon A, Polygon B*) which provides “TRUE” returns if the two shapes share any common space, i.e., if their boundaries or interiors intersect. Here, *Polygon A* would be the alert target area, and *Polygon B* would be a cell RF footprint polygon. Therefore, to determine if a target area intersected any cell RF footprint polygon in the database, the project team executed a query similar to the following simplified example:

```
SELECT cell_sector_id, site_name
FROM Cell_RF_Footprint_Table
WHERE ST_Intersects(TargetAreaPolygon, Cell_RF_Polygon)
```

The statement told the SDE to return all the cell sector ids whose RF coverage polygon intersected the alert target area for all of the existing cell records in the database.

Design Refinement and Assumption

As the research progressed, TCS implemented several design refinements. First, instead of designing a project-specific SDE function and constructing the entirety from scratch, TCS determined it was more reasonable to use an existing COTS application (PostGIS). Second, the project team expected the cell RF coverage footprints data to be readily available or simply generated using existing tools. TCS discovered that it would have taken significant effort to generate a large enough amount of RF footprints to exercise the algorithm, however.

As a result, the RF polygon generation program required implementation based on the model described under the section “Cell RF Footprint Polygon Modeling” on page 5. For the modeling equations to hold true, TCS needed to assume that they are applied under the ideal conditions listed below:

- d is much greater than λ (which will always be true in cellular application).
- The antennas are located in unobstructed free space, with no multipath.
- A minimal loss of power occurs in delivering power from power source to antennas to free space.
- The antennas are correctly aligned and polarized.
- The bandwidth is narrow enough that a single value for the wavelength can be assumed.
- The antenna is omnidirectional, and therefore only one sector (instead of three sectors in most real situations) is assumed for each base station.

Terrestrial cellular communication almost never achieves the ideal conditions due to man-made and natural obstructions, such as reflections from buildings and terrain variations. Taking these factors into consideration when constructing an RF propagation model can achieve a good approximation, however.

With regard to this research project, the project team did not consider such factors as part of the scope. TCS used the basic model to generate an RF polygon for every cell tower belonging to a selected nationwide carrier to stress the speed and accuracy of polygons to polygons comparison algorithm.

TESTING AND EVALUATION

Test Goals

This section discusses the test cases based on the requirement goals and results. It provides a summary of all performance goals versus performance achieved during the research.

The goal of the testing is to determine the latency performance of the algorithm execution (time taken to execute the algorithm) given a large number of cells to be processed. To accurately measure the performance of the algorithm, the functionality needs to be first validated for correctness. The test category can be organized sequentially as follows:

- 1) **Feature Testing** determines if the algorithm behaves as expected. For example, if the number of cells returned for a particular area is expected to be 50, then the algorithm must return 50 under no load condition.
- 2) **Performance Testing** determines the algorithm execution latency for different alert target area scenarios, i.e., size of target area, number of target areas, and location of target areas, to observe the latencies for each of these scenarios.
- 3) **Stability Testing** determines the system's stability under load while observing if the results of Feature Testing and Performance Testing still hold.

Feature Testing

The project team executed the following test cases to determine the correct functionality of the algorithm.

- 1) Perform spatial operation on two sets of polygon points to determine if the cell is correctly reported when the target area is smaller than a cell RF polygon.

Result:

Target Area: -90.4452896118164, 36.06807192944057
-90.44443130493164, 36.06210515234035
-90.43404579162598, 36.06439478310754
-90.43473243713379, 36.06994512658326

Cell ID: 98479 at LAT/LON 36.060033, -90.439783

Execution Time: 217 milliseconds

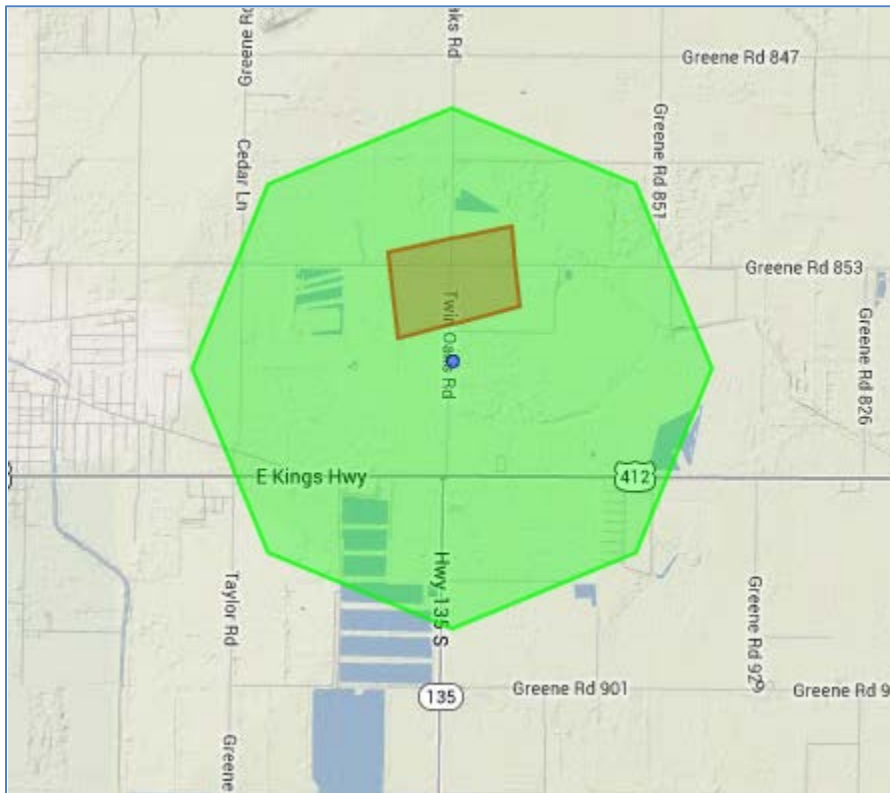


Figure 10 - Result of Test Case 1 Perform spatial operation on two sets of polygon points to determine if the cell is correctly returned when the cell RF polygon is completely inside the target area polygon.

Result:

Target Area: -90.58502197265625, 36.0659948832363
-90.46623229980469, 36.06615098882352
-90.46932220458984, 36.000351078682485

-90.62416076660156, 35.99979557131408

Cell ID: 98481 at LAT/LON 36.031622, -90.516703

Execution Time: 211 milliseconds

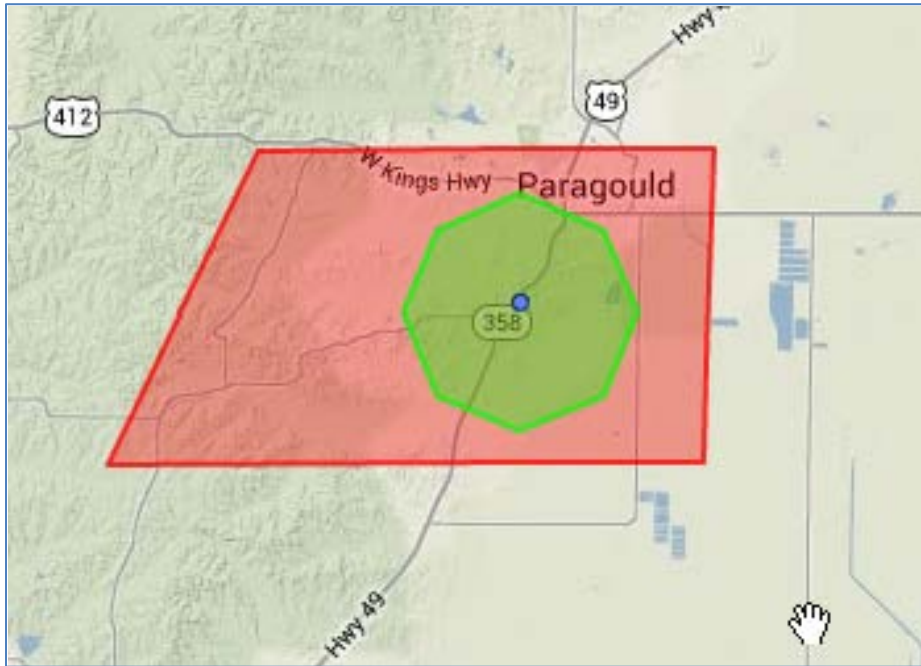


Figure 11 - Result of Test Case 2

- 2) Perform spatial operation on two sets of polygon points to determine if the RF polygon intersects the target area polygon.

Result:

Target Area: -90.55317878723145, 35.98852400253472

-90.55300712585449, 35.97831439944754

-90.52957534790039, 35.978175484174855

-90.52940368652344, 35.98956572449296

Cell ID: 98483 at LAT/LON 35.970875, -90.553675

Execution Time: 489 milliseconds

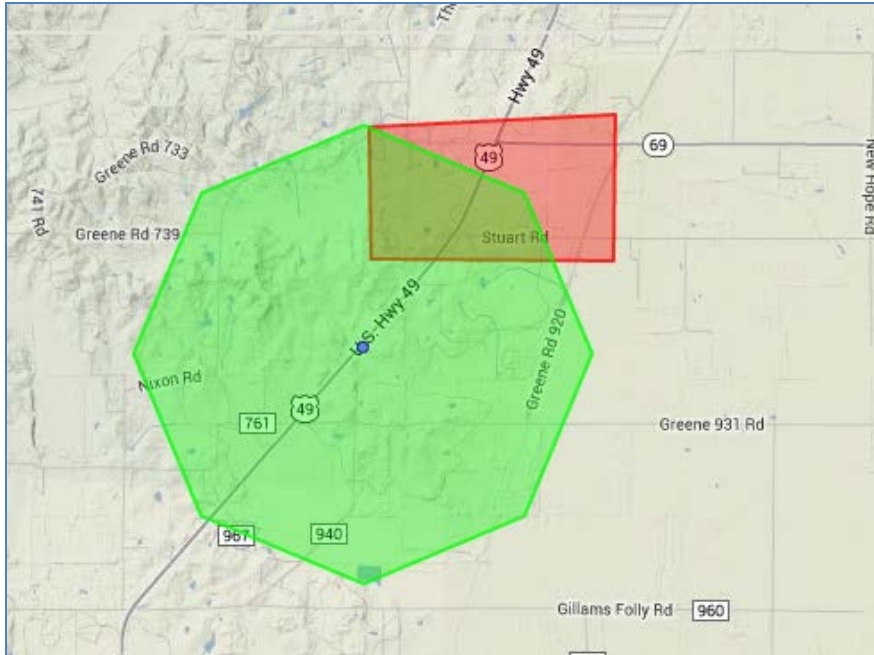


Figure 12 - Result of Test Case 3

- 3) Perform spatial operation on two sets of polygon points to determine if the RF polygon touches the target area polygon.

Result:

Target Area:

-77.15191040039062, 39.43500213623047

-77.03243408203124, 39.43431549072266

-77.10280448, 39.37046435

Cell ID: 76121 at LAT/LON -77.10280448, 39.37046435

Execution Time: 228 milliseconds

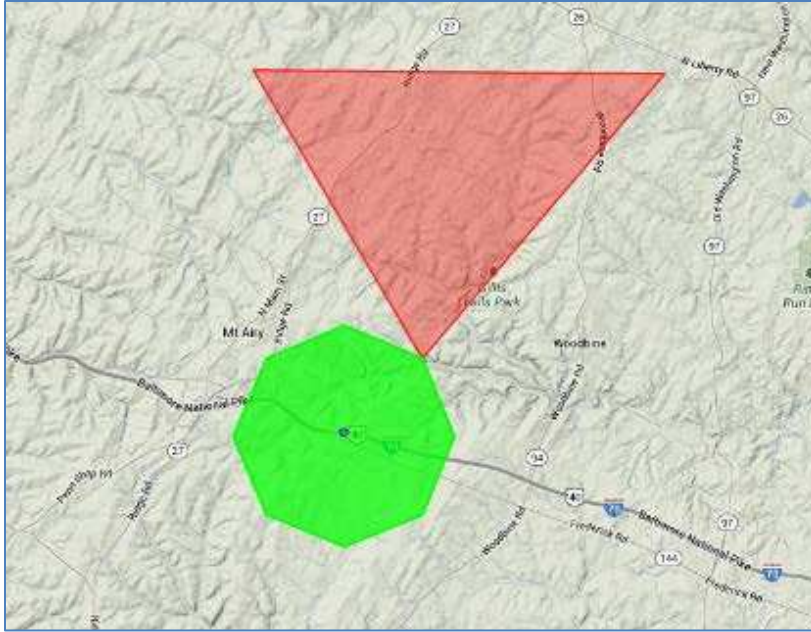


Figure 13 - Result of Test Case 4

- 4) Issue WEA alert and provide metric information on time interval for message arrival and delivery to determine the latency of the algorithm execution.

Result: It takes an observed average of 235.4 milliseconds to execute the algorithm to determine if any cell RF polygon(s) belonging to a national carrier is impacted by a single alert target area.

- 5) With 10,000 cell tower records loaded in the database, verify that when an alert is received with a targeted area, the application executes the algorithm to correctly determine which cells or cell sectors in the database that have their RF polygon(s) touch, intersect or reside within the targeted area polygon(s) and record the time of execution.

Result: The project team performed all tests using a selected national carrier with 10,000 cell tower records loaded in the system. The resulting average time of execution of 234.5 milliseconds was recorded.

- 6) The targeted cells will be submitted for delivery to the cellular network for all supporting protocols.

Result: The same output resulting from the algorithm execution is submitted for delivery using any protocol, i.e., the geo-targeting algorithm result does not affect how the message is delivered to the cellular network.

7.) Verify that the algorithm returns zero matches when the target area is selected in an area with no cell site coverage or polygons.

Result:

Consider this area before the alert is submitted:

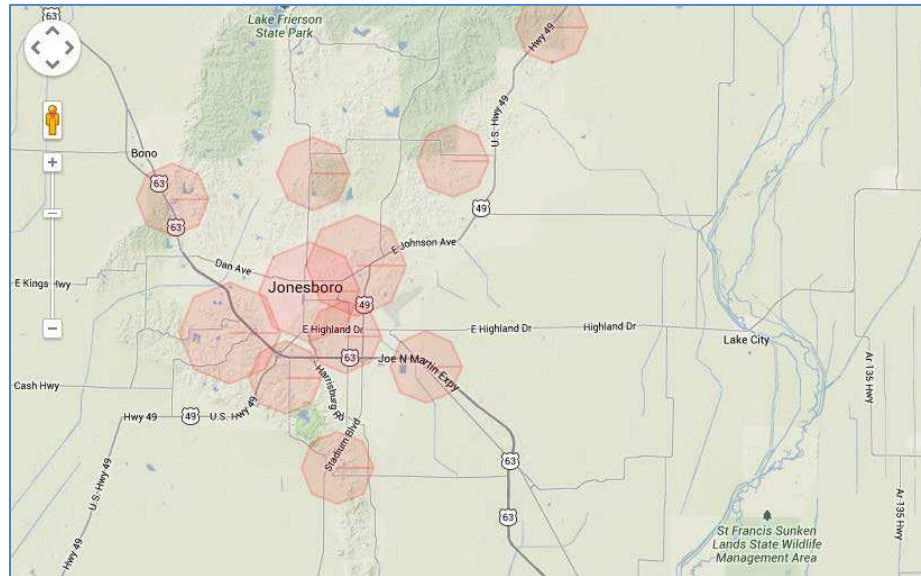


Figure 14 - Area Before Alerts

Figure 15 depicts the result of algorithm execution where the alert area does not touch or intersect with any cell, and therefore no cell is returned.

Target Area:

-90.50331115722656, 35.83698524444435
-90.47996520996094, 35.8993059822744
-90.45455932617188, 35.915434612196975
-90.41336059570312, 35.85924827697019
-90.45249938964844, 35.77350132223685
-90.48271179199219, 35.7813003261748

Execution Time: 225 milliseconds

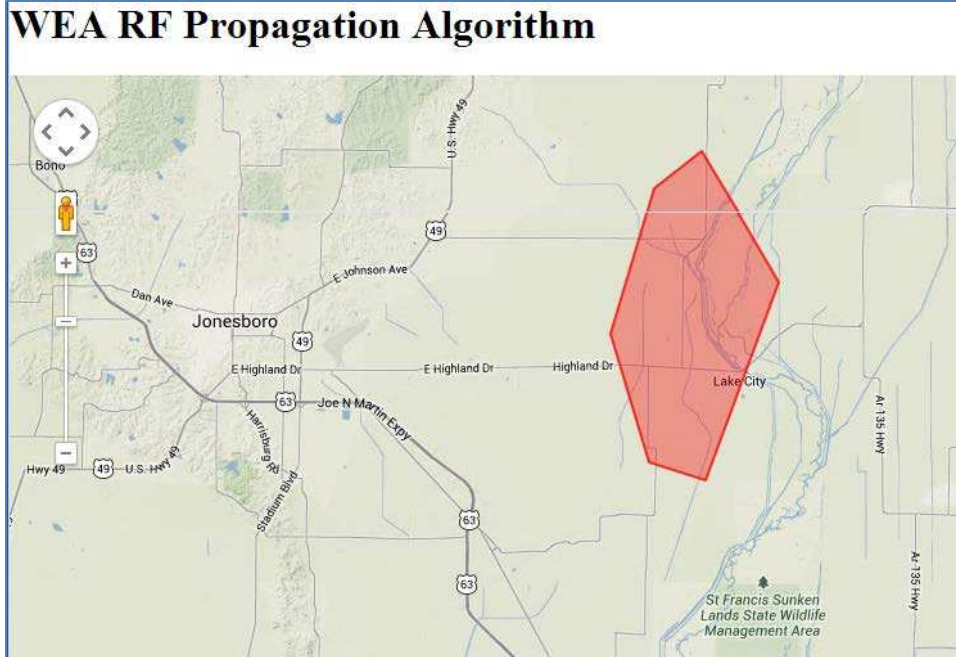


Figure 15 - Result of Test Case 8 Showing No Intersection

- 7) Verify the correct output of resulting targeted cells for different size of targeted polygons.

Result:

Target Area #1:

-77.2658935546875, 39.46555786132813
 -77.26726684570312, 39.299389648437504
 -77.5075927734375, 39.26780395507813
 -77.51033935546874, 39.46830444335938

Execution Time: 249 milliseconds

Cell Sites: 109651, 109801, 109953, 109417, 109457, 109493, 109419, 109459, 109495, 109421, 110005, 110025, 109989, 110007, 110027, 109991, 110009, 110029, 75435, 75643, 75851, 75505, 75713, 75921, 75507, 75715, 75923, 75509, 75717, 75925, 75511, 75719, 75927, 75513, 75721, 75929, 75515, 75723, 75931, 75555, 75763, 75969, 75557, 75765, 75971

Target Area #2:

-77.30846557617187, 38.439709472656254
 -77.36751708984374, 38.030468750000004
 -77.36751708984374, 38.030468750000004
 -78.22994384765624, 38.18015747070313
 -78.04180297851562, 38.68552856445313

Cell Sites: 70335, 70985, 71635, 70337, 70987, 71637, 70339, 70989, 71639, 70341, 70991, 71641, 70343, 70993, 71643, 70349, 70999, 71649, 70351, 71001, 71651, 70405, 71055, 71705,

70429, 71079, 71729, 70437, 71087, 71737, 70441, 71091, 71741, 71829, 72151, 72473, 71831, 72153, 72475, 71833, 72155, 72477, 71837, 72159, 72481, 71839, 72161, 72483, 71841, 72163, 72485, 71843, 72165, 72487, 71845, 72167, 72489, 71847, 72169, 72491, 71921, 72243, 72565, 71953, 72275, 72597, 71963, 72285, 72607, 71971, 72293, 72615

Execution Time: 48 milliseconds

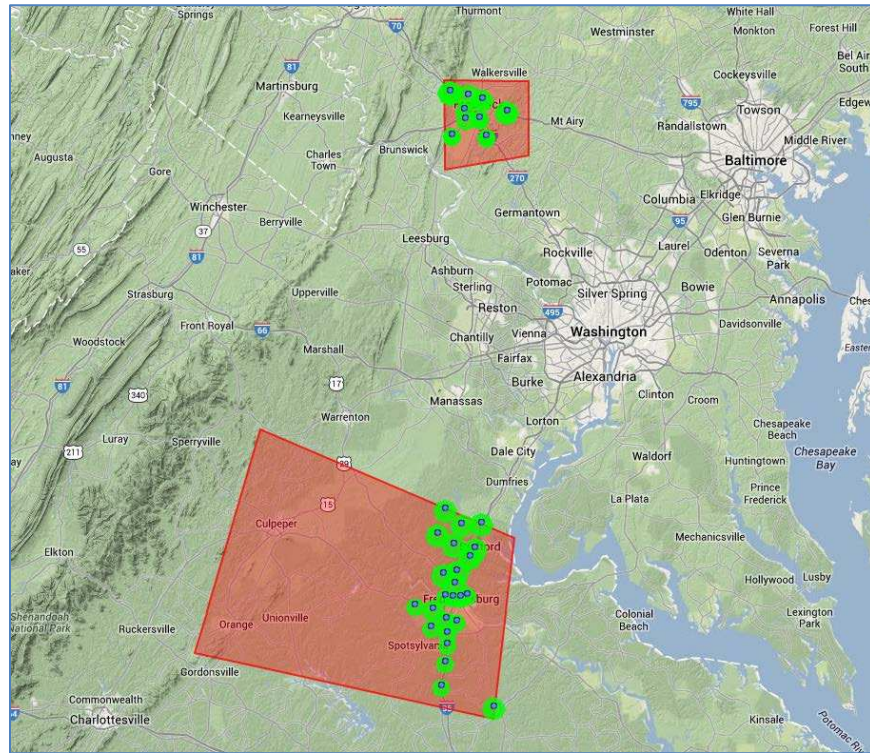


Figure 16 - Result of Test Case 9

Performance Testing

- 1) Verify the correct output of the resulting targeted cells; verify an acceptable execution time for multiple targeted polygons across the country.

Result: Four target areas were selected from coast to coast with the following results:

Target Area #1:

-76.40072021484374, 38.821484375000004
-76.579248046875, 38.846203613281254
-76.47762451171874, 39.170300292968754
-76.37325439453124, 39.118115234375004
-76.37325439453124, 39.118115234375004

Cell Sites: 109575, 109725, 109877, 109259, 109309, 109357, 109261, 109311, 109881, 109581, 109731, 109885, 109625, 109777, 109929, 109973, 109271, 109321, 109369, 109645, 109795, 109947, 109277, 109327, 109957, 74485, 74831, 75177, 74487, 74833, 75179, 74489, 74835, 75181, 74497, 74843, 75189, 74499, 74845, 75191, 74503, 74849, 75195, 74563, 74909, 75255, 74565, 74911, 75257, 74567, 74913, 75259, 74587, 74933, 75279, 74649, 74995, 75341, 74651, 74997, 75343, 74665, 75011, 75357, 74699, 75045, 75391, 74709, 75055, 75401, 74735, 75081, 75427, 74737, 75083, 75429, 75445, 75653, 75861
Execution Time: 256 milliseconds

Target Area #2:

-112.64461669921874, 33.476635742187504
-112.50179443359374, 33.506848144531254
-112.4660888671875, 33.322827148437504
-112.63363037109374, 33.300854492187504
-112.64461669921874, 33.476635742187504

Cell Sites: 102701, 102709, 102715

Execution Time: 19 milliseconds

Target Area #3:

-116.89495239257812, 33.08524780273438
-116.82491455078124, 33.09074096679688
-116.82354125976562, 33.00834350585938
-116.89220581054687, 33.012463378906254

Cell Sites: 63489, 63745, 64001, 63491, 63747, 64003, 63493, 63749, 64005, 63495, 63751, 64007

Execution Time: 38 milliseconds

Target Area #4:

-120.151025390625, 37.04581909179688
-119.9807373046875, 37.05131225585938

-119.98211059570312, 36.887890625000004
-120.15377197265624, 36.874157714843754
-120.151025390625, 37.04581909179688

Cell Sites: 88767, 89059, 89351, 88771, 89063, 89355, 88773, 89065, 89357, 88775, 89067, 89359, 88809, 89101, 89393, 88821, 89113, and 89403 at LAT/LON -77.10280448, 39.37046435
Execution Time: 26 milliseconds



Figure 17 - Result of Performance Test Case 1

The total latency is 339 milliseconds

- 2) Verify that the execution time is within acceptable range when an alert with eight target areas with different locations and sizes are submitted simultaneously.

Result:

Target Area #1:

-80.5517578125, 31.978958480753228
-80.61767578125, 32.25810410713092
-80.70556640625, 32.55491613824475
-80.31005859375, 32.850749781706554
-80.04638671875, 32.5178680435577
-80.35400390625, 32.27668343339889
-80.5517578125, 31.978958480753228

Execution Time: 228 milliseconds

Target Area #2:

-79.4970703125, 33.292655662521405
-79.365234375, 33.714059324224124
-78.92578125, 33.823652757842055
-78.75, 33.69578012931697

-78.94775390625, 33.200775086578396
-79.34326171875, 32.75840715084112
-79.4970703125, 33.292655662521405

Execution Time: 13 milliseconds

Target Area #3:

-78.837890625, 34.38764597384264
-78.72802734375, 34.82169535497484
-78.22265625, 34.83973145942067
-77.76123046875, 34.62303770546258
-77.80517578125, 34.15159051366224
-78.1787109375, 34.11521551429773
-78.837890625, 34.38764597384264

Execution Time: 12 milliseconds

Target Area #4:

-78.2666015625, 35.396886504015946
-78.33251953125, 36.12789245231785
-77.84912109375, 36.605606472395536
-76.904296875, 36.358269017192455
-76.92626953125, 35.52216747798627
-77.3876953125, 35.34313496028189
-78.2666015625, 35.396886504015946

Execution Time: 22 milliseconds

Target Area #5:

-77.67333984375, 37.09790760669941
-77.6513671875, 38.26298470036053
-77.14599609375, 38.55568323796419
-76.75048828125, 38.211209018340156
-76.75048828125, 37.499920931273685
-77.05810546875, 36.97512967493797
-77.67333984375, 37.09790760669941

Execution Time: 27 milliseconds

Target Area #6:

-77.05810546875, 39.71458175667416
-77.67333984375, 39.25671479372372
-77.1240234375, 38.79583799119041
-76.31103515625, 38.79583799119041
-76.17919921875, 39.32473709379018
-77.05810546875, 39.71458175667416

Execution Time: 186 milliseconds

Target Area #7:

-75.38818359375, 39.20565471434283
-75.146484375, 39.731481865131
-74.64111328125, 39.79904087286648
-74.1357421875, 39.76526965512217
-74.1357421875, 39.34173234304089
-75.38818359375, 39.20565471434283

Execution Time: 45 milliseconds

Target Area #8:

-75.146484375, 41.008920735004885
-75.322265625, 42.51665075361142
-73.740234375, 43.22519255488631
-71.630859375, 42.71069600569494
-71.3671875, 41.47154438707647
-75.146484375, 41.008920735004885

Execution Time: 16 milliseconds

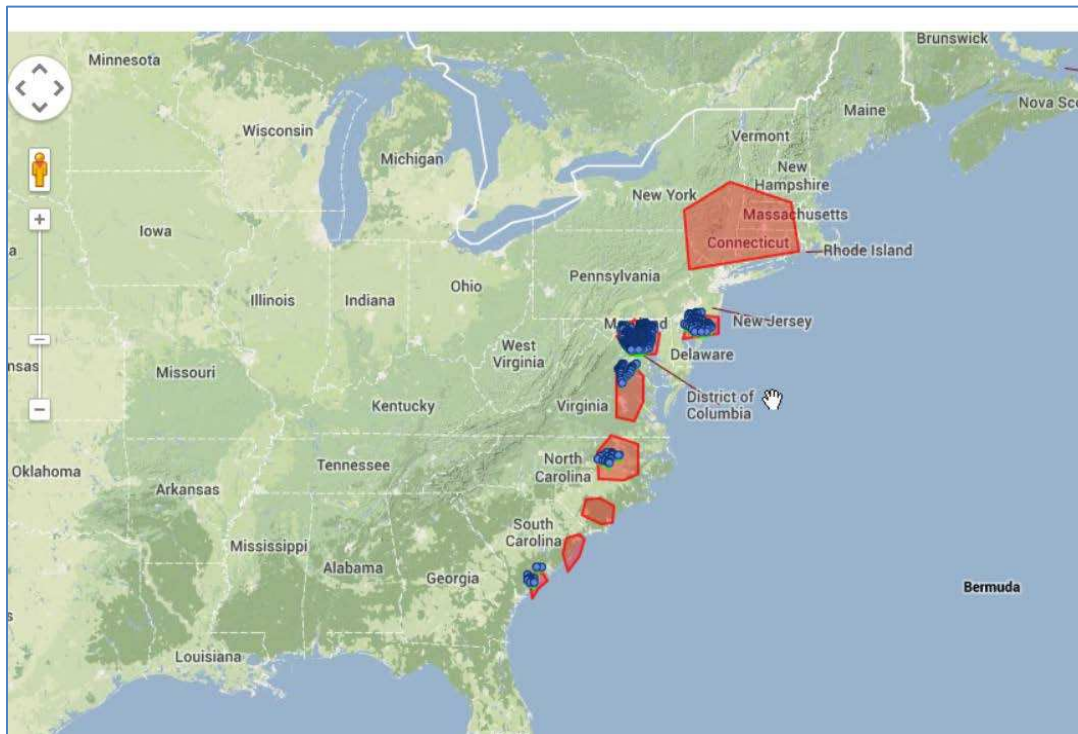


Figure 18 - Result of Performance Test Case 2

The total latency is 549 milliseconds

- 3) Verify that the execution time is within acceptable range when an alert with 21 target areas with different locations and sizes are submitted simultaneously.



Figure 19 - Result of Performance Test Case 3

Result:

Number of polygons: 21

Total Latency: 1081 milliseconds

Average Latency: 51.5 milliseconds

- 4) Observe the execution time difference for different cell polygon records in the database.
The following targeted area was executed repeatedly for different number of polygon records.

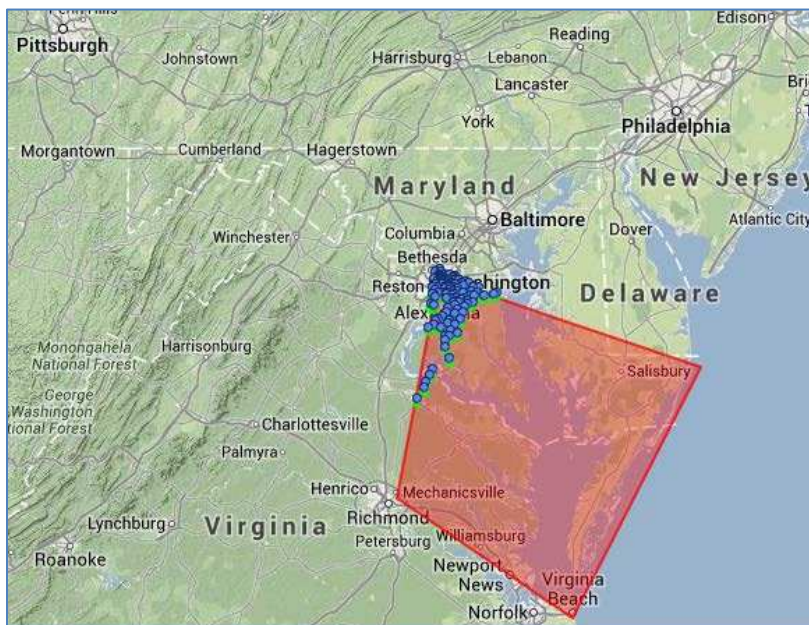


Figure 20 - Result of Performance Test Case 4

Result:

Number of Records: 10,000

Target Area:

-77.431640625, 37.53096540025999
-77.0361328125, 38.92042119903319
-74.970703125, 38.543332126932796
-76.00341796875, 36.84830713884688
-77.431640625, 37.53096540025999

Execution Time: 272 milliseconds

Number of Records: 8,000

Target Area:

-77.36572265625, 37.56961676185728
-77.0361328125, 38.932707274379595
-74.970703125, 38.38365119432096
-75.9814453125, 36.81698084233672
-77.36572265625, 37.56961676185728

Execution Time: 265 milliseconds

Number of Records: 6,000

-77.431640625, 37.53096540025999
-77.0361328125, 38.92042119903319
-74.970703125, 38.543332126932796
-76.00341796875, 36.84830713884688
-77.431640625, 37.53096540025999

Execution Time: 269 milliseconds

Number of Records: 4,000

-75.970458984375, 36.857098179191205
-77.45361328125, 37.53967731569061
-77.01416015625, 38.95460326144689
-74.77294921875, 38.45735265386234
-75.970458984375, 36.857098179191205

Execution Time: 269 milliseconds

Number of Records: 2,000

-77.431640625, 37.53967731569061
-77.025146484375, 38.92896825930919
-74.849853515625, 38.45735265386234
-76.00341796875, 36.83072202540981
-77.431640625, 37.53967731569061

Execution Time: 206 milliseconds

Number of Records: 100

-76.00341796875, 36.83951508755616
-77.464599609375, 37.53967731569061
-77.025146484375, 38.92042119903319
-74.8828125, 38.52614444334863
-76.00341796875, 36.83951508755616

Execution Time: 208 milliseconds

Stability Testing

To ensure the geo-targeting algorithm is deployable in production environment, it needs to support a WEA peak traffic requirement of at least 6,000 messages per day with acceptable execution time (latency) in accordance with the J-STD-101³ standard reference. To do so, the project team integrated the algorithm with the TCS live test WEA system and performed a load run for stability.

The project team established the following parameters for the load run:

- 1) 6,000 messages were injected into the system at a rate of 3,600 messages per hour
- 2) 30,000 cell RF polygons were loaded in the system
- 3) The cells were scattered throughout the U.S., covering all 50 states and 3,144 counties
- 4) An alert target area was included for each message

The project team observed the following results:

- 1) It took 2 hours and 30 minutes to complete the run
- 2) The shortest latency to execute the algorithm was 200 milliseconds
- 3) The longest latency to execute the algorithm was 9,180 milliseconds
- 4) The average latency was 1.5 seconds per message

³ J-STD-101: Joint ATIS/TIA CMAS Federal Alert Gateway to CMSP Gateway Interface Specification

KEY FINDINGS AND LESSONS LEARNED

Successes

The goal of this research was to determine the feasibility of developing an enhanced geo-targeting algorithm using the cell tower RF propagation information to improve the alert broadcast accuracy. Research successes include:

- **Algorithm meets and exceeds performance criteria**

The key performance parameter to be determined is the time required to execute the algorithm of different alert's target scenarios. Although WEA does not require an exact speed of alert delivery, it expects the alert to be delivered within a few minutes of submission. Through experimentation, TCS successfully built and demonstrated that it required approximately 0.25 seconds to process a single alert going through a national carrier.

Figure 21 summarizes a selected test result:

Test Result Summary with 10,000 cell RF polygons provisioned across USA			
Test Case	Target Area Polygon Size	Number of Polygon Points	Latency per Alert (ms)
Target area is smaller than a cell RF polygon	small	4	217
Cell RF polygon is inside the target area	medium	4	211
RF polygon intersects the target area	small	4	489
RF polygon touches the target area	medium	3	228
Target area does not intersect any cell RF	large	6	225
Mixed 2 target areas of different sizes	small/large	4	297
Mixed 4 target areas across US	mixed	mixed	339
Mixed 8 target areas on East Coast	mixed	mixed	549
Mixed 21 target areas on East Coast	mixed	mixed	1081
100 cell polygon records	large	4	208
2000 cell polygon records	large	4	206
4000 cell polygon records	large	4	269
6000 cell polygon records	large	4	269
8000 cell polygon records	large	4	265
10000 cell polygon records	large	4	272
Stability/Load Run at 6000 alerts/2.5 hours	medium	4	1500

Figure 21 - Test Result Summary

For a single alert containing multiple target areas, the first target area required approximately 250 milliseconds to process and each subsequent target area added an average latency of approximately

25 milliseconds. For an alert with 52 target areas across the entire U.S., one can extrapolate that the algorithm would require approximately 1,525 milliseconds, or 1.5 seconds, to perform geo-targeting.

For a performance run with varying numbers of cell polygon records in the database, the project team observed very little increase in latency with increasing numbers of polygon records. This indicates that the algorithm is scalable.

Finally, for the stability run, 6,000 alerts were injected into the system at a rate of 3,600 alerts per hour resulting in an observed average latency of 1.5 seconds per message.

These tests advocate a very positive outcome illustrating that the algorithm is fast, efficient, and can undoubtedly be used in a production environment.

- **RF propagation program developed**

A major achievement of this project was the successful development of a base model to estimate the cells' RF propagation. The development resulted from the necessity to generate a large amount of RF propagation polygons as the real RF data was not readily available in the timeframe of the project.

For a cost-effective operation of enhanced geo-targeting, the process of the cell RF data acquisition and processing must be automatic to minimize, or remove, human intervention. As actual RF data acquisition is time consuming, a computerized automated approach is the preferred method with a trade-off in accuracy. The model generated in this research project is basic, but it can be enhanced to achieve the most accurate approximation. Once the model is refined, automated RF propagation polygons can be generated using today's available cell tower parameters, such as antenna height, orientation, and gain.

- **Algorithm deployable today for improved accuracy**

The method developed in this project can be deployed without changes to existing networks, protocols, or handset software. While the Communications, Security, Reliability, and Interoperability Council (CSRIC) working group continues to refine the standard for improving WEA geo-targeting accuracy, this method can complement the CSRIC effort, as the method would be completely transparent to cellular networks and the protocols being used today.

Remaining Issues

As stated earlier, actual cell RF propagation data collection and processing could present major challenges from both business operations and policy perspectives. Although all carriers maintain their cell RF propagation data as part of their business operational efforts, preparing this data for WEA processing could be a major undertaking. This is because the raw cell RF propagation data need to be converted into a format that is readable by WEA algorithm processing. Another issue relates to the fact that the RF propagation data may need to be shared, for example to business partners interested in using this enhanced method for WEA. In this situation, carriers may not be willing to disclose this data

to the third party, for fear of losing confidential information and trade secrets. This would not be an issue if a carrier wholly owned and operated the CMSP gateway, as no data would be shared with a third party. Many Tier-2 and Tier-3 carriers have opted for a hosted or managed WEA solution. In this case, they have to provide this RF propagation data to their service vendor through Non-Disclosure Agreements (NDA).

Without actual data available from the carriers, the other option is to generate the cell RF propagation data using the model developed in this project. This model should not be used in its current capability to generate the RF propagation data as a substitute to actual data, however. For this model to be useable, the following factors need to be considered for enhancement:

- The model needs to account for all sectors available in a cell tower. In most cases, each cell tower features three sectors.
- The model needs to consider all of the available RF cell tower data for the model calculation such as:
 - Antenna LAT/LON
 - Antenna power
 - Frequency
 - Sector orientation
 - Antenna height
 - Antenna azimuth
 - Antenna gain
 - Antenna tilt

With the information above, a model can be formulated to generate a reasonable approximation of the cell RF propagation polygons. Because the RF polygons need to be generated automatically as the cell tower data changes (usually on a daily basis), the model cannot take into account certain parameters, such as terrain and human-made or natural obstacles, as it would make the model overly complex.

Finally, the project team conducted the study solely in a lab environment. Field testing with real RF coverage data and actual mobile devices would validate the algorithm's effectiveness for alert delivery accuracy.

PROJECT IMPACT

Operational Impact

The accurate acquisition and maintenance of the cell RF coverage data represent the main challenges of this project's implementation. It is conceivable that some number of cell towers change on a daily basis, especially for large national carriers. Since the algorithm operates on the RF coverage in terms of cell towers RF propagation LAT/LON points, polygons need to be generated and imported into the geo-targeting database. From the perspective of the carriers, this effort may not be justified if it is done solely for the purpose of WEA service. Fortunately, for most carriers, cell RF coverage data is already available as it is needed for other services, such as E911. The data would need to be reformatted for compatibility with the database used by the WEA geo-targeting algorithm, however.

The process of collecting, converting, and importing cell coverage RF data into a WEA database needs to be automated given that changes can occur on a daily basis. For many carriers, this work could be perceived as a major undertaking with little incentive to justify such effort. For those carriers, especially rural ones, where this data does not yet exist, such an initiative could be considered a low priority.

Technological Impact

The project team was concerned that an enormous amount of processing power would be required to determine the intersection of the targeted areas and store up to a few hundred thousand cell polygon records in the database. As the experiments demonstrated, however, this is not the case. The efficiency of the algorithm and a well-defined data structure eliminated this uncertainty. The algorithm can support very large amount of cell polygons exceeding the size of the major national cellular carrier in the U.S.

This study shows that if implemented, geo-targeting technology would provide major benefits to the public without impacting existing cellular infrastructure. As the change only requires a software upgrade in the CMSP gateway, the solution can be deployed very quickly without changes to the existing WEA protocols or mobile devices' firmware.

Marketplace Impact

From the operator's perspective, the cost of introducing this technology into the marketplace consists of three main categories:

- 1) Cost of development
- 2) Cost of deployment
- 3) Cost of operation and maintenance

Cost of development consists mainly of software specification, design, coding, and testing. No additional hardware should be needed as the only impact is the geo-targeting function of the CMSP gateway or the

Cell Broadcast Center (CBC), depending on developer's design preference. Based on comparison with similar projects and given sufficient resources, the project team estimated this type of effort could be completed within a few quarters of a calendar year by a small software development team of three to five individuals.

For a carrier already offering the WEA service, deployment of this algorithm only needs a software upgrade. As such, the project team expected the cost of deployment to be low since there is no hardware impact. Based on TCS's experience with deploying software upgrades, the estimated effort should take approximately four to six weeks, including planning. Such an activity is usually performed during maintenance hours (12-6 a.m.) to minimally impact traffic on the network and consumers.

The most important aspect of the cost would be the operation and maintenance of the cell RF propagation polygons. As stated earlier, the cell tower data changes on almost a daily basis for a large carrier, and the RF propagation data would also need to be updated accordingly. Therefore, the process of collecting, converting, and importing cell coverage RF data into a WEA database needs to be automated to keep the cost and resource impact at a minimum.

As operators are prohibited from charging consumers for WEA service, there could be little motivation to invest additional resources and funds into a service that offers no return on investment. Retention of subscribers may provide some incentives, but that will occur over a time period when the consumers start to see the efficiency and pertinence of the alerts delivered to them.

Due to the infrequent nature of the WEA alerts, little difference would be immediately noticed from the consumer perspective. Over time as alert fatigue becomes less common and additional alerts can be issued due to improved accuracy, consumers might further recognize the significance and value of these alerts. Each potentially life-saving alert can become additionally pertinent to their daily lives.

Additional Comments

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 assumptions need to be made to provide a service to the public which can be considered a "best-effort solution." Looking at the various methods available today, none would provide better granularity than a tower LAT/LON. The basic requirement stated in the J-STD-101, asserting county level accuracy, is only effective for the type of alerts that cover large geographical areas, such as weather and AMBER alerts. The more efficient method of allowing alert target areas to be based on circles or polygons would provide improved granularity, but it would still result in instances of over-alerting and under-alerting. Therefore, this will not be suitable for a campus emergency, chemical spill, or road block due to a major accident.

The RF propagation footprint algorithm could be provided as the best-effort solution for cell broadcast technology available today. Given that it considers the RF propagation characteristics, the cell RF propagation algorithm serves as a better option for localized alerts despite the fact that its approximation is not 100 percent accurate. Its limitation becomes evident as the size of the alert area is so small that the RF propagation approximation becomes compromised. At this limit, a better technology, such as handset based geo-targeting using GPS technology, could be used. Moreover, this algorithm is less useful for large target areas when the size of target area is much larger than the cell

site, or approaching the size of a city or county. In this case, standard dynamic geo-targeting can be used to improve speed of delivery. An efficient WEA geo-targeting solution would be one that incorporates such programmatic decisions into the WEA software business logic, and likewise determines which methods to use depending on the size and number of the alert targeted areas.

APPENDIX A – Acronyms List

Acronym	Meaning
CAP	Common Alert Protocol
CBC	Cell Broadcast Center
CMSP	Commercial Mobile Service Provider
COTS	Commercial Off-The-Shelf
CSRIC	Communications Security, Reliability and Interoperability Council
DHS	Department of Homeland Security
FIPS	Federal Information Processing Standard
FSPL	Free Space Path Loss
LAT/LON	Latitude/Longitude
NDA	Non-Disclosure Agreement
NWS	National Weather Service
PostGIS	PostGreSQL DB GIS
RDBMS	Relational Database Management System
RF	Radio Frequency
SDE	Spatial Data Engine
TCS	TeleCommunication Systems, Inc.
WEA	Wireless Emergency Alert