Wireless Emergency Alerts

Arbitrary-Size Location-Aware Targeting

Final Report

June 2015

Homeland Security

Science and Technology

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EXECUTIVE SUMMARY

This document describes research being done on a new Wireless Emergency Alerts (WEA) geotargeting mechanism by the Johns Hopkins University Applied Physics Laboratory (JHU/APL). This work was undertaken with the support of the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T). The WEA service provides the ability to send geographically targeted text alerts to the public. However, the current WEA geotargeting mechanism is limited by the relatively coarse granularity of cellular network sites. JHU/APL investigated methods of improving the geotargeting accuracy of WEA.

The new WEA geotargeting mechanism is called Arbitrary-Size Location-Aware Targeting (ASLAT). This document compares the performance of the new mechanism with existing WEA geotargeting, discusses the requirements for the new mechanism and identifies the required changes to existing WEA standards. ASLAT utilizes the location awareness of mobile devices to improve geotargeting accuracy.

In ASLAT, WEA alerts are broadcast to an area wider than the target area, but are only displayed to the user if the mobile device is inside the target area. This approach eliminates the false positives and the false negatives that occur due to the mismatch between the shape of the target area and the shape of the set of cellular network sites selected to broadcast the alert. In addition to enhancing the geotargeting accuracy, ASLAT would enable people to receive alerts when they are in the vicinity of a target area and have interest in a particular location inside the target area.

Performance analysis of ASLAT shows that it can improve the geotargeting accuracy of WEA significantly without consuming excessive mobile device power or radio resources. ASLAT introduces some delay in delivering alert because mobile devices need to learn their location before processing a received alert. However, the maximum delay introduced by ASLAT can be controlled by a configurable parameter. The mobile device can use the default WEA behavior if the ASLAT delay reaches this maximum value. The project team used a maximum ASLAT delay of one minute in the analyses. Highly delay-sensitive alerts such as earthquake warnings would bypass ASLAT automatically and be processed using the default WEA behavior. These alerts would be displayed to the user immediately as in current WEA, without comparing the location of the mobile device with the target area.

ASLAT depends on a variety of geolocation technologies to determine the location of a mobile device. The project team investigated different geolocation technologies to see what technologies would be suitable for use with ASLAT and concluded that mobile-device-based technologies should be used. These geolocation technologies include the Global Positioning System (GPS), mobile-device-based Time Of Arrivals (TOA) and Time Difference Of Arrivals (TDOA) techniques and Wi-Fi proximity. These are all suitable for ASLAT because they provide adequate location precision, they do not introduce additional load on the cellular network and they maintain user privacy.

ASLAT would require some changes to existing standards. Specifically, WEA standards that specify functionality in the cellular networks and mobile device behavior would require amendments to support ASLAT. Some modifications to GPS, TOA/TDOA and Wi-Fi

standards and implementation of new indoor location capabilities would further enhance ASLAT performance.

The new geotargeting mechanism and the related findings described in this document could affect important technical, programmatic and policy decisions regarding the evolution of the WEA system. The DHS S&T WEA Program Management Office should work with other stakeholders, including the Federal Communications Commission, Federal Emergency Management Agency, cellular service providers, the Alert Originator community and state and local first responders, to determine detailed requirements on geotargeting accuracy and to analyze various alternatives to meet these requirements. Such an analysis of alternatives study would benefit from the findings presented in this document, but should also include the level of effort and cost required for each alternative as that was outside the scope of this effort.

1 BACKGROUND

1.1 Wireless Emergency Alerts Architecture

The Wireless Emergency Alerts (WEA) program was established in response to the Warning, Alert, and Response Network Act of 2006 to allow wireless service providers to send geographically targeted emergency alerts to their subscribers. Under Executive Order 13407, the secretary of homeland security, in coordination with the Department of Commerce and the Federal Communications Commission (FCC), is responsible for implementing and administering the national public emergency alert system and ensuring that the president can alert and warn the American people in the case of an emergency. Within the Department of Homeland Security (DHS), the Federal Emergency Management Agency (FEMA) is responsible for the implementation and administration of the Integrated Public Alert and Warning System (IPAWS). WEA was implemented as one of the dissemination channels in IPAWS.

Figure 1 shows the WEA architecture. Public alerts and warnings are first generated in Common Alerting Protocol (CAP) format [5] by the Alert Originators and sent to an Alert Aggregator, called IPAWS Open Platform for Emergency Networks (IPAWS-OPEN). IPAWS-OPEN verifies the integrity and validity of the alerts and sends them to the WEA service and other dissemination channels. WEA messages use a different format than CAP, called the Commercial Mobile Alert for C Interface (CMAC).[6] IPAWS-OPEN performs the necessary conversion from CAP to CMAC for all valid WEA messages and then sends a copy of the CMAC-formatted WEA message to each participating Commercial Mobile Service Provider (CMSP). A participating CMSP that receives a WEA message finds the target area in the message, decides which cell towers should broadcast the alert and then broadcasts the alert text using these cell towers.

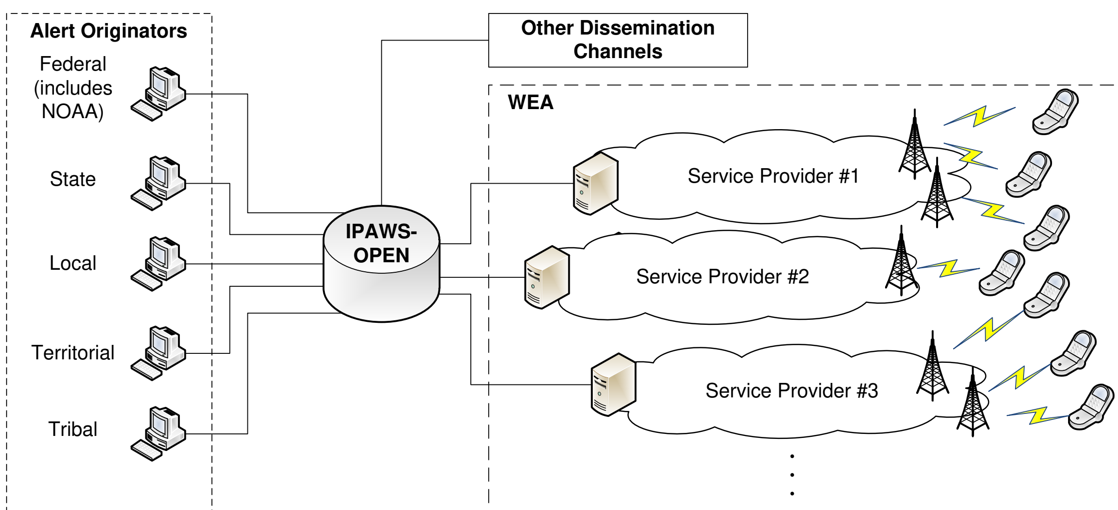


Figure 1: WEA Architecture

1.2 Geotargeting

WEA provides the ability to send geographically targeted text alerts to the public. The target area to be alerted is described in the CAP message as a list of counties or as geospatial shapes (commonly polygons). The target area description is passed from the CAP messages to the associated CMAC messages so that each CMSP can get the description and identify the cell towers to broadcast the alert.

The current WEA geotargeting mechanism has limited precision due to the relatively coarse granularity of cellular network sites. Even if the target area is accurately described to the CMSPs using polygons instead of Federal Information Processing Standards (FIPS) codes, the actual area that receives the alert is determined by the location of the cell towers. Figure 2 shows an idealized depiction of the cellular coverage areas. Each hexagon represents a cell site, which is the coverage area of a cell tower. The figure also shows an example target area for an emergency alert and the corresponding broadcast area (i.e., the area that receives the broadcast of the alert). As illustrated in the figure, an exact match between the radio frequency (RF) coverage of all the selected cells and the target area specified in the CMAC message is highly unlikely. Therefore, the granularity of the broadcast area is limited by the RF footprint and the locations of the cell sites selected to broadcast the alert message in each CMSP network. The granularity can be especially low in suburban areas where cell towers are typically further away from each other and serve larger areas. In this case, either some people who are not at risk would receive the alert or some people who are at risk would not receive the alert.

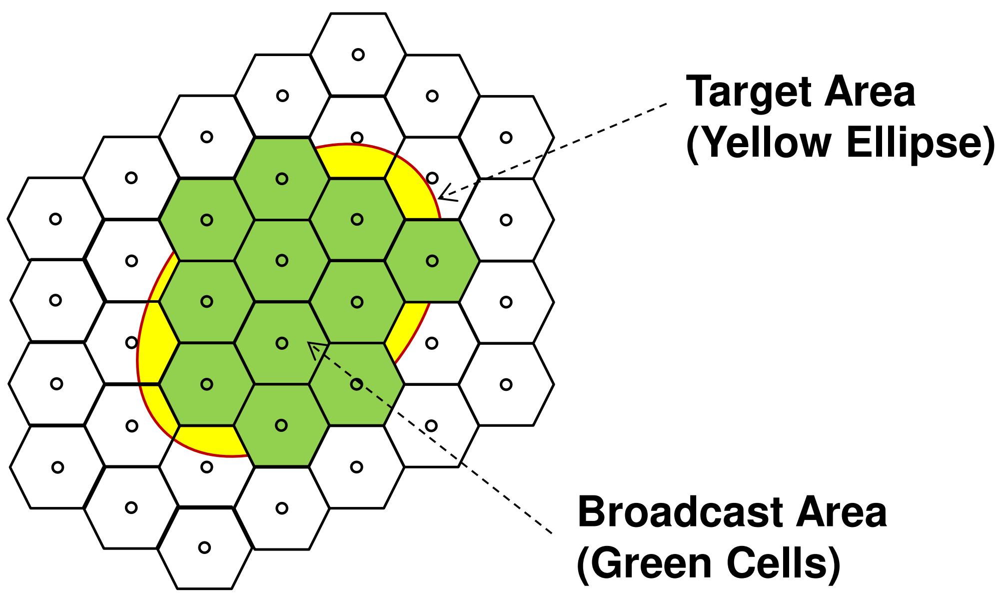


Figure 2: Target and Broadcast Areas

Numerous benefits of accurate geotargeting for public alerts and warnings have been identified in earlier studies. A National Academy of Sciences workshop [1] on this topic concluded that specific information about which locations are and are not at risk increases the likelihood that people take protective action. The workshop report also argues that the less precise the geotargeting, the more likely the recipient will ignore the alert or choose to opt out of the alerting system because they are not sure whether the message applies to them. Similarly, Woody and Ellison mentioned that continued receipt of irrelevant alerts desensitizes the public to the alerting process and reduces the likelihood that they will receive and respond to future alerts and warnings.[2] The authors also concluded that coarse geotargeting granularity in WEA may result in many people receiving irrelevant alerts, which would reduce Alert Originator trust in the system. McGregor et al. reported an additional benefit of accurate geotargeting as preventing bleed over between different jurisdictions.[3] Since different Alert Originator agencies have different jurisdictions, it is important for an issued alert not to be disseminated beyond the boundaries of the intended jurisdiction. Banerjee, Mukherjee and Misra discussed the properties of a “smart” public alert and warning system.[4] In addition to the importance of accurate geotargeting for events that would directly affect a given individual, they also mentioned the need to consider an individual’s general preferences (e.g., medical condition, locations of interest) in alert delivery.

1.3 Accuracy Enhancement

The DHS Science and Technology Directorate (S&T) has engaged the Johns Hopkins University Applied Physics Laboratory (JHU/APL) to investigate methods that can improve the accuracy of the WEA geotargeting mechanism. Such improvements would be possible by enhancing the algorithms CMSPs use in selecting the cell towers to broadcast an alert, or by utilizing the location-awareness capability of the mobile device. The main focus of this document is the latter approach, where alerts are broadcast to an area wider than the target area but are only displayed if the mobile device is inside (or about to enter) the target area. This document proposes an enhanced geotargeting mechanism for WEA based on this approach, called Arbitrary-Size Location-Aware Targeting (ASLAT).

In addition to enhancing the geotargeting accuracy, ASLAT would also enable people to receive alerts when they are in the vicinity of a target area and have interest in a particular location inside the target area. This feature of ASLAT is called “related targeting.” For example, a person may be at work when an alert is issued for a target area that includes his home. This person will not receive the alert in the existing system if his physical location is outside the selected broadcast area. On the other hand, ASLAT can extend the broadcast area to a certain vicinity of the target area, so the same person would receive the alert at work, provided that the work location is within this vicinity and the mobile device was previously configured to notify the user about alerts targeting the home location.

The rest of this document is organized as follows: Section 2 introduces the performance metrics that are used to compare the existing WEA geotargeting mechanism with ASLAT and other alternatives for enhanced geotargeting accuracy. Section 3 provides the performance analysis of the current system and alternative cell tower selection options. Section 4 describes ASLAT in detail. Section 5 provides a performance analysis of ASLAT and compares it with the existing geotargeting mechanism. Sections 6 and 7 discuss

requirements for ASLAT and the required changes to existing WEA standards. Finally, Section 8 summarizes the main findings.

2 MEASURING GEOTARGETING PERFORMANCE

Because the objective of this work is to design enhanced geotargeting mechanisms for WEA, it is important to define performance metrics for comparing the existing WEA geotargeting mechanism with ASLAT and other alternatives. Four different types of metrics are relevant for assessing geotargeting performance:

- Geotargeting accuracy;
- Resources consumed by WEA during operation;
- Alerting latency; and
- Maintenance of privacy.

These metric types are discussed in the rest of this section. The cost and complexity of implementing a new geotargeting mechanism are also important factors that should be considered before making a decision. Although a complete analysis of implementation cost and complexity is beyond the scope of this document, the functional requirements for ASLAT and required changes to the standards are discussed in Sections 6 and 7. These sections provide the important basis for evaluating the cost and complexity required to implement each geotargeting scheme considered.

2.1 Geotargeting Accuracy

Ideally, WEA should alert every subscriber that is required (by the Alert Originator) to be alerted and should not alert any subscriber that is not required to be alerted. The geotargeting (in)accuracy is measured by the deviations from this ideal. Therefore, two main metrics that can measure geotargeting accuracy are the False Positives (FP) and the False Negatives (FN), defined as follows:

> FP = (Number of subscribers alerted who should not have been alerted) / (Number of subscribers alerted)

> FN = (Number of subscribers required to be alerted, but not alerted) / (Number of subscribers required to be alerted)

FP and FN are the most important metrics in comparing alternative geotargeting mechanisms. They can be calculated for a given emergency alert, and ideally both should be zero. Note that in general, FP and FN can fluctuate between 0 and 1 (between 0 and 100 percent).

In practice, it may be difficult to determine the number of subscribers required to be alerted or actually alerted. This would require an exact knowledge of the population in arbitrary target areas at any time and an acknowledgement from each subscriber when an alert is received. To address this issue, the following approximations will be used as the definitions of FP and FN for the remainder of this document (unless explicitly stated otherwise):

FP = (Area of the region alerted that should not have been alerted) / (Area of the region alerted)

FN = (Area of the region required to be alerted, but not alerted) / (Area of the region required to be alerted)

These simplified definitions of FP and FN also fluctuate between 0 and 1 and should ideally be zero. While the calculation of FP or FN with the earlier definition requires knowledge of the number of subscribers, the calculation with the simplified definition is not precluded by lack of this data.

The main reason for FP or FN to be greater than zero is the granularity of the cell RF coverage footprints. Figure 3 illustrates a case of non-zero FP and FN for an elliptical target area. In this example, cell towers (denoted by red dots inside the hexagons) broadcast the alert only if they are in the target area. The broadcast (alerted) area is the entire region bounded by the dashed red line. The portion of this area intersecting with the target area (shown in green) corresponds to the correctly alerted region, while the portion outside the target area (shown in red) should not have been alerted. Therefore, FP is the area of the red-colored region divided by the area inside the dashed red line. In the same example, portions of the elliptical target area are not alerted (shown in yellow) because the cell towers in these cells are outside the target area. These regions contribute to the FN, which is the area of the yellow-colored region divided by the area of the ellipse.

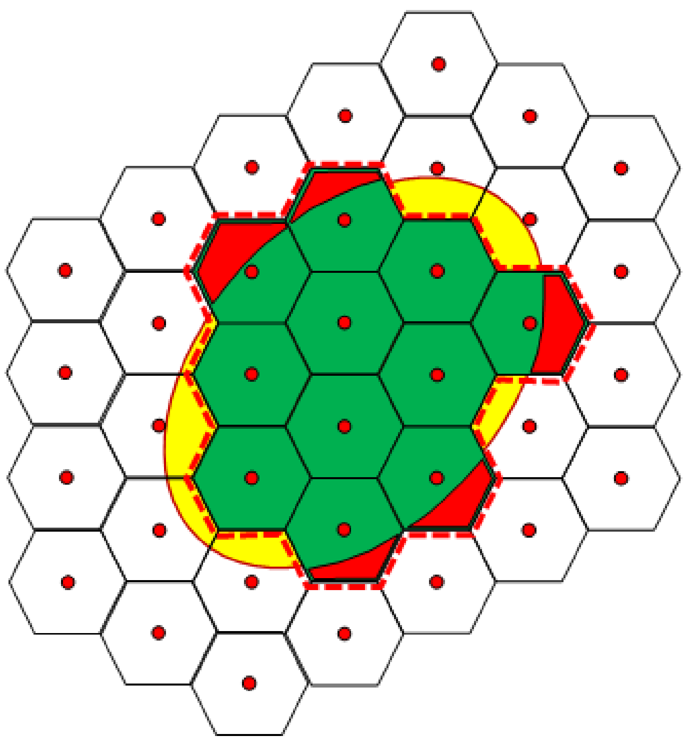


Figure 3: False Positives and False Negatives

Note that even though a mobile device is inside an alert area, there may be other reasons why a user does not receive an alert. For instance, the user's mobile device may be

configured to block some alert information. This may be due to the user opting out of receiving some particular types of alerts. A mobile device may also miss an alert if it is busy (e.g., a call is in session) or in a geographic area that has poor cellular reception. Such cases are not related to geotargeting accuracy, so they are not included in FN calculation.

2.2 Resources Consumed by WEA during Operations

From the perspectives of the CMSPs and their subscribers, WEA service consumes processing, bandwidth and energy resources in the gateways, network elements, wireline infrastructure, cell towers, radio resources and end devices. Potential impacts of these resource consumptions include: the need for extra capacities in the resources affected; additional delay and other performance degradations for WEA and other services using the resources; additional cost of energy; and reduction in the battery life of the mobile device.

Cellular networks are typically designed to get the maximum possible utilization of precious radio resources. Relatively less expensive wireline bandwidth and processing capacities in switches and routers in the infrastructure are more generously planned. Hence, the radio resources are more likely to be congested during heavy traffic loads than the wireline infrastructure resources. Thus, within the CMSP infrastructure, it is sufficient to focus only on the radio resource for a capacity analysis.

The battery in a mobile device becomes another critical resource when a subscriber is away from a charging mechanism during an emergency. Therefore, additional energy consumption due to WEA and its impact on the battery life become important for comparing potential geotargeting schemes. Communication and, to a lesser degree, the computing load on the mobile device are the main factors that impact energy consumption.

Resources other than the battery in each mobile device and the radio spectrum for air interface are not likely to be heavily utilized; hence, the impact of the additional demand from new WEA geotargeting schemes should be minimal.

2.2.1 Battery Usage in Mobile Devices

The WEA capability consumes energy in the mobile device, reducing the battery life. If the mobile device is in the broadcast area during an emergency, it receives the alert messages. Until the emergency is over, alert messages are repeated periodically. These messages are received by the mobile device, processed to determine whether to alert the subscriber and, if needed, converted to information for the subscriber. All of these steps consume energy. The frequency of repetition of these messages during an emergency and the amount of processing required for each message determine the impact on energy consumption. The complexity of the geotargeting scheme and subscriber controls directly affect the amount of communications and processing, and as a result, the energy consumption. The number of simultaneous emergencies being handled also has a significant impact because the frequency of messages increases with the number of simultaneous emergencies. An earlier analysis of the energy consumption for the existing geotargeting scheme showed relatively small additional energy consumption from WEA.[7]

If the location of the mobile device is important for the geotargeting scheme (as in ASLAT), then the CMSP network or the mobile device needs to implement a mechanism

that allows the mobile device to know its current location with appropriate accuracy. This mechanism may be device-based like the Global Positioning System (GPS), network-based with communication to the mobile device or a hybrid. The energy cost of providing the location information to the device can then be attributed to the geotargeting scheme, with the assumption that the geotargeting scheme was the only application using the location information when an alert was received.

2.2.2 Radio Resource Consumptions

Radio resources would be consumed by WEA messages and any additional messaging associated with geolocation. The contributing factors are very similar to those affecting the energy consumption in mobile devices, except that the resources involved are radio broadcast links between the CMSP infrastructure and mobile devices instead of battery usage.

Since the relatively expensive radio resources are sized to maximize utilization, added bursts of traffic can have a strong performance impact (e.g., additional delays, losses) on WEA and other cellular services.

If geolocation of the mobile device is needed for the geotargeting scheme chosen, additional radio downlink and uplink capacities between the CMSP infrastructure and the mobile device may be required. The specific geolocation scheme(s) used would determine the types of messages and their frequencies. The choice of the geolocation scheme(s) is constrained by the geolocation accuracy required, which in turn is determined by the geotargeting scheme selected.

2.3 Alerting Latency

Latency is an important performance metric for WEA and any other alert and warning system. It measures the total time from when the Alert Originator submits an alert until the alert is viewable by a cellular subscriber. When evaluating the performance of any alternative geotargeting mechanism, it is important to make sure that it does not cause significant delays in notifying the public at risk. Contention for the radio resources and processing in the mobile device (including the time to find its own location, if necessary) are likely to be major contributors to this latency.

2.4 Maintenance of Privacy

Some users are concerned when a service provider or a third party tracks their whereabouts and behavior. These concerns would increase when a geotargeting scheme requires and allows the network to obtain additional information about a mobile device's geolocation and movements. Alternative geolocation schemes may involve different amounts of information available to the network or third parties.

3 PERFORMANCE ANALYSIS OF THE CURRENT SYSTEM

This section focuses on the geotargeting accuracy of the current system. The main results presented in this section are later compared with ASLAT in Section 5. The impact of ASLAT on consumed resources and alerting latency is also analyzed in Section 5.

3.1 Impact of Cell Tower Selection

The geotargeting performance of the current WEA implementation is limited by the granularity of the RF footprint of the cell broadcast sites (as compared to the size of the target area). In order to send an alert message using cell broadcast technology, there are a number of steps involved in specifying the target area and the broadcast area. The relevant step within the federal domain is to map the actual target area into a location descriptor and send it to the CMSPs. Various descriptors can be used in CAP and CMAC messages for this purpose, but polygons provide a higher level of accuracy for arbitrary target areas than other descriptors. The step within the CMSP domains translates the location descriptor into the set of cell towers selected to broadcast the alert. The broadcast area is given by the RF coverage of all selected cell sites. Because of the cell-level granularity of the RF coverage in cellular networks, this step is the main contributor to FP and FN, and in general its contribution is higher as the ratio of cell coverage area to target area increases.

Figure 4 shows an example of three possible selection options for the set of cell towers. The target area is illustrated by the red oval in the figure, and the cell tower in each cell site is shown as a red dot. The set of cell sites selected in each option is shaded in blue.

Let “IC” be the set of “interior cells,” defined as the cells with RF coverage strictly inside the target area. Let “BC” be the set of “border cells,” which are the cells that are partially inside the target area. Finally, let “SC” and “SBC” be the sets of all selected cells and selected border cells, respectively. Referring to Figure 4, SC is the set of blue shaded cells in each option and SBC is the set of blue cells that intersect with the oval boundary. The set of interior cells, IC, is always included in SC. Cell selection strategies differ in the way SBC is selected for a given BC. The first option in the figure sets SC equal to IC as it is made up of all interior cells and excludes border cells. SBC is an empty set in this option. The second option includes some of the border cells in addition to the interior cells. Specifically, SBC consists of those border cells with towers that are physically located in the target area. This is the most common option currently being used by CMSPs for WEA messages. Finally, the third option includes any cell with an RF footprint that overlaps fully or partially with the target area (i.e., all interior and border cells). In this case, SC is simply the union of IC and BC, and SBC is equal to BC.

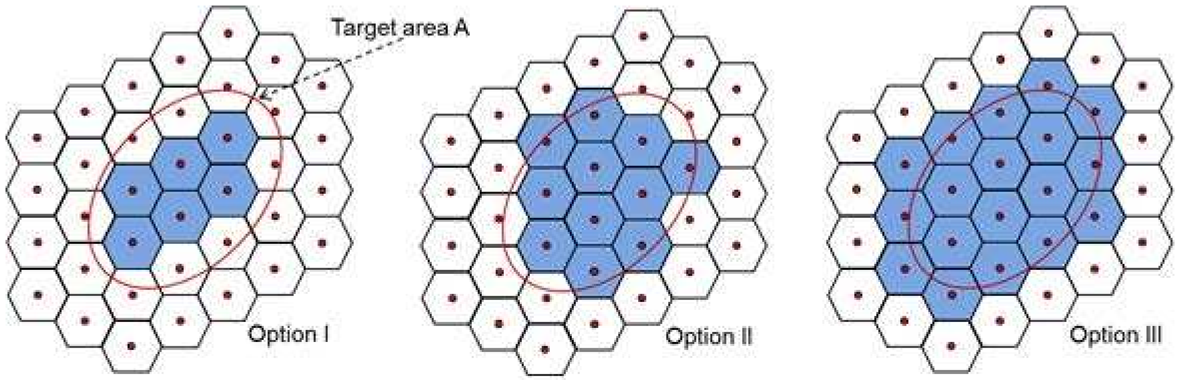


Figure 4: Cell Selection Options

In general, SC is the union of IC and SBC, with SBC ranging from an empty set as in option I (no border cell selected) to all of BC as in option III. If the set BC is made up of N border cells, there are a total of 2^N different choices for the set SBC (and thus for the set SC). In the example above, there are 12 border cells for the given target area, so there are a total of 4,096 different selection options, three of which are shown in the figure.

The particular choice of the set SBC directly impacts geotargeting performance in terms of FP and FN. FP and FN typically behave as illustrated in Figure 5 when the number of cell sites in SC and the resulting aggregate RF coverage increase. The origin of the horizontal axis corresponds to an extreme case where an alert is not broadcast to any cells. In this case, SC is an empty set, FP is zero and FN is one since none of the target area receives the alert. As SC starts to grow by including more and more interior cells, FN starts to decrease. As long as there are more interior cells to include, FP remains zero because the broadcast area remains strictly inside the target area. This is labeled as “Region 1” in the figure. At some point, P0, all of the interior cells are included, but no border cells are included (i.e., SC is equal to IC). After this point, FN can be reduced further only by increasing FP. This is shown in “Region 2” of the figure, where more and more border cells are included in SC until point PN, where all border cells are used in the broadcast (i.e., SC is equal to the union of IC and BC). Note that FN becomes zero at this point, assuming the entire target area is within the service area of the CMSP. Once PN is reached, SC can only grow further by including exterior cells, which increase FP. This is labeled as “Region 3” in the figure. There is no reason to operate in Region 3 with the current WEA architecture, since it reduces the geotargeting performance. However, as explained later in Section 4, a new architecture like ASLAT that uses mobile device location to determine whether to alert the user or not can benefit from operating in Region 3.

In the current WEA architecture, the geotargeting performance can be optimized by operating in Region 2 and carefully selecting the cell towers to be used for broadcast. There are a total of 2^N different choices for the selection of border cell towers, each resulting in a different SBC with different FP and FN. As mentioned previously, the most common cell tower selection method currently being used by CMSPs for broadcasting WEA messages relies on using the cell towers inside the target area (Option II in Figure 4). This option is just one of the 2^N possible options, and is denoted by SBCw in Figure 5.

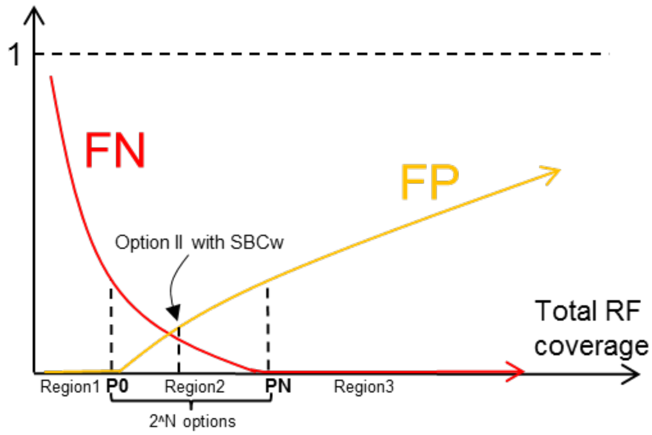


Figure 5: Typical FP and FN as a Function of Total RF Coverage

A natural question to ask is whether SBCw is the best choice or whether there is a more optimal SBC. In other words, the problem is finding SBC*, which is the best set of border cells to be used for alert delivery to a given target area. To solve for the optimal selection SBC*, the border cells will need to be characterized in terms of their exterior and interior areas with respect to a given target area. An objective function will need to be defined, such as minimizing FN while keeping FP smaller than some threshold, or minimizing a weighted combination of FN and FP. Selection of the objective function depends on the preference between non-zero FP and non-zero FN. Analysis can then be carried out to characterize the optimal solution and to devise an algorithm for deriving this solution. Finding an appropriate objective function for different types of alerts and processing complexity associated with finding exterior and interior areas of the border cells are open problems not discussed further in this document.

3.2 Analysis of Current WEA Geotargeting

3.2.1 Analysis Approach

The project team analyzed the performance of the current system to provide a baseline for evaluating the new ASLAT approach and other alternatives. The analysis was performed by generating random target areas in a county, estimating the actual broadcast areas and calculating FP and FN. The location and size of each cell site in the cellular network were calculated from a cell tower location database that was made available to the project team. This database contains the locations of cell towers in Jefferson County, Colorado. Each cell tower in the database is used by one or more CMSPs. Cell towers of five CMSPs are listed in the database.

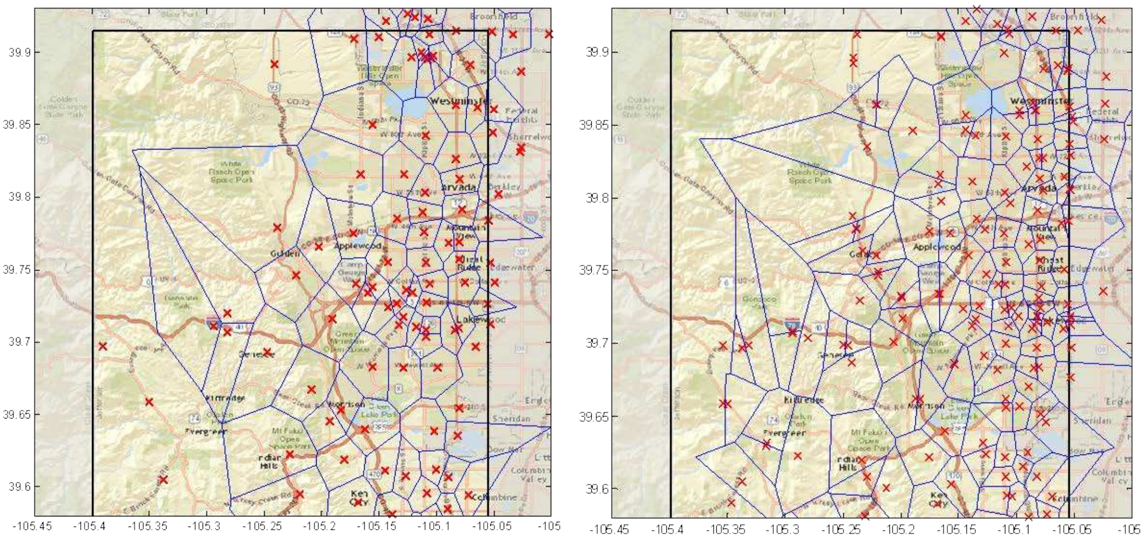


Figure 6: Cell Tower Locations and Cell Sites of Two CMSPs in Northern Jefferson County

Figure 6 shows the cell tower locations of two of the five CMSPs in northern Jefferson County. The location of each cell tower is shown by an “x” in the figure. The solid black rectangle is the county border. The figure also shows the estimated cell sites’ coverage areas (separated by solid blue lines) based on the cell tower location data. A cellular device typically searches for the strongest signal it can receive and registers with the cell tower transmitting that signal. The received signal strength is determined by many factors, including the transmit power and the distance to the cell tower. The transmit power of the cell towers in Jefferson County was not available to the project team; therefore, the geometry of the cell sites’ coverage areas were estimated by assuming equal transmit power at all cell towers. The estimated site coverage can differ from actual site coverage due to varying transmit power at different cell towers and other factors that affect radio signal propagation, such as buildings and terrain.

Target alert areas used in the analysis were randomly generated polygons. A computer simulation first selected the number of corners of the polygon randomly between four and eight, inclusive. Triangular regions (i.e., polygons with only three corners) and polygons with more than eight corners were excluded from the simulation to reduce the complexity. Then, the simulation selected the coordinates for each corner of the polygon such that the entire polygon lay inside Jefferson County. Finally, the simulation calculated FP and FN, assuming the generated polygon is the target area. This procedure was repeated multiple times with different polygons.

Two methods for selecting the set of broadcasting cell towers were analyzed in the simulation. The first method broadcasts an alert only to the sites whose cell towers are located inside the target area polygon (Option II in Figure 4). This method is illustrated in Figure 7 for the Jefferson County dataset and two different CMSPs. The figure shows a randomly selected polygon (i.e., the target area) with four corners. The broadcast area is the

union of all sites whose cell towers are inside the polygon. The intersection of the polygon with the broadcast area, shown as the blue-colored regions in the figure, is the correctly alerted region. The portion of the broadcast area that is outside the polygon, shown as the red-colored regions in the figure, is the FP region, which should not have been alerted. Finally, the colorless areas inside the polygon are the FN regions, which should have been alerted. These areas do not receive an alert with Method 1 because their cell towers are outside the polygon.

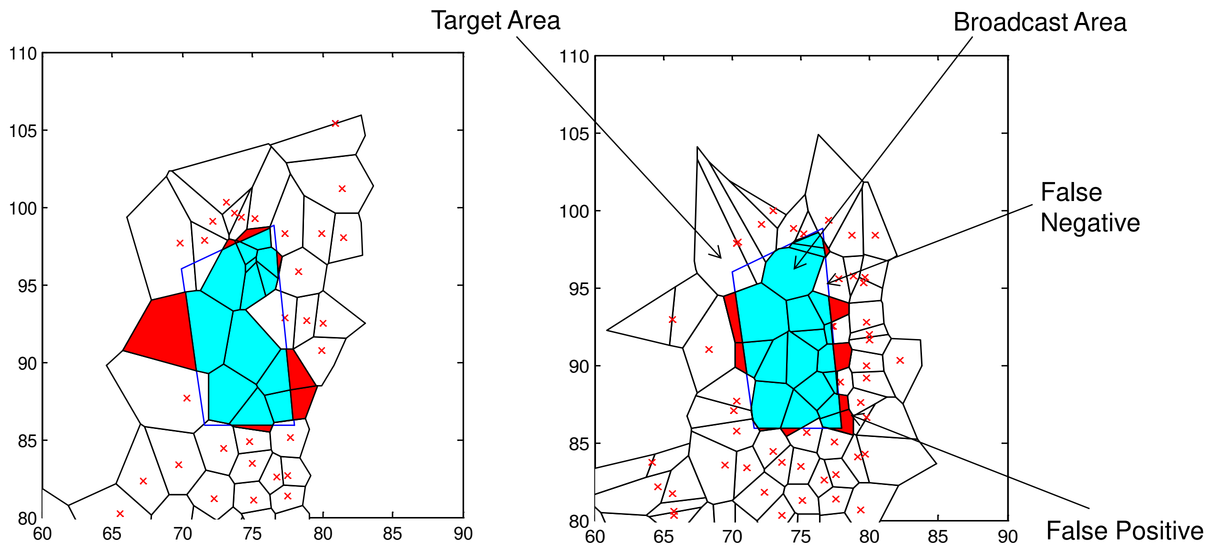


Figure 7: Illustration of FN and FP Areas for Two CMSPs using Method 1 (Only Cell Towers inside the Target Area Broadcast the Alert)

The second method analyzed in the simulation broadcasts an alert to all cell sites that intersect with the target area polygon (Option III in Figure 4). This is illustrated in Figure 8 for the Jefferson County dataset. In this case, the broadcast area covers the entire polygon, so there are no FN areas. However, FP areas are larger compared to Method 1, because some of the towers outside the target area transmit the alert in this case.

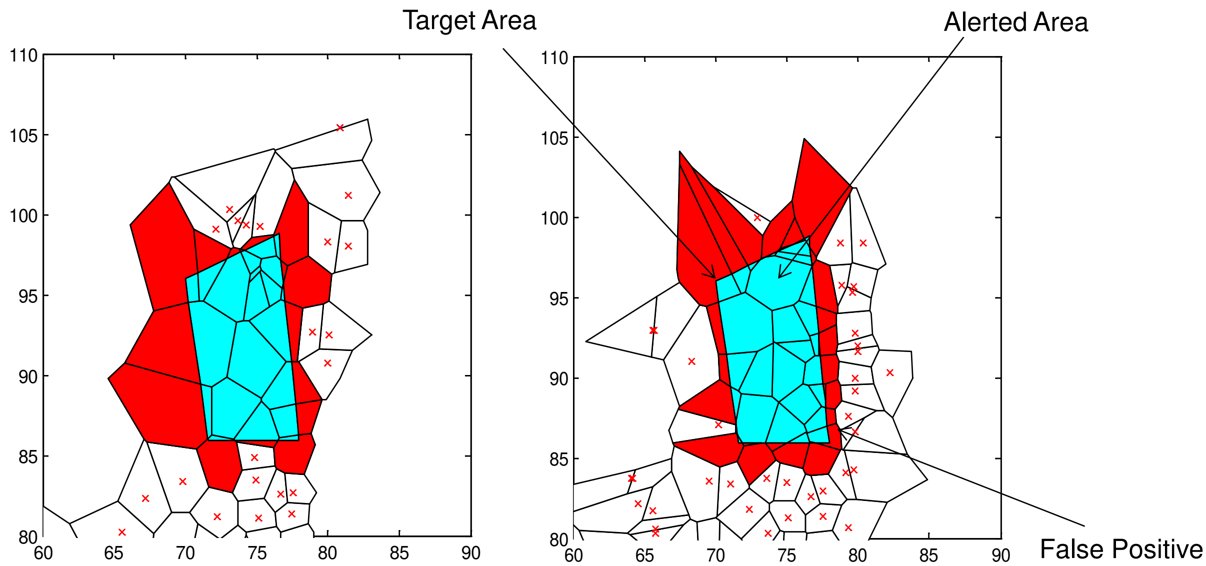


Figure 8: Illustration of FP Areas for Two CMSPs Using Method 2 (All Cell Sites that Intersect with the Target Area Receive the Alert)

3.2.2 Analysis Results

The simulation analysis explained in the previous section was repeated for 10,000 different polygons that lie in northern Jefferson County. The percentage of FP and FN in each CMSP network with Method 1, are shown in Figure 9 and Figure 10, respectively. The figures also show the average FP and FN curves, obtained by averaging across the CMSPs. Both of the displayed metrics decrease as the target area increases. On the other hand, both metrics exceed 20 percent for target areas smaller than 80 km^2 and exceed 40 percent for target areas smaller than 20 km^2.

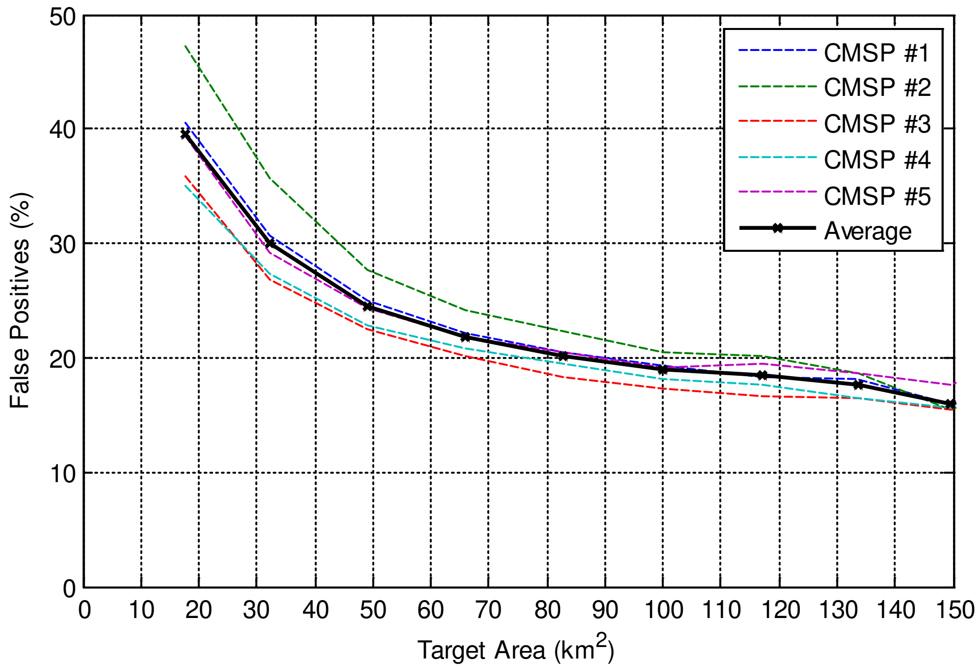


Figure 9: Percentage of FP with Method 1

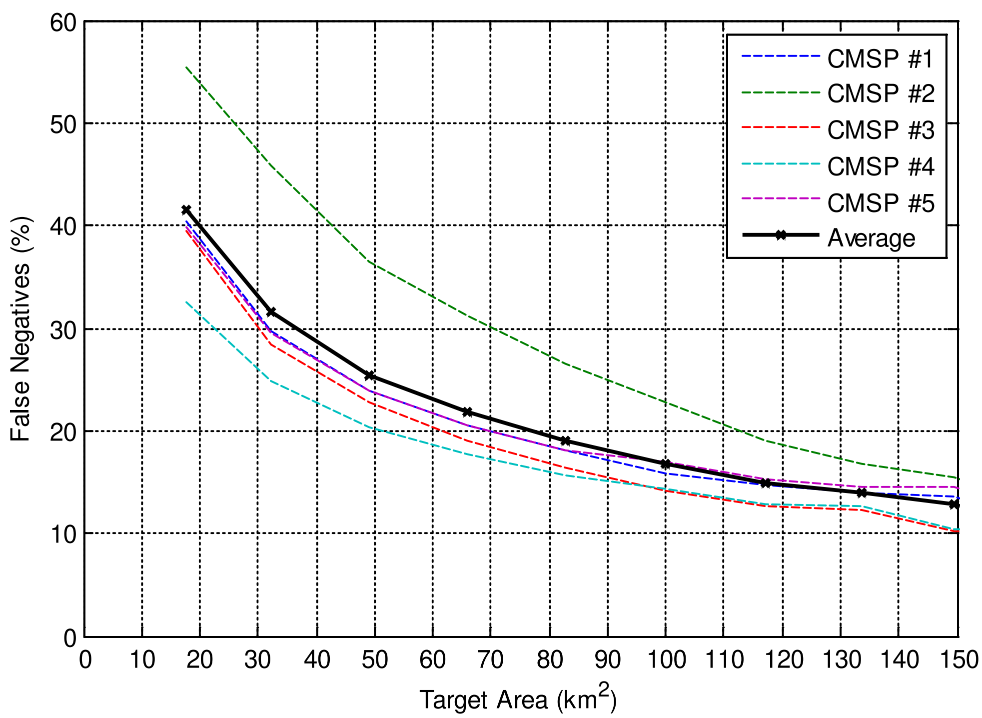


Figure 10: Percentage of FN with Method 1

The percentage of FP in each CMSP network with Method 2 is shown in Figure 11. FN (not shown) is zero with Method 2, because the broadcast areas always cover the target areas. On the other hand, Figure 11 shows that Method 2 has significantly higher FP than Method 1. On average, FP exceeds 50 percent for target areas smaller than 120 km^2 and exceeds 70 percent for target areas smaller than 20 km^2.

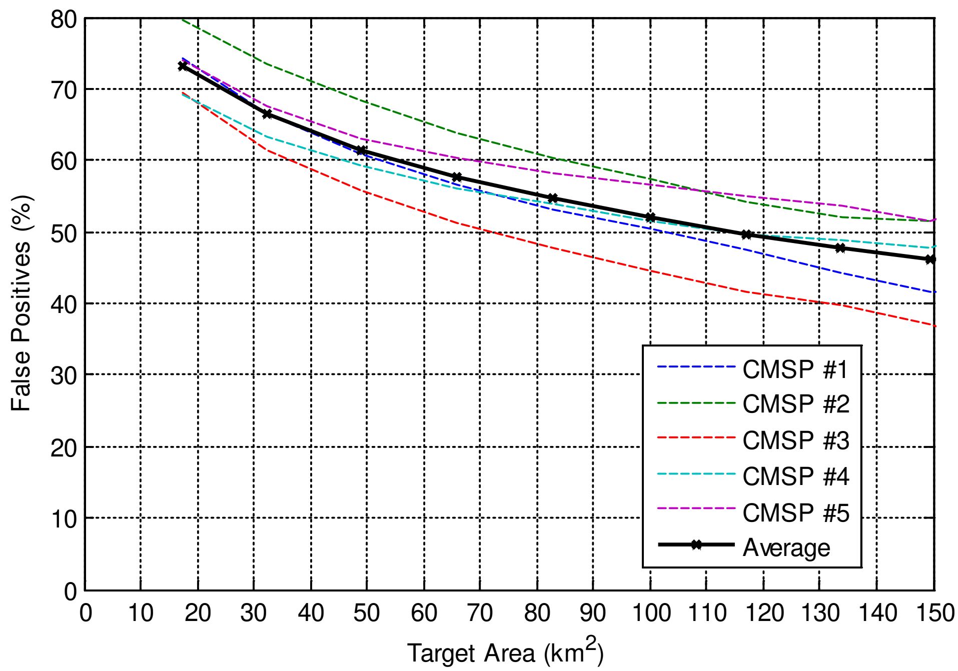


Figure 11: Percentage of FP with Method 2

3.2.3 Discussion

The simulation results shown in the previous section demonstrate limitations of the current system in terms of geotargeting accuracy. The granularity of the system is limited by the size and location of the cell sites. There is a tradeoff between FP and FN. If a CMSP uses only the cell towers inside a target area to broadcast an alert, then in general there will be regions in the target area that do not receive the alert (FN) and regions outside the target area that receive the alert (FP). On the other hand, if a CMSP broadcasts the alert to all cell sites that intersect with the target area, then FN is minimized, but FP increases significantly.

4 A NEW ARCHITECTURE WITH ENHANCED GEOTARGETING ACCURACY

4.1 Enhanced Geotargeting

As discussed in Section 3, an ideal alert and warning system would ensure that both FP and FN are close to zero. However, since the mobile device presents all received alerts to the users in the current WEA architecture, the granularity of the cell sites prevents reducing these metrics simultaneously. This section introduces the new ASLAT mechanism, which takes advantage of the increasing mobile device capabilities to obtain self-location information. Using the device's location awareness, ASLAT would enhance geotargeting capabilities of WEA beyond what is possible in the current architecture and provide much tighter controls over FP and FN.

There are three potential models for alerting the population in a given geographic area by cell broadcast:

1) Broadcast the message to the smallest area that adequately covers the target area (under constraints of cell broadcast coverage granularity), and let the mobile device alert the user whenever an alert message is received. This is the "push-to-user" model currently used by WEA.
2) Use the push-to-user model, but also include a clear description of the target area in the message. In this case, the device user can make the decision of whether he/she is indeed in the target area. We refer to this model as "push-to-user with user-selectivity," since it relies on the user to deal with the lack of accurate geotargeting. Current WEA messages are limited to 90 characters of text, so a clear description of the target area cannot be included in most cases.
3) Include a description of the target area as non-displayable information in the message, and let the mobile device decide whether to alert the user or not based on this information. In this case, the message can be broadcast to a wider area than the immediate target area. The mobile device receiving the message will first compare its current location with the description of the target area and then decide whether to alert the user or not. We refer to this model as "push-to-device with device-selectivity."

The ASLAT solution fits the push-to-device with device-selectivity model. In ASLAT, the alert message includes a descriptor of the target area as non-displayable information and it is broadcast to an area wider than the target area. When a mobile device receives the message, it compares its current location (and possibly information on its trajectory) with the target area and reacts in one of the following ways:

- If the device is not able to determine its location in a timely fashion, then it alerts the user by displaying the text information in the message.
- If the device is inside the target area or if it is approaching the target area, then it alerts the user by displaying the text information in the message.

- If the device is outside the target area, but the user is “related” to the target area, then the device warns the user by displaying the text information in the message.[1]
- If none of the above conditions is true, then the device does not alert the user.

The basic ASLAT mode of targeting requires the device to alert the user if the current location is within the target area. Figure 12 (a) shows a target area in the form of an ellipse with the green cells representing the ASLAT broadcast area. If the mobile device is inside the target area, then a received alert will be displayed; if not, then the alert will not be displayed. As discussed earlier, the red portion in Figure 12 (b) represents FP if the current WEA scheme is used in the same scenario. The red area also represents locations where a received alert with ASLAT will not be displayed to the user. Effectively, ASLAT removes the red area from the “alerted area” and eliminates FP. There is no FN in either case. In general, having the broadcast area larger than the target area keeps FN at zero, and FP is made zero by not displaying the alert to the user when the device is outside the target area.

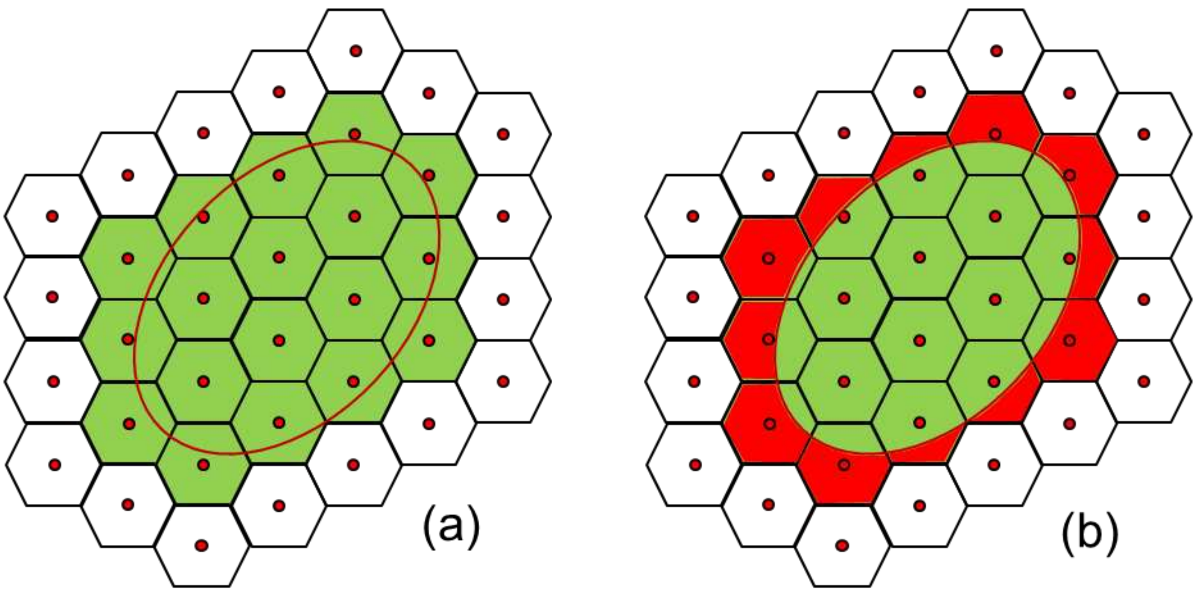


Figure 12: Broadcast area with basic ASLAT (a) and FP under current WEA (b)

ASLAT’s achieved gain in geotargeting accuracy comes at a cost, in particular due to mobile device self-localization and the additional resources required to transmit and process target area information. These resources include radio bandwidth for supporting communication, processing resources at the mobile device for localization algorithms and energy resources (battery life of the mobile device). Note that although FP was zero in the ideal case discussed in the above example, there are several reasons it may not be exactly zero in a more realistic scenario. These reasons include the inaccuracy in the mobile device’s location information and device movement. ASLAT may also increase the alerting

[1] This mode of alerting is called “related targeting” and is described in detail in Section 4.2.

delay due to additional processing and communications. These are discussed in Section 5 in detail.

4.2 Related Targeting

One problem with geographically targeted alerts is the lack of related targeting, which is sending messages to individuals who are not physically in the target area but have an interest in the target area. For instance, WEA was used when Superstorm Sandy hit the U.S. east coast in late October 2012. Several emergency messages were issued for blizzard warnings, flood warnings and evacuation notifications in various locations along the East Coast. While WEA was successful overall during the storm, some commentators expressed concern that "individuals who may be from the East Coast but were not physically in the storm-affected areas when alerts were being sent would not have received the messages."[8] The motivation behind this concern is that individuals should be notified when an alert message is issued to their home area, even if they happen to be outside that area at the time the alert message is broadcast. ASLAT would also enhance WEA with some related targeting capability as described in this section.

In general, for a given emergency event, the associated alert message can be targeted to a population that belongs to one of the following categories (see Figure 13):

- People physically present in the target area, referred to as “affected individuals” in the figure.
- People who were present in the target area when an initial alert was issued, but later relocated, possibly as directed by the initial alert. They are referred to as "relocated individuals" in the figure. Relocated individuals may still be interested in getting further alert messages regarding some locations inside the target area.
- People outside the target area, but with an interest in one or more locations in the target area, such as having relatives, property, business or other responsibilities in the target area. This category is referred to as “related individuals.”

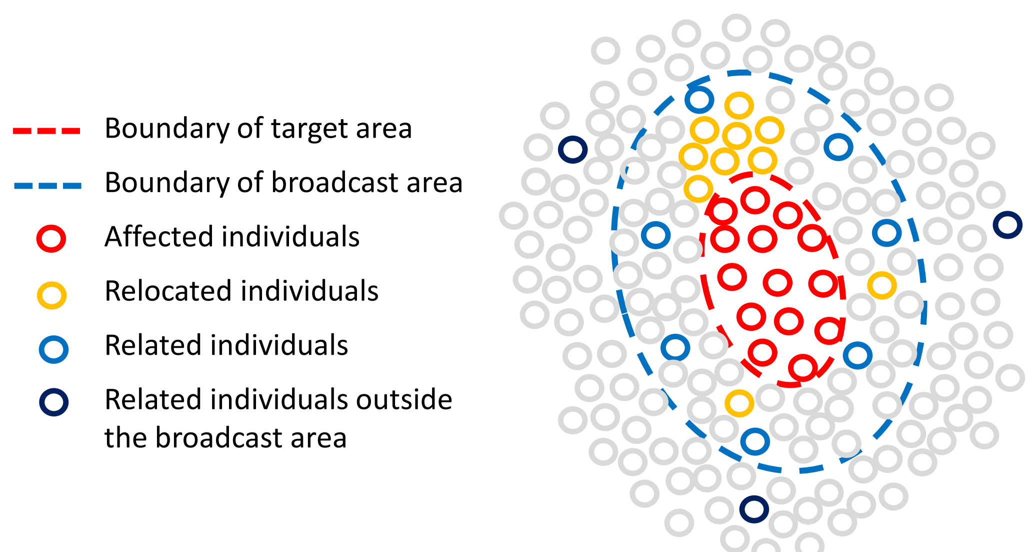


Figure 13: Illustration of Alerted Categories

ASLAT would enable WEA to send alert messages to relocated and related individuals in some vicinity of the target area. With ASLAT, a CMSP will broadcast an alert to a wider area than the target area, possibly including some cell sites that are strictly outside the target area. As described in the previous section, the message will include a description of the target area, and it will first be processed by the mobile device to determine whether the user should be alerted or not. To enable related targeting in ASLAT, users will have to configure their devices by specifying their locations of interest. This can be done through different means, such as a user interface with a map on the device. When a message is received, the device will make a decision based on its current location, as well as the user-specified locations of interest. If the device is outside the target area, but decides to alert the user, it can use a different type of tone and visual indicator than an alert received inside the target area. This would let the user better distinguish between messages alerting the user about an imminent danger and messages that are mainly providing information about another area.

Related targeting by ASLAT requires the broadcast area of a message to be wider than the target area. Consideration must be given to determining the size of the broadcast area relative to the target area. Relocated and related users will only receive alerts if they are inside the broadcast area. Choosing a wider broadcast area allows reaching a larger number of relocated and related users. However, widening the cell broadcast area would also increase the radio resource and battery consumption and may need to be limited.

5 PERFORMANCE ANALYSIS OF ASLAT

This section analyzes the performance of ASLAT and compares it with the performance of the current WEA geotargeting mechanism. The analysis includes geotargeting accuracy, resources consumed during operation, alerting latency and maintenance of privacy.

5.1 Geotargeting accuracy

5.1.1 Analysis Approach

The project team analyzed the geotargeting accuracy of ASLAT by developing a computer model. This is similar to the approach explained in Section 3.2 for the analysis of the current WEA geotargeting mechanism. The analysis was performed by generating random target areas inside a region corresponding to Jefferson County, Colorado, and estimating the actual broadcast areas. ASLAT analysis also modeled the capabilities of mobile devices in the broadcast area. Each simulated mobile device inside the broadcast area made an independent assessment of whether to alert the user based on its geolocation capabilities and estimated position relative to the target area.

The geotargeting accuracy analysis of ASLAT depended on the number of ASLAT-capable mobile devices with location services enabled. Data from several major CMSPs and a market survey were used to estimate these numbers.

5.1.2 Computer Model

The computer model assumed uniformly distributed WEA-enabled mobile devices over the simulated Jefferson County, Colorado, region. All of the simulated mobile devices were WEA-enabled, since mobile devices without WEA capability cannot receive or display an alert with or without ASLAT and therefore do not impact the relative performance of ASLAT compared to current WEA geotargeting. There were three types of WEA-enabled mobile devices in the computer model:

- *Legacy* mobile devices, which are mobile devices that do not have ASLAT capability.
- *No-location* mobile devices, which are mobile devices that have ASLAT capability and do not have location services (these have been disabled by the user). For example, a user can permanently disable the location services for all applications or not allow WEA/ASLAT to use the location services on the mobile device.
- *Other* mobile devices, which are mobile devices with ASLAT capability and with location services enabled for ASLAT use.

The percentage of *legacy* mobile devices among WEA-enabled mobile devices was estimated using current mobile device offerings of three major CMSPs.[42][43][44] According to this data, 90 percent of WEA-enabled mobile devices currently offered by three major CMSPs are smartphones. If ASLAT is adopted as the WEA geotargeting mechanism in the future, smartphones would support ASLAT as part of the phone's operating system or as a separate application. Therefore, it can be assumed that only "non-smart" phones, which are less than 10 percent of the WEA-enabled mobile device offerings, cannot have ASLAT capability. This percentage is expected to decrease as the market penetration of smartphones continues to increase.

The percentage of *no-location* mobile devices was estimated using the results of an existing survey conducted by Princeton Survey Research Associates International from March 15, 2012 to April 3, 2012.[45] One of the questions in this survey was:

"Have you ever turned off the location tracking feature on your cell phone because you were worried about other people or companies being able to access that information?"

Out of 1,954 cell phone owners, age 18 and older, who responded to this question, 19 percent answered "yes," 78 percent answered "no," and three percent answered "don't know." Based on this result, it can be expected that location services will be disabled in at most 19 percent of the WEA-enabled mobile devices and at least the remaining 81 percent will have the ability to find their geolocation.

ASLAT would work on WEA-enabled mobile devices, excluding the *legacy* and *no-location* devices. The percentage of mobile devices that can utilize ASLAT can be calculated from a range of *legacy* and *no-location* mobile device percentages as shown in Figure 14.

		WEA Phones with Location Services Off			
		30 %	**19 %**	**10 %**	**5 %**
WEA Phones without ASLAT	**10 %**	63 %	73 %	81 %	85 %
	5 %	66 %	77 %	85 %	90 %
	1 %	69 %	80 %	89 %	94 %
		WEA Phones Utilizing ASLAT Geotargeting			

Figure 14: Percentage of WEA-enabled Mobile Devices in the Computer Model

ASLAT geotargeting performance was simulated using a subset of the combinations of *legacy* and n*o-location* mobile device percentages shown in Figure 14. The computer model randomly assigned one of the three mobile device types (*Legacy*, *No-Location*, other) to each simulated mobile device. *Legacy* and n*o-location* mobile devices did not have access to their location information in the simulation, whereas all of the other (i.e., ASLAT-enabled) mobile devices learned their estimated location. In reality, some ASLAT-enabled mobile devices may not find their location in a timely manner, in which case they would behave just like a *Legacy* or *No-Location* mobile device (see Section 7.5). Target alert areas used in the simulation were randomly generated and the corresponding broadcast areas were determined as explained in Section 3.2. Each simulated mobile device behaved in one of the following ways:

- Mobile devices outside the broadcast area did not receive the alert message and did not notify the user.
- Legacy and no-location mobile devices inside the broadcast area received the alert message and always notified the user. If these devices were outside the target area, the notification increased the FP.
- Other (i.e., ASLAT-enabled) mobile devices inside the broadcast area received the alert message and obtained an estimate of their location. The simulation assumed 100-meter accuracy for all geolocation techniques. The location estimate of each mobile device was generated randomly within ±100 meters of its true location.
    - If the location estimate of an ASLAT-enabled mobile device is inside the target area, that device notified the user. This may be a correct notification or an FP depending on the true location of the mobile device.
    - If the location estimate of an ASLAT-enabled mobile device is outside the target area, that device did not notify the user. This is an FN if the true location of the mobile device is inside the target area.

The above simulation procedure was repeated many times with different target area polygons and different mobile device type assignments to calculate the average FP and FN.

5.1.3 Results and Findings

The FP and FN percentages obtained with the simulation analysis are shown in Figure 15 and Figure 16, respectively. Five different CMSPs with different cell tower locations in the Jefferson County area were analyzed by separate simulation runs. The figures show the combined percentages of the five CMSPs. Each plot in the figures shows a different mix of *Legacy* (Leg), *No-Location* (NoLcn) and ASLAT-enabled mobile devices. Figure 15 shows that FP would decrease significantly with ASLAT as the number of l*egacy* and n*o-location* mobile devices decrease. Figure 16 shows that FN would increase slightly with a decreasing number of *legacy* and *no-location* mobile devices. This result is expected because *legacy* and *no-location* mobile devices always display an alert to the user and therefore do not contribute to FN; however, there is a small percentage of FN with ASLAT-enabled mobile devices due to the inaccuracy in the location estimate. The percentage of ASLAT-enabled mobile devices that cannot find their location was not incorporated into the simulation analysis. This number depends on a number of factors, such as the availability of geolocation services at a given location and ASLAT configuration in the device, and would best be investigated by testing. A non-zero percentage of these cases would increase FP and reduce FN compared to the simulation results.

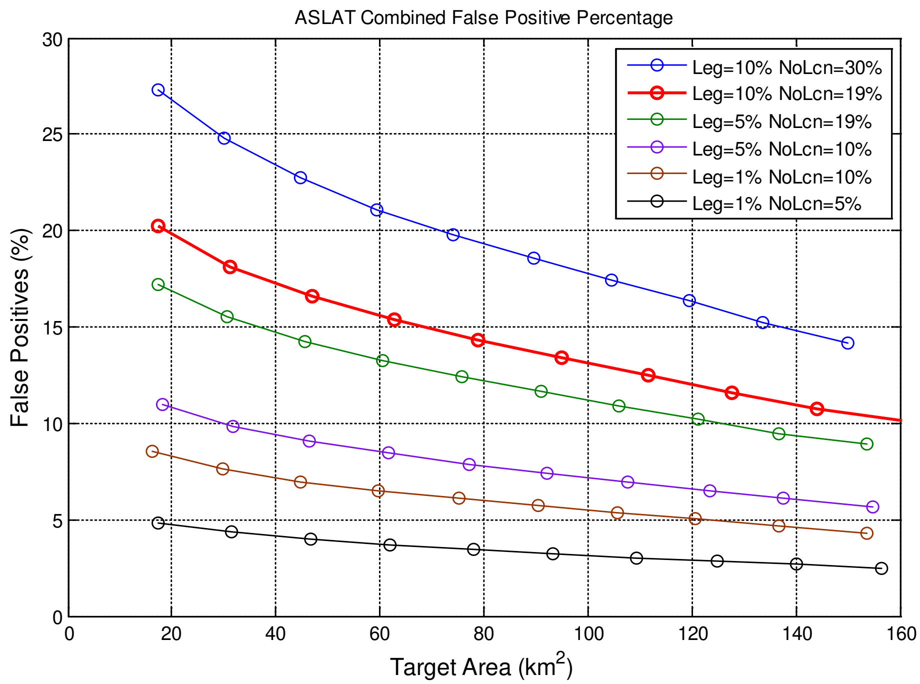


Figure 15: Combined FP Percentage with ASLAT

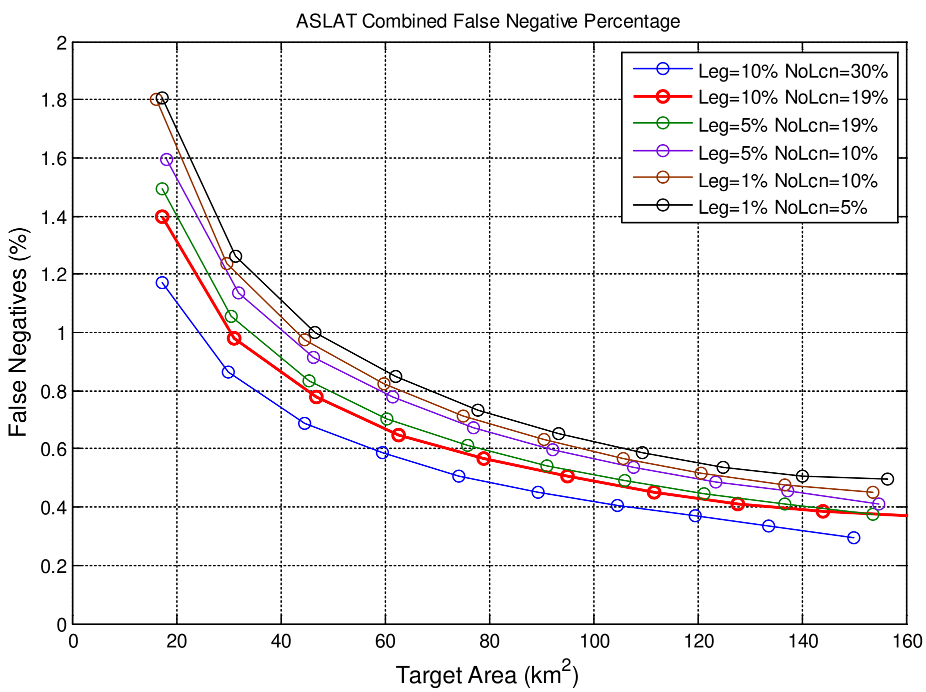


Figure 16: Combined FN Percentage with ASLAT

The geotargeting performance of ASLAT is compared with the geotargeting performance of the current WEA system in Figure 17 and Figure 18. The plots labeled as

“Method 1” and “Method 2” in the figures correspond to the current WEA system. As explained in Section 3.2, “Method 1” is broadcasting an alert only to the cellular sites whose cell towers are located inside the target area. “Method 2” is broadcasting an alert to all cell sites that intersect with the target area. Figure 17 shows that FP with ASLAT is less than the FP of the other two methods, and it would decrease further with the decreasing number of *legacy* and *n-location* mobile devices. The figure also shows that Method 1 has significantly smaller FP than Method 2.

Figure 18 compares the FN in ASLAT with the FN of Method 1. There is no FN with Method 2. The figure shows that ASLAT would reduce FN significantly compared to Method 1.

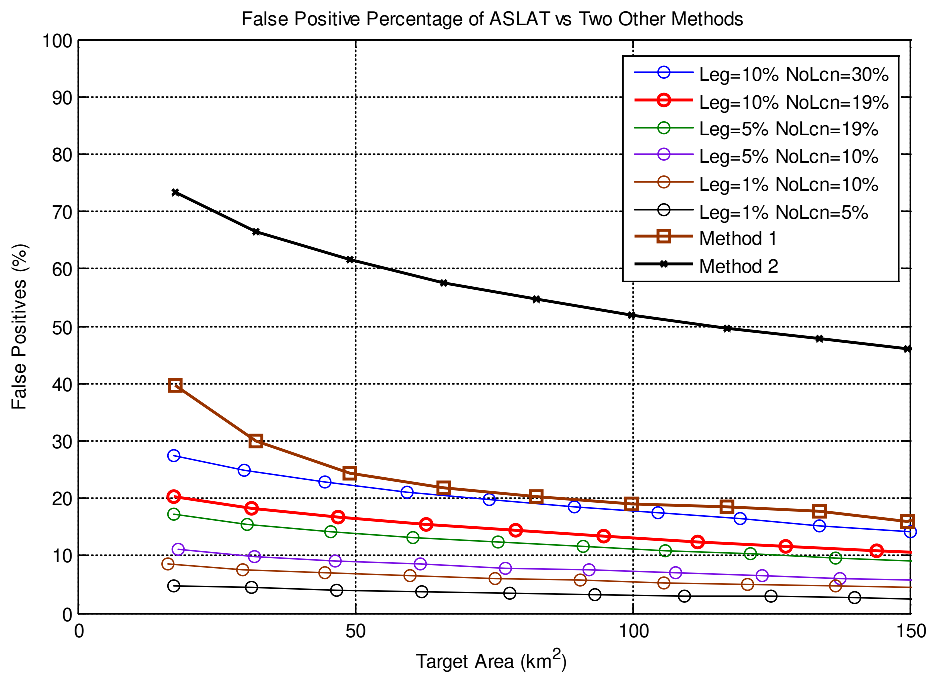


Figure 17: Comparison of FP in ASLAT and Current WEA

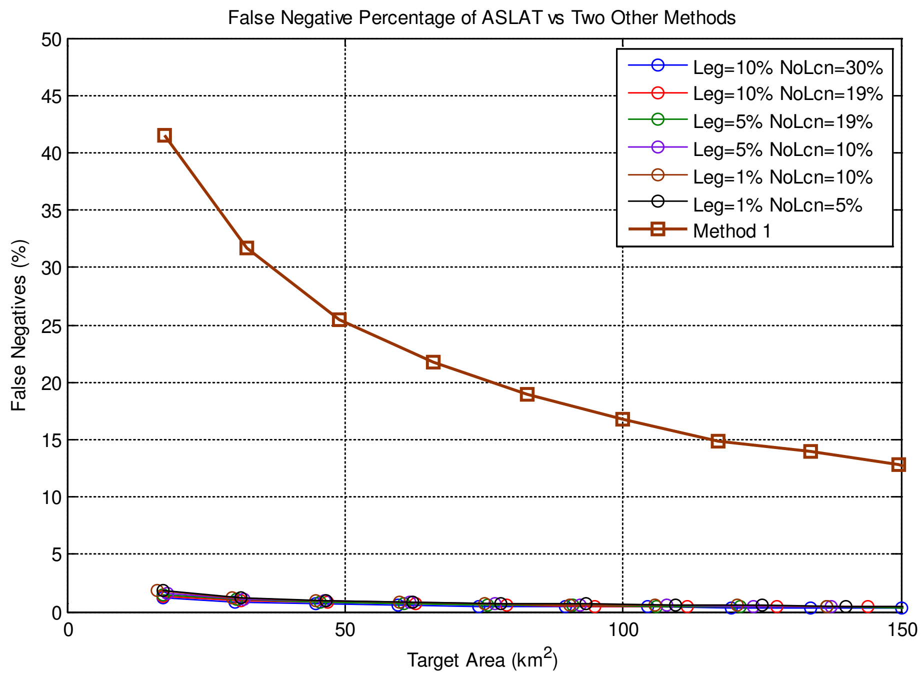


Figure 18: Comparison of FN in ASLAT and Current WEA

The results show that significant improvements in geotargeting accuracy can be achieved by ASLAT compared to current WEA geotargeting capabilities. Using Method 1 with the current WEA has a high FN, and using Method 2 with the current WEA has a high FP. Using ASLAT can simultaneously reduce both FP and FN.

5.2 Resources consumed by WEA during operation

5.2.1 Battery Power Consumption

ASLAT would require mobile devices to learn the current location and to receive target area information via cell broadcast. These activities would consume additional power from the battery of the mobile device. This section analyzes the battery power consumption impact of using GPS for ASLAT, using Wi-Fi to find device location for ASLAT and receiving the target area information.

5.2.1.1 Battery Power Consumption Due to GPS

GPS is one of the geolocation technologies ASLAT would use to learn the current location of the mobile device. ASLAT would turn GPS on only for a short interval to limit the battery power consumption and alerting latency. If the mobile device is not able to determine its geolocation within this interval, then it will turn GPS off and resort to default WEA behavior by displaying the new alert message to the user. Using GPS in ASLAT is discussed in detail in Section 7.

The project team analyzed the battery power consumption of ASLAT due to GPS by first measuring the power consumption in two mobile devices with different battery

capacities. Both mobile devices were chosen as Android devices because of the availability of applications that can control GPS and measure the power levels on a mobile device. GPS TEST v1.3.2 was used to start and stop the GPS module on the mobile devices, while POWERTUTOR II v2 was used to measure the GPS and the background power consumption. For each mobile device, power consumption measurements were recorded over 25 test cycles. Each test cycle consisted of a GPS ON state that lasted 60 seconds and a GPS OFF state that lasted 90 seconds. The difference between the power consumptions in GPS ON and GPS OFF states gives the power consumption due to GPS usage. Figure 19 shows the measured GPS power consumption in the two mobile devices during each test cycle. The average GPS power consumption was calculated from this data as 421 mW.

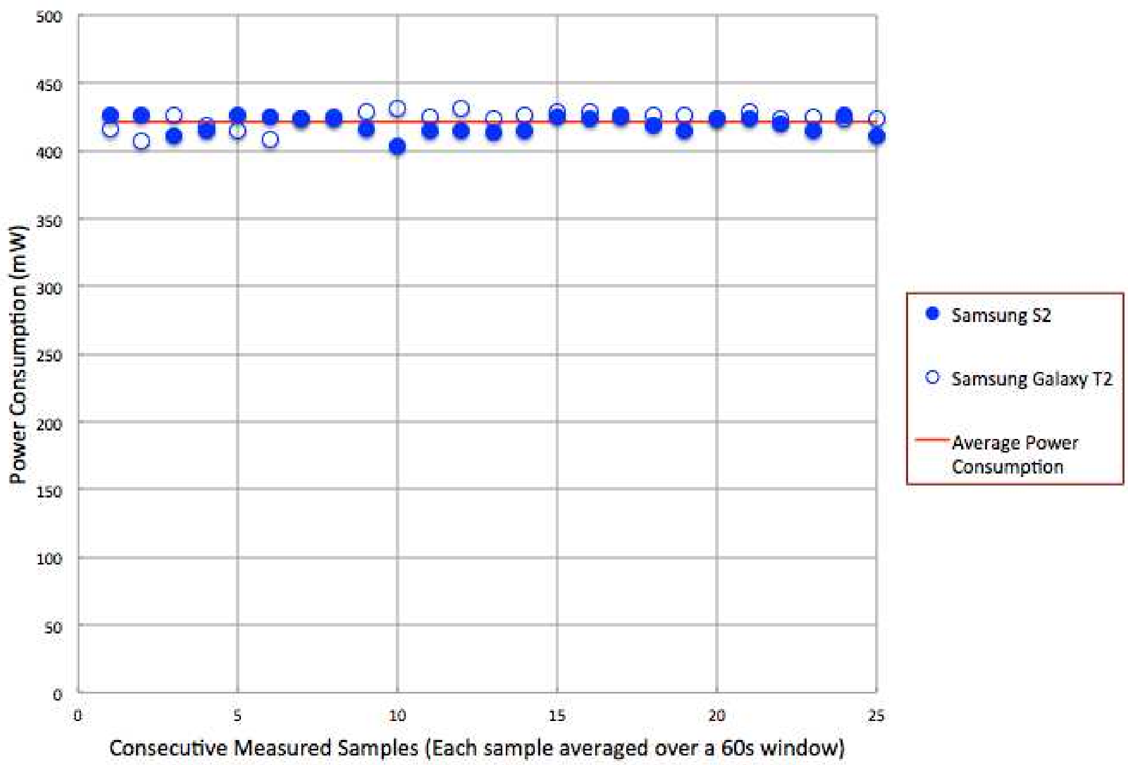


Figure 19: GPS Module Power Consumption

The ASLAT usage of GPS depends on the maximum duration of the GPS ON state. The analysis below assumes a 60-second maximum duration. Using shorter maximum durations would reduce both the battery impact and the alerting latency, but may increase the chance that the location of the device cannot be learned. The battery impact can be calculated as the percent battery capacity consumed for GPS access for each alert message:

$$Battery_{impact} = \frac{\left(Duration_{on} \times \frac{GPS_{pwr}}{Battery_{voltage}} \right)}{Battery_{capacity}} \times 100$$

Both mobile devices used in testing had 3.7 V batteries. One of them had a battery with 1800 mAh capacity, and the other had a battery with 4000 mAh capacity. Using these numbers in the above equation with a 60-second maximum GPS ON duration gives 0.11 percent battery impact for the 1800 mAh battery and 0.05 percent battery impact for the 4000 mAh battery.

This analysis shows that each GPS access by ASLAT would only consume about 1/1000 of a mobile device battery. This power would be consumed only when the mobile device receives a WEA message; therefore, it will not be significant among other typical activities of a mobile device.

5.2.1.2 Battery Power Consumption Due to Wi-Fi Proximity

The Wi-Fi proximity method, described in Section 7, is another technology ASLAT would use to learn the location of the device. In this case, the location of the Wi-Fi Access Point (AP) would be communicated to the mobile device during the Wi-Fi acquisition state and used by the mobile device as an estimate of its own location.

The battery power consumption of ASLAT due to Wi-Fi proximity was analyzed similarly to the GPS analysis described in the previous section. The same mobile devices were used to measure the power consumption due to Wi-Fi proximity. In this case, another Android application, DATUM MOBILE v2.8.0.22, was used to start and stop Wi-Fi access on the mobile devices. Power consumption in the mobile devices was measured again by POWERTUTOR II v2. In addition to the power levels, the duration of the acquisition state was also measured in each test cycle. Figure 20 shows the measured power consumption due to Wi-Fi activity during the acquisition state in 25 test cycles. The average Wi-Fi power consumption was calculated from this data as 681 mW. The average duration of the acquisition state was 13 seconds.

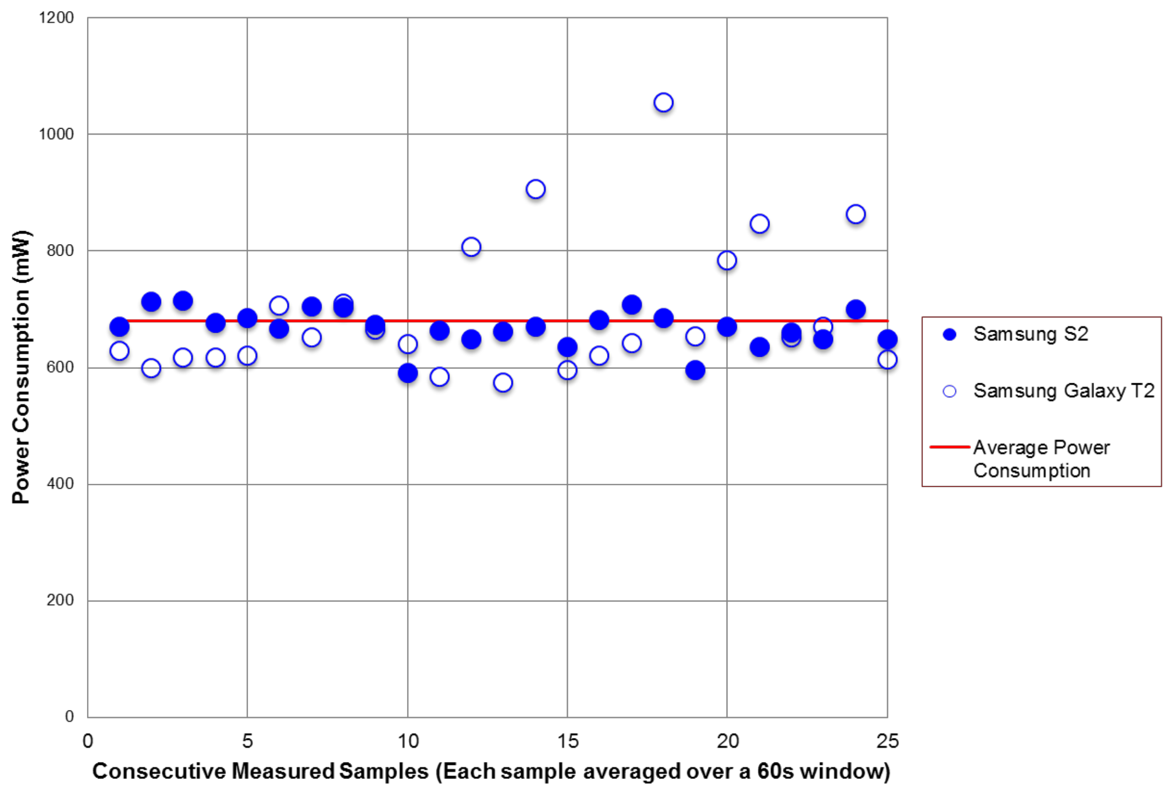


Figure 20: Wi-Fi Module Power Consumption

The battery impact of Wi-Fi proximity in ASLAT can be calculated using a formula similar to the one used for GPS. The only change in the formula is using the acquisition duration instead of the maximum GPS ON duration:

$$Battery_{impact} = \frac{\left(Duration_{acq} \times \dfrac{WiFi_{pwr}}{Battery_{voltage}} \right)}{Battery_{capacity}} \times 100$$

Using a 13-second acquisition duration in the above formula gives 0.04 percent battery impact for the 1800 mAh battery and 0.02 percent battery impact for the 4000 mAh battery. Once again, this power consumption will not be significant among other typical activities of a mobile device.

5.2.1.3 Battery Power Consumption Due to Additional WEA Pages

ASLAT requires mobile devices to receive target area coordinates in additional WEA cell broadcast pages. The additional pages increase the power consumption during message reception. The project team analyzed the power consumption due to receiving additional WEA pages using the results of an earlier analysis described in the Alliance for Telecommunications Industry Solutions (ATIS) Implementation Guidelines and Best Practices for GSM [Global System for Mobile Communications]/UMTS [Universal Mobile

Telecommunications System] Cell Broadcast Service.[7] The earlier analysis in the ATIS document calculated the percent increase in baseline mobile device activity as a result of adding cell broadcast support to the mobile device and as a result of receiving a WEA message.

Each page of cell broadcast is transmitted to mobile devices as a sequence of four Cell Broadcast Channel (CBCH) blocks. WEA also requires transmission of a schedule message to mobile devices. The analysis in [7] found that reception of each CBCH block increases the activity of the mobile device by 1.4 percent, and reception of the schedule message increases the activity by 1.4 percent. Each WEA message requires reception of one schedule message and four CBCH blocks, so the analysis concluded that a WEA message would increase the mobile device activity by 7 percent. The main findings of this earlier analysis are shown in the first three columns of Table 1.

CELL BROADCAST IMPACT ON MOBILE DEVICE ACTIVITY IN IDLE MODE	WEA (1 PAGE)		WEA with ASLAT (2 PAGES)			WEA with ASLAT (3 PAGES)		
	Activity	Increase wrt Baseline	Activity	Increase wrt Baseline	Increase wrt WEA	Activity	Increase wrt Baseline	Increase wrt WEA
Baseline Typical Case	0.269%	N/A	0.269%	N/A	**N/A**	0.269%	N/A	**N/A**
Cell Broadcast Support	0.273%	1.4%	0.273%	1.4%	**0**	0.273%	1.4%	**0**
WEA Message	0.288%	7%	0.303%	12.6%	**5.2%**	0.318%	18.2%	**10.4%**

Table 1: Battery Power Consumption Due to Message Reception

The analysis in [7] assumed one-page WEA messages (up to 90 characters), but it can easily be extended to the ASLAT case, which would require two- or three-page WEA messages. ASLAT would require the reception of the schedule message as in current WEA, so the only activity increase would be due to the reception of additional pages. Each additional page in ASLAT would require reception of four CBCH blocks, resulting in an activity increase of 5.6 percent. Therefore, the total activity increase for two- and three-page WEA messages would be 12.6 percent and 18.2 percent, respectively, as shown in columns five and eight of Table 1. These increases are with respect to the baseline activity level of 0.269 percent, so the mobile device activity during two- and three-page WEA message reception can be calculated as 0.303 percent and 0.318 percent, respectively. Finally, these numbers can be compared with the activity level for a one-page WEA message reception to find the increase due to ASLAT. As shown in columns six and nine of Table 1, ASLAT would require only 5.2 percent (two-page) or 10.4 percent (three-page) more power for message reception compared to current WEA.

5.2.1.4 Battery Power Consumption Summary

The analyses on the power consumption of using GPS for ASLAT, using Wi-Fi proximity and receiving additional cell broadcast pages with the target area information show that the increase in power consumption will be very small. Therefore, it is concluded that ASLAT will not have a significant impact on battery life.

5.2.2 Radio Resource Consumption

Transmission of additional cell broadcast pages for ASLAT would consume additional RF capacity. Different radio access technologies, such as UMTS and Long Term Evolution (LTE), allocate available RF capacity to various logical and physical channels. The term Radio Resource Unit (RRU) is used to denote the smallest block of resources used for this allocation. The RRU is a time slot for UMTS and a Physical Resource Block (PRB) for LTE. The analysis in this section calculates the number of RRUs required to transmit WEA pages in UMTS and LTE and compares these with the total number of available RRUs to determine the radio resource consumption.

5.2.2.1 Radio Resource Consumption in UMTS

UMTS broadcasts a WEA message using the Common Traffic Channel (CTCH), which is transmitted through the Secondary Common Control Physical Channel (S-CCPCH). The frame structure of S-CCPCH is shown in Figure 21 and taken from [46]. Each 10 ms radio frame is divided into 15 time slots. Each time slot carries 72 data bits, excluding the Transport Format Combination Indicator (TFCI) and Pilot overhead.

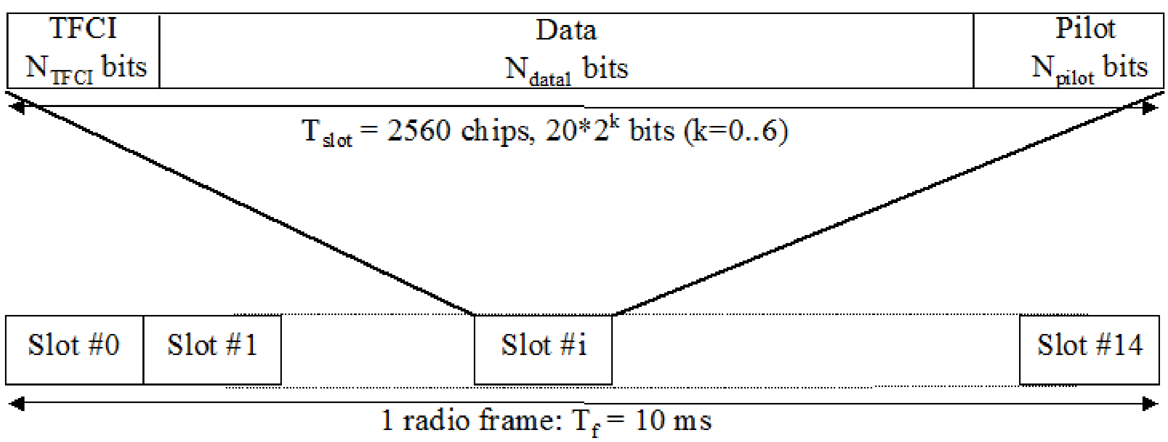


Figure 21: S-CCPCH Frame Structure

CTCH processes WEA data as transport blocks of 360 bits. After channel coding, each transport block becomes 1140 bits and is then mapped onto S-CCPCH time slots.[47] Each WEA page requires two CTCH transport blocks, resulting in 2,280 bits; therefore, it is mapped to 32 time slots.

There are 1,500 time slots available during each second. Therefore, each WEA page consumes 2.1 percent of the time slots measured over a second. If the WEA broadcast is repeated every two minutes, then the average time slot consumption by each WEA page will be 0.02 percent over the duration of an alert. A two-page WEA message and a three-

page WEA message will consume about 0.04 percent and 0.06 percent of the radio resources in UMTS, respectively.

5.2.2.2 Radio Resource Consumption in LTE

LTE broadcasts WEA messages using the Broadcast Control Channel (BCCH), which is mapped to the Physical Downlink Shared Channel (PDSCH). Each WEA message is transmitted inside a System Information Block 12 (SIB12) through PDSCH.

The LTE frame structure shown in Figure 22 is taken from [48]. Each 10 ms radio frame is divided into 20 time slots. Each time slot has a duration of 0.5 ms and contains 600 Orthogonal Frequency Division Multiplexing (OFDM) subcarriers (assuming a 10 MHz LTE system). In LTE, a PRB is the smallest unit used in resource allocation, which consists of 12 OFDM subcarriers inside one time slot. In a 10 MHz LTE system, there are 50 PRBs every 0.5 ms.

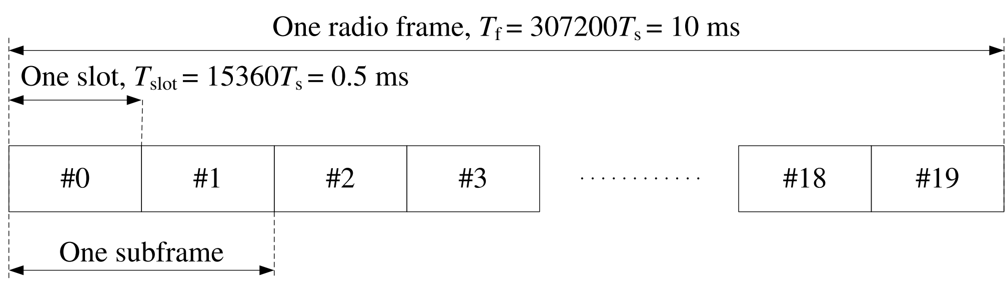


Figure 22: LTE Frame Structure

WEA messages are processed as SIB12 data using transport blocks of 6,144 or more bits.[49] After channel coding, each WEA page becomes 2,184 coded bits. SIB12 data uses Quadrature Phase Shift Keying (QPSK) modulation. Each QPSK symbol carries two encoded bits and each OFDM subcarrier in one time slot can transmit seven QPSK symbols. Therefore, each WEA page requires 2184 / (2 x 7 x 12) = 13 PRBs.

There are 100,000 PRBs available during each second. Therefore, each WEA page consumes 0.013 percent of the PRBs measured over a second. If the WEA broadcast is repeated every two minutes, then the average PRB consumption by each WEA page will be about 0.0001 percent over the duration of an alert. A two-page WEA message and a three-page WEA message will consume about 0.0002 percent and 0.0003 percent of the radio resources in LTE, respectively.

5.2.2.3 Radio Resource Consumption Summary

The analysis of radio resource consumption in UMTS and LTE networks shows that transmitting one or two additional WEA pages would have negligible impact to radio resources. This result is expected, since each additional WEA page of 88 bytes transmitted every two minutes requires an average data rate of only 6 bits/second, which is a very small rate compared to typical data rates used by other cell phone applications in UMTS and LTE.

5.3 Alerting latency

An ASLAT-enabled mobile device needs its location to determine whether it is inside or outside the target area of an alert. When the mobile device receives a new alert but does not know its current location, it will use a variety of geolocation techniques to learn its location. This process introduces an additional delay before the user is alerted. As described in Section 7.5, ASLAT limits this delay by using a timer. If this timer expires before the location can be found, the alert is displayed to the user by default. Therefore, the maximum additional alerting latency introduced by ASLAT can be controlled by this timer setting. Using a small timer value would reduce the maximum latency, but it would also reduce the chance that the device can learn its location before the timer expires.

5.4 Maintaining privacy

Section 7 discusses various geolocation technologies applicable to ASLAT. Some of these technologies require disclosing the location of mobile devices and therefore may cause privacy concerns. ASLAT can operate with geolocation technologies that maintain user privacy. These geolocation technologies do not send the location of mobile devices to the cellular network or third-party service providers. However, if the user has explicitly consented to share information with some third-party location services, ASLAT can make use of these services as well.

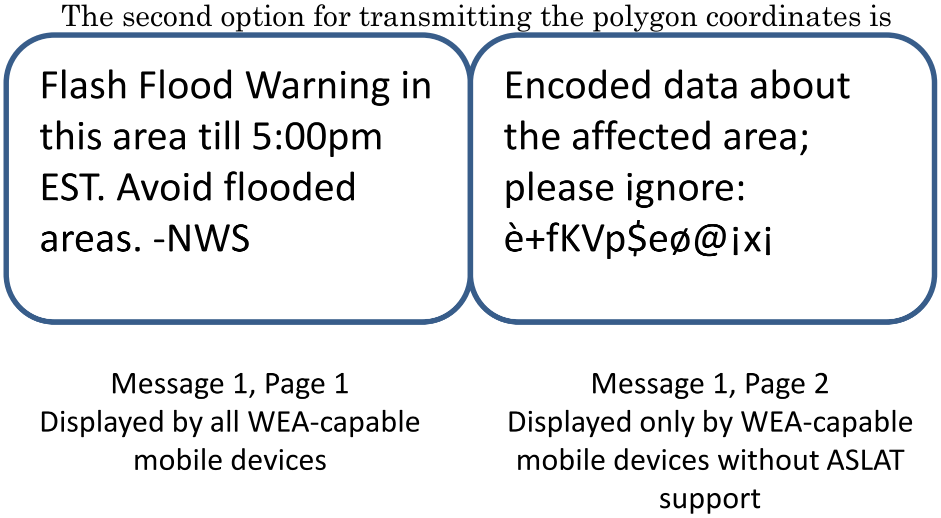
6 CELL BROADCAST SERVICE WITH ASLAT

The main prerequisite for the ASLAT concept of operations is transmitting the target area to the mobile device in the form of a polygon, so that the mobile device can decide whether to alert the user or not. Polygon information can be compressed during transmission to conserve cell broadcast resources. ASLAT also allows some flexibility in the selection of the broadcast area, and makes services like related targeting possible. These are discussed in detail in the remainder of this section.

6.1 Polygon Transmission

There are two potential options for transmitting the coordinates of the target area polygon to the mobile device. The first option is transmission within the same cell broadcast message. In this case, the polygon coordinates are transmitted in the cell broadcast message that also carries the alert text. The alert text is broadcast in the first page of the cell broadcast message, and the polygon coordinates are broadcast in the subsequent page(s). This option is readily supported by the existing cell broadcast standards. The only potential drawback of transmission within the same message is that mobile devices without ASLAT support will display polygon coordinates to the user as illegible text. This issue can be partially mitigated if polygon information is preceded by a note that asks the user to ignore the following portion. Polygon transmission within the same message is illustrated in Figure 23. The illegible text at the end of Page 2 in the figure represents a polygon, and will be described later in this section.

Figure 23: Polygon Transmission within the Same Message



The second option for transmitting the polygon coordinates is to send the coordinates in a separate cell broadcast message referencing the one with the alert text, as illustrated in Figure 24. In this case, a new message format can be defined for polygon data, so that a mobile device without ASLAT support ignores that message and uses only the one with the alert text. However, this option requires significant changes to cell broadcast standards, including the definition of a new message format and the definition of a referencing mechanism among cell broadcast messages.

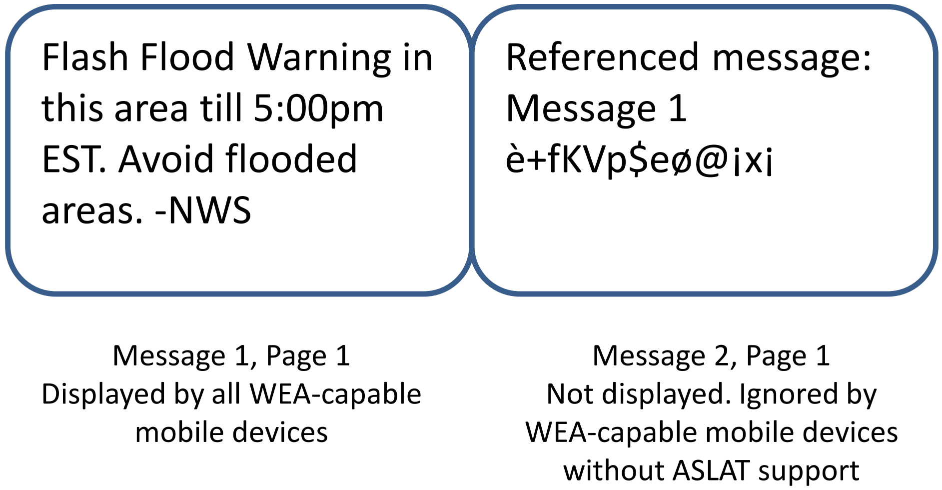


Figure 24: Polygon Transmission in Separate Message

Implementing the required changes for polygon transmission in a separate message would increase the cost and complexity of ASLAT deployment. Therefore, the first option is preferred in this paper, where polygon data is transmitted in the same cell broadcast message with the alert text.

6.2 Polygon Compression

WEA supports polygons with as many as 100 vertices. Each vertex is represented by a pair of decimal numbers that specify the latitude and longitude of that vertex. A polygon with 100 vertices may require more than 1,000 characters in uncompressed text format. This polygon data can be compressed to much smaller sizes using binary formats, so that cell broadcast resources are utilized more efficiently. Furthermore, unless compression is used, mobile devices without ASLAT support would display all these numbers to the user, which would be confusing to many people. Compression reduces the length of the displayed data in these devices, which may be more acceptable.

There are many alternatives for polygon compression, and a thorough investigation of the best option is beyond the scope of this document. However, the project team developed a binary polygon compression algorithm and verified that its compression performance is adequate for ASLAT.

The compression algorithm assumes that accuracy with two decimal places in latitude and longitude will be sufficient for ASLAT. This assumption is based on current National Weather Service (NWS) practices, which use only two decimal places in polygon coordinates for all NWS alerts. The NWS also limits the number of vertices in a polygon to a maximum of 20. If more accuracy than two decimal places in coordinates would be required for some alerts, then the compression algorithm can be extended to handle a variable number of decimal places.

The compression algorithm developed by the project team uses a differential encoding method to convert polygon coordinates to binary format. The latitude and longitude of the first polygon point are converted to binary directly. For the remaining polygon points, the algorithm first calculates the difference in latitude and longitude relative to the previous

polygon point, and then it converts these differences to binary format instead of the latitude and longitude values themselves. For most polygons, differential encoding substantially reduces the number of bits required to represent the coordinates. Details of the polygon compression algorithm are explained in Appendix A.

The performance of the compression algorithm was tested using a set of actual NWS alert polygons. There were 67 different polygons in the set, with four to 20 vertices. The original comma-separated representation required 64 to 272 characters (56 to 238 bytes) per polygon. Each of these polygons was compressed by the compression algorithm. Figure 25 shows the compressed and uncompressed sizes of the polygons. As seen in the figure, the algorithm compresses all polygons to less than 45 bytes. Figure 26 shows the compression factor achieved by the algorithm as a function of the number of polygon points. The algorithm was able to compress all polygons to 13.7 to 21.4 percent of their original sizes.

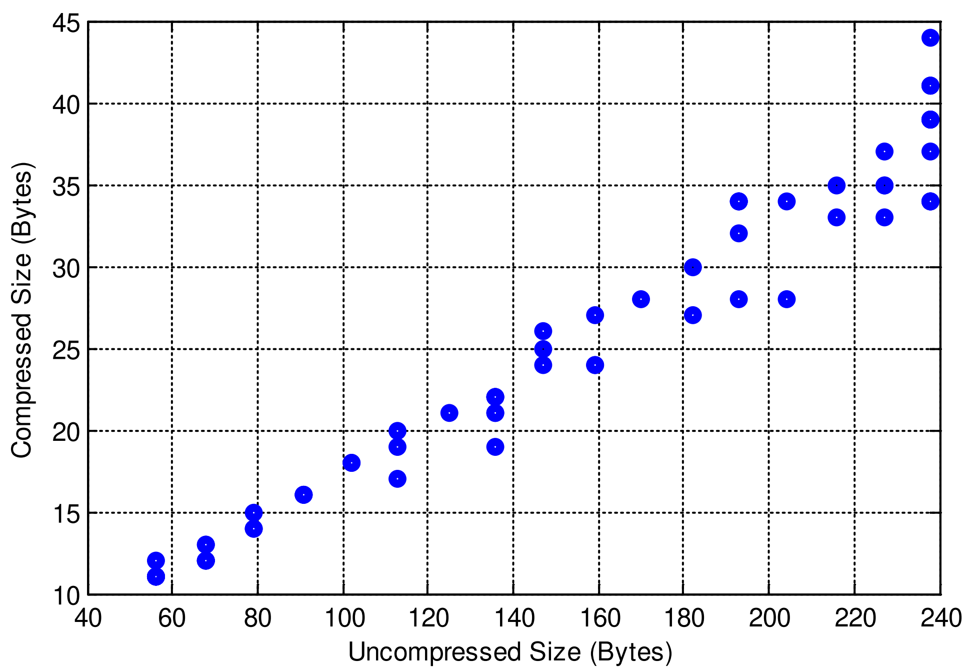


Figure 25: Compressed vs Uncompressed Polygon Sizes

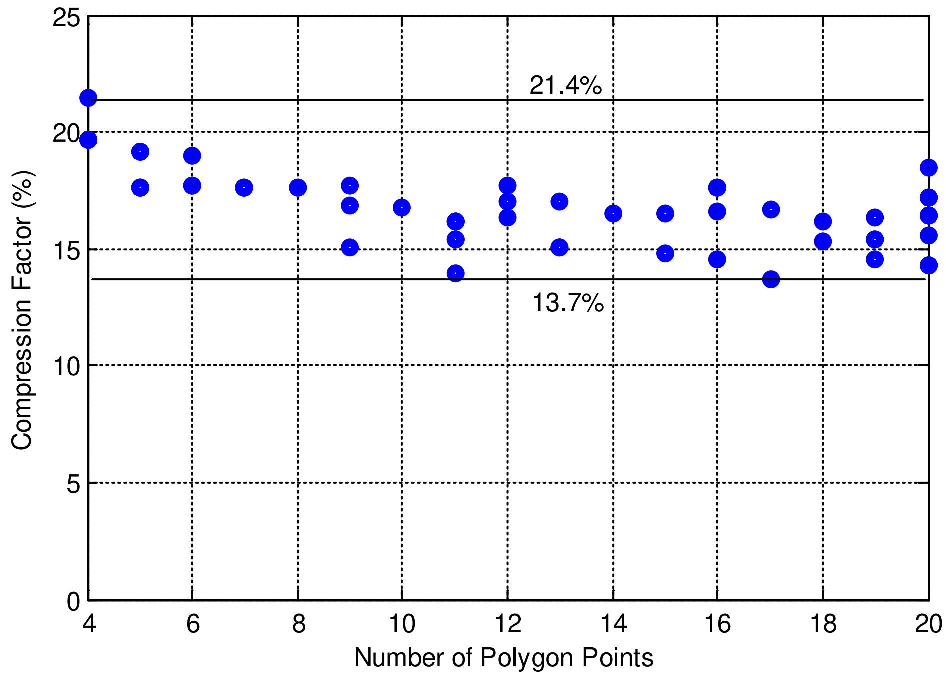


Figure 26: Compression Factor Achieved by the Algorithm

These results show that simple algorithms can compress most polygons into a single page of cell broadcast message. Polygon information can then be sent to mobile devices without extensive use of RF resources. Larger compression ratios may be possible by using more complex algorithms, but there is no apparent need to increase compression complexity any further.

6.3 Determination of Broadcast Area

ASLAT allows flexibility in selecting the broadcast area of an alert. Conceptually, a service provider can broadcast an alert to an arbitrarily large area covering the target area because the alert will only be displayed on mobile devices of the users inside the target area. However, in practice, there are several limitations when choosing an arbitrarily large broadcast area. The first limitation is due to mobile devices without ASLAT support. Since these devices will display all received alerts to the user, FP will increase with increasing broadcast area.

The second limitation on the size of the broadcast area is due to available geolocation technologies. As discussed in Section 7 in detail, there are many geolocation technologies that let the mobile device find its location, but all of them have their limitations. As a result, it is always possible that a mobile device cannot determine its location in a timely manner even if it supports ASLAT. In this case, the mobile device will default to displaying the received alerts to the user, and this will cause an FP if the mobile device is outside the target area.

The third limitation is that an efficient mechanism requires each mobile device in the broadcast area to calculate its geolocation when an alert arrives and then decide if the alert should be reported to the user. This process consumes battery and processing in the mobile device. A larger area will affect more mobile devices.

Finally, radio resource usage is also a limitation on the size of the broadcast area. A service provider may utilize the cell broadcast channel for services other than WEA. Increasing the WEA broadcast area would consume more of this limited resource and may cause conflicts with other services.

The above constraints on the size of the broadcast area should be weighed against the potential benefits of a large broadcast area. One such benefit is providing a related targeting service to the population as described in Section 4.2. As the broadcast area is increased, people will be able to receive alerts about a location of interest from farther distances. For instance, if the service provider chooses to broadcast an alert to the entire state that contains the target area, then people interested in alerts about a specific location will be able to receive those alerts as long as they do not leave the state.

Another benefit of a large broadcast area is establishing a “guard zone” around the target area. A mobile device in the guard zone will receive the alert, but will not alert the user immediately. If the device later detects that the person is moving toward the target area, then it may decide to alert the user. The guard zone concept can be especially useful for people driving on highways toward the target area. Without a guard zone, such people may not receive an alert before they are well inside the target area boundary, putting them at risk. On the other hand, if such a guard zone is implemented, then people moving toward the target area can be alerted even before they reach the target area, allowing them to change course or turn back.

Selection of the broadcast area for ASLAT should be at the discretion of each service provider, as is the case with WEA today. Initially, the broadcast areas can be small and just cover the target areas, which will limit FP due to mobile devices without ASLAT support. As market penetration of ASLAT-capable mobile devices increases and using geolocation services becomes more common, service providers may increase the size of the broadcast areas, offering the benefits of related targeting and guard zones to their customers.

7 GEOLOCATION AND ASLAT ALERT FILTERING

Section 4 introduced the key ideas in ASLAT. Upon receiving an alert via cell broadcast, the mobile device retrieves the description of the polygon target area from the message. The ASLAT algorithm then determines whether the mobile device is located in the polygon target area or not; if it is, the user is alerted and if it is not, the user is not alerted, except when related targeting applies, as described previously. As was shown in Section 4.1, the FP and FN are both zero if the mobile device's knowledge of its own geolocation is exact and the broadcast area covers the entire target area. Inaccuracy in geolocation will lead to some nonzero FP and FN.

The mobile device's geolocation is critical to the geotargeting accuracy of ASLAT. For ASLAT to be feasible to deploy and use, the techniques used to provide geolocation information to the mobile device should have the following characteristics:

- Accurate enough to keep FP and FN small;
- Low latency so the alert is not delayed beyond its usefulness;
- Low incremental cost of development and deployment (mobile device and network);
- Minimal increase in the utilization of radio resources;
- Zero or minimal impact on the subscriber bill;
- Minimal reduction in the battery life; and
- Minimal additional privacy concerns.

The above characteristics, in effect, define the metrics for comparing various geolocation techniques and assessing their suitability for ASLAT.

Providing a mobile device with its geolocation is a major undertaking. Fortunately, the infrastructure and algorithms for geolocation capabilities have already been developed and deployed for other important applications. They are being enhanced continually in terms of accuracy, latency and cost. If these developments and deployments can be leveraged for ASLAT, then the incremental cost could be minimal. Thus, it is important to assess the suitability of the existing technologies for ASLAT. Two of the most important applications driving the deployment of the mobile device geolocation capabilities are:

- Automobile or pedestrian navigation, typically using GPS; and
- Locating E911 callers, mandated by the FCC.[8]-[13]

Various types of geolocation techniques [18]-[27] have been developed to support these two applications. Based on where the measurements and calculations are carried out, the techniques can be classified as follows:

- Mobile-device-based measurements and calculations with passive assistance from satellite constellation

GPS-based geolocation is the key technology in all navigation applications using cellular mobile devices, as well as standalone navigation devices. More than 60 percent of phones in the United States are currently equipped with GPS, and the number is expected

to increase to more than 80 percent before 2018.[14]-[17] This number could reach close to 100 percent if the FCC mandates GPS capability in every phone sold after some sunset date. The use of GPS has been extended from navigation to E911, as well as many other location-based services (e.g., finding nearby gas stations, gas prices, restaurants and friends).

- Mobile-device-based measurements and calculations with passive assistance from cellular networks

These techniques estimate the mobile device's location via multilateration, triangulation or other algorithms using signals from the cellular base stations. All of these utilize some measurements performed by the mobile device, such as the arrival times, strengths or angles of arrival of the signals from the base stations. In addition to these measurements, the cellular network may provide additional data, such as the locations of the base stations, which are useful for the calculation of the mobile device location.

- Network-based measurements and calculations with passive assistance from the mobile device

These techniques are similar to the techniques discussed above. However, here the measurements and calculations are performed by the network instead of the mobile device. Measured quantities include the times of arrival, strengths and angles of arrival of signals from the mobile device.

- Hybrid techniques

These techniques involve significant active involvement from both the network and the mobile device for providing the mobile device its geolocation.

- Proximity-based techniques
- These techniques use the information about the locations of the cell towers or Wi-Fi Access Points (APs) from where the mobile device can get signal to estimate the geolocation of the mobile device. Several third parties have developed databases that can be queried by the mobile device to obtain its own location. Alternatively, the Wi-Fi AP geolocation can be input directly into the mobile device.

Network-based and hybrid techniques are excellent for locating an E911 caller and providing that location information to a Public Safety Answering Point (PSAP). The accuracy is high because the network has the computing resources to apply sophisticated algorithms. However, computing effort, radio resource utilization and additional privacy concerns make them unsuitable for ASLAT, where all mobile devices in a broadcast area need to be located and informed about their locations. Proximity-based geolocation of the mobile device using third-party database services suffer from the same disadvantages: load on the database service from all mobile devices, requiring their geolocations almost simultaneously; additional radio resource utilization; and additional privacy concerns.

Mobile-device-based techniques using multilateration from satellite or cellular network signals have minimal adverse impact on the network computing load, radio resource utilization and privacy concerns. They provide adequate accuracy in most environments. They are therefore suitable for ASLAT. For indoor environments, these techniques can be supplemented with Wi-Fi-based geolocation using private location information in the

mobile device. It is important that the implementation of mobile-device-based techniques using measurements of the base station signals get minimal active assistance from the network and the knowledge of the location resides in the mobile device only. Otherwise, these techniques would be in the hybrid category and have the disadvantages mentioned above.

Section 7.3 provides more detailed descriptions and a comparison of the above techniques for ASLAT.

7.1 Applications Driving Geolocation Technology

As mentioned earlier, E911 and navigation applications have been driving the development and deployment of geolocation capabilities in mobile devices and cellular networks.

7.1.1 E911 Geolocation Requirements

It is estimated that more than 70 percent of 911 emergency calls are now made from cell phones [8] and that number is growing. Since these phones are not tethered to a line with a known location, the location of the device is dynamic and not readily known to the network. It is important to develop and deploy mechanisms that will be able to quickly and accurately geolocate a mobile device from which a 911 call is made. This information is then provided to the PSAP, which can pass the geolocation information to first responders, law enforcement personnel or other emergency response personnel. Recognizing this importance, the FCC has been issuing increasingly stringent requirements on the geolocation accuracy of mobile devices and the cellular network infrastructure. In 2007, the FCC mandated that every carrier will meet the following Enhanced 9-1-1 Phase 2 requirements for each PSAP:[9]-[13]

- For network-based measurements and calculations, geolocation accuracy within 100 meters at least 67 percent of the time and within 300 meters at least 95 percent of the time.
- For handset-based techniques, geolocation accuracy within 50 meters 67 percent of the time and within 150 meters 95 percent of the time.

The above level of accuracy seems adequate for ASLAT needs for most scenarios of interest. Thus, compliance with the FCC mandate may imply ASLAT needs will be satisfied. However, E911 requires that the network obtains the geolocation of a mobile device (which is making the 911 call) and communicates that information to the PSAP. On the other hand, ASLAT requires each mobile device in the broadcast area to know its own geolocation and to update it regularly during an emergency. These key differences in where the geolocation information is required, the number of geolocation calculations required per mobile device and the number of mobile devices requiring geolocation have significant implications on the network computing load, radio resource utilization and privacy implications. These play critical roles in the selection of geolocation techniques suitable for ASLAT.

Recently, the FCC has been considering tighter accuracy requirements for urban environments, where an accuracy of less than 10 meters horizontally and 3 meters or less

in vertical dimension may be required to geolocate a caller on a specified floor within a building.[10][11] Geolocation techniques based on Wi-Fi signals may be employed to achieve this level of accuracy indoors. It is unlikely that WEA will require this level of accuracy; however, the possibility of losing satellite and cellular network signals inside of buildings requires indoor geolocation techniques such as the ones based on the Wi-Fi AP locations.

7.1.2 Navigation Geolocation Requirements

Real-time, turn-by-turn driving directions using standalone GPS devices or cell phones with GPS capability have replaced paper maps for a large percentage of the U.S. population. This percentage is increasing rapidly. As the accuracy of GPS devices increased, the geolocation techniques also became useful in providing navigation support to pedestrians in smaller geographical areas. Navigation support is provided by geolocating a mobile device on a map and then using map routes to provide driving or walking instructions.

Geolocation capability in GPS is provided by 24 satellites, of which at least five are visible from any point on Earth. These satellites provide their locations and timing signals. These are used by a mobile device to calculate its distances from the satellites and to find its location by multilateration. As discussed below, GPS provides accuracy good enough for road navigation, which seems better than that required for WEA. Since the calculations are carried out on the mobile device where the geolocation information is needed, there is no burden on the cellular network and there is no added privacy concern.

As mentioned earlier, more than 60 percent of the cell phones used in the United States have GPS-based geolocation capability. This number is expected to rise to more than 80 percent by 2018. Besides navigation, GPS-based geolocation is increasingly important for E911 applications, as well as for many other location-based services. The FCC is considering mandating GPS capability (and its enhancement, Assisted GPS [A-GPS]) for all cell phones after a sunset date beyond 2018. Such a mandate will make GPS a ubiquitous capability that can be leveraged by ASLAT. The E911 applications will require better accuracy and lower latency than that required for navigation. The enhancement in latency (via A-GPS) may benefit ASLAT significantly.

7.2 Measurements and Algorithms for Geolocation

In addition to the classification based on the location of measurements and calculations, geolocation techniques developed to address the needs of E911, navigation and other location-based services can also be classified based on the quantities measured and the algorithms used to calculate geolocation of the mobile device. Four common approaches are triangulation, multilateration, RF fingerprinting and proximity to known locations.

As shown in Figure 27, triangulation uses Angles of Arrivals (AOAs) of signals from and to two or more base stations and calculates the third vertex of the triangle as the mobile device's location. AOA measurements can be taken by the mobile device or by the base stations. However, accurate measurements of angles require multiple antennas or digital beam forming (smart antenna), making it expensive to implement in the mobile device.

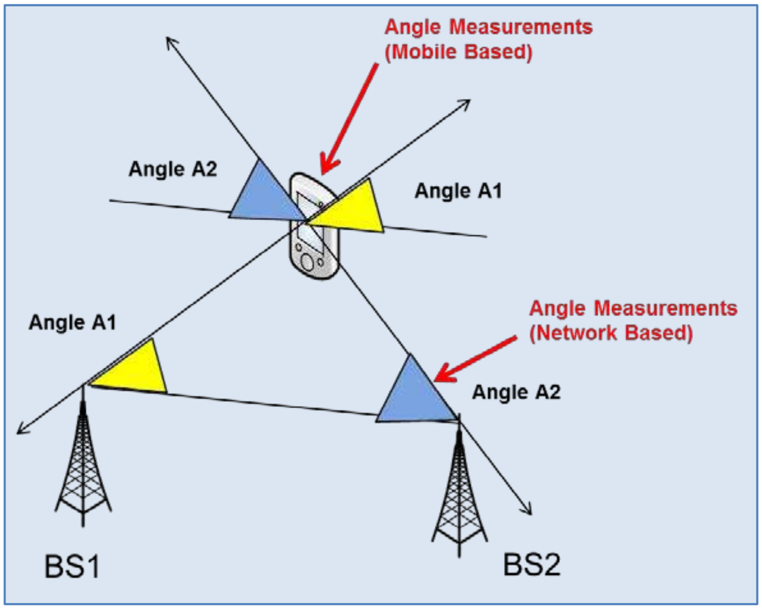


Figure 27: Geolocation by Triangulation

Multilateration, illustrated in Figure 28, uses the estimates of the distances of the mobile device from three or more entities with known locations (e.g., satellites, base stations, Wi-Fi APs) to locate the mobile device at the intersection of circles or hyperbolas.

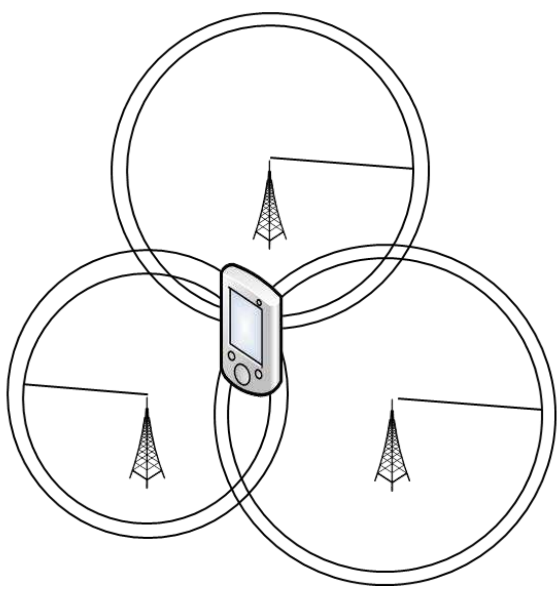


Figure 28: Geolocation by Trilateration and Multilateration

The distance can be estimated from two types of measurements:

- Time taken by the signal to traverse between the signal source and the signal destination where the measurements are taken. This time and the signal propagation speed provide the estimate of the distance. The source can be a mobile device, a satellite, a base station antenna or a Wi-Fi AP. As mentioned earlier, the measurement location can be the base station or the mobile device.
- Loss of signal strength while traversing between the signal source and the signal destination where the measurements are taken. Propagation loss models [18]-[22] then provide an estimate of the distance between the two points.

RF fingerprinting involves capturing offline measurements of the received signal strengths from multiple base stations or Wi-Fi APs as a function of the mobile device geolocation and generating a database relating each location to a vector of measurements. Then, the database is searched using real-time measurements to estimate the location. This technique is useful in complex RF environments (mainly indoor, but possibly in very dense urban areas) where other techniques fail.

Proximity-based geolocation techniques use the knowledge of the cell IDs of cellular base stations or the Service Set Identifiers (SSIDs) of the Wi-Fi APs that are currently "hearable" by the mobile device to obtain the geolocation of the cell towers or the APs. This information can be supplied to the mobile device by the base station, the AP or a third-party providing location services. In the simplest case, the retrieved geolocation of the base station or AP with the strongest received signal is used as an estimate of the geolocation of the mobile device. More sophisticated proximity-based techniques involve the entire mix of cell IDs and AP SSIDs that the mobile device can hear and use a combination of their geolocations to estimate the mobile device's geolocation. These calculations can be done by the mobile device or by the third party providing location services.

7.3 Geolocation Techniques for ASLAT

This section evaluates various geolocation techniques for use in ASLAT. Techniques suitable for ASLAT are discussed in greater detail, while other techniques are mentioned only briefly.

7.3.1 Network-based and Hybrid Geolocation Techniques

As mentioned earlier, network-based geolocation techniques suffer from a heavy load on the network and radio resources and may raise serious privacy concerns. Therefore, in spite of their excellent accuracy and deployment for E911 applications, they are not recommended for ASLAT. The same conclusions apply to the hybrid schemes and proximity-based schemes using third-party databases.

7.3.2 Mobile-device-based Geolocation Techniques

7.3.2.1 GPS

The primary mobile-device-based geolocation technique utilizing a satellite network is the basic GPS, depicted in Figure 29. It does not require any help from the cellular network, and the early road navigation applications used standalone GPS devices without any network connectivity. The basic GPS has the following advantages for ASLAT:

- Deployment and ongoing maintenance of the GPS satellites and heavy deployment in mobile devices, motivated by navigation applications, allow tremendous leverage for ASLAT.
- Accuracy within 30 to 80 meters in most environments is expected to be adequate for ASLAT.
- All measurements and calculations are performed in the mobile device using satellite signals. Therefore, there is:
    - No additional load on the cellular network;
    - No additional load on the radio resources; and
    - No privacy issues.

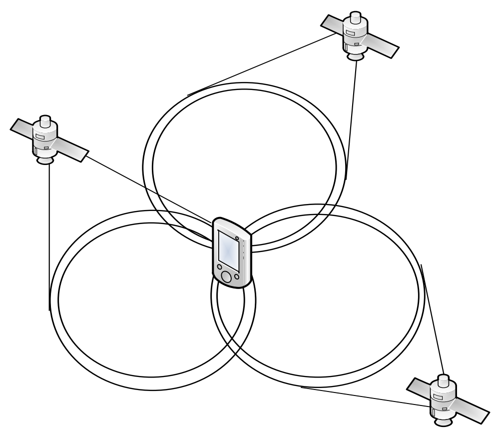


Figure 29: GPS-based Geolocation

There are several issues that need to be addressed for using GPS in ASLAT. These include high battery consumption, large latency and locations with poor GPS signal.

Battery consumption in GPS is due to monitoring and collecting satellite signals, receiving satellite almanac and ephemeris over low speed satellite link and processing to calculate geolocation. This issue can be mitigated by using GPS conservatively for ASLAT. GPS can be started when an alert arrives and shut down after the geolocation is obtained. This is especially important when the mobile device is on, not connected to a charging mechanism and the subscriber has not turned on the GPS. The battery consumption issue is also mitigated by the techniques used to reduce the latency.

Large GPS latency occurs when the GPS is used in a new area for the first time or when the satellite ephemeris or almanac is updated. Then, the ephemeris or almanac data needs to be downloaded over a low speed (50 bps) satellite link, which may require anywhere between 30 seconds to more than 12 minutes. The lower end (30 seconds to one minute) of this Time To First Fix (TTFF) happens once every several hours for ephemeris updates, while the upper end (more than 12 minutes) happens once every several months for almanac updates. Significant improvement in the TTFF is possible by using A-GPS in which the A-GPS server provides the satellite almanac and ephemeris, precise reference

time and other important information over a high-speed cellular bearer channel (or even a Wi-Fi link if available). This can reduce worst-case TTFF from more than 12 minutes to 30 seconds. Once the relevant data is obtained from the server, the mobile device could continue to function like a standalone GPS device.

For ASLAT, the data transfer from the server would increase the network load and the utilization of radio resources because the information would be communicated to each mobile device. However, data transfer is done once per mobile device and only if the satellite data updates are needed. Therefore, the impact on the network load and radio resource consumption can be small compared to those for network-based geolocation techniques. If A-GPS proves to be useful for ASLAT and the total network load is prohibitive, then service providers can migrate from using a dedicated channel to using the cell broadcast channel for A-GPS. This could completely eliminate concerns about utilization of radio resources and scalability. The cell broadcast channel has limited capacity, and it will have to send out periodic updates for A-GPS, so further analysis is required to assess the desirability of its use for A-GPS.

While the penetration of GPS-equipped mobile devices is already close to 60 percent and is increasing rapidly, it may not be 100 percent in the near future. Also, the GPS signal can be weak or suffer from serious multipath propagation effects in indoor or dense urban settings. This requires using other mobile-device-based techniques to supplement the GPS-based techniques.

7.3.2.2 D-TOA and D-TDOA

Mobile-device-based techniques with minimal possible involvement and assistance from the network can provide an alternative to GPS without generating significant burden on the network and radio resources. In particular, downlink Time of Arrival (D-TOA) and downlink Time Difference Of Arrival (D-TDOA) are appropriate techniques for ASLAT. Figure 30 and Figure 31 below show these two approaches.

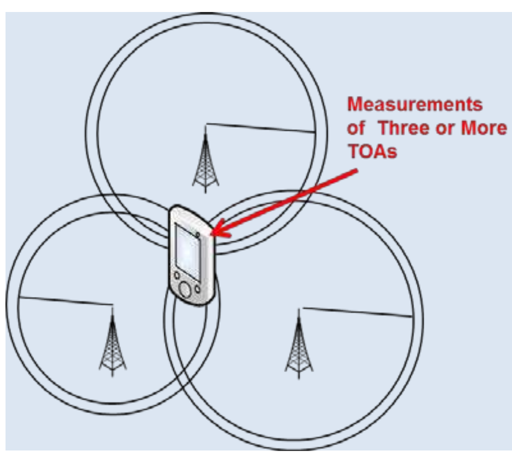


Figure 30: Geolocation Using D-TOA

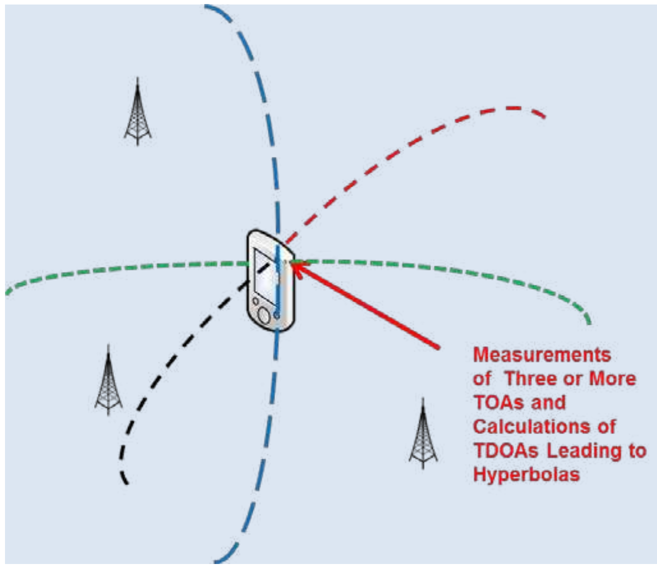


Figure 31: Geolocation Using D-TDOA

Both D-TOA and D-TDOA use Times Of Arrivals (TOAs) of signals from three or more base stations as measured at the mobile device. In D-TOA, the base stations and the mobile device are synchronized. If TOT_1 is the time of signal transmission from base station 1, then signal speed x (TOA_1-TOT_1) gives an estimate of the distance between base station 1 and the mobile device. The mobile device is also given the location of base station 1. The circle with its center at the base station 1 location and radius equal to the estimate of the distance gives possible locations of the mobile device. Repeating the same process with two other base stations gives three intersecting circles, where the intersection gives the mobile device's location. Only Code Division Multiple Access (CDMA) networks synchronize mobile devices and base stations, and thus can use the basic D-TOA.

If the base stations are synchronized (possibly via Location Measurement Units, or LMUs), but are not synchronized with mobile devices, then the three differences in TOAs ($TOA_1 – TOA_2$, $TOA_2 – TOA_3$ and $TOA_1 – TOA_3$) give hyperbolas to geolocate the mobile device at their intersection. This technique is the D-TDOA technique shown in Figure 31. GSM, UMTS and all newer cellular technologies do not synchronize mobile devices with base stations, but synchronize base stations among themselves with or without LMUs. Therefore, D-TDOA has become a popular technique for mobile-device-based geolocation using multilateration.

D-TOA (where available) and D-TDOA have the following advantages for ASLAT:

- Existing development and deployment to support E911 requirements. Each cellular technology has defined standards for D-TDOA, and CDMA has defined standards for D-TOA. These techniques can provide an accuracy of 50 to 300 meters in good environments.
- All measurements and calculations are performed in the mobile device using network signals and key data about the network. Therefore, there is:
    - Moderate additional load on the cellular network;

- Moderate additional load on the radio resources; and
- No privacy issues.

- Battery consumption, while significant, is much lower than that for GPS-based geolocation techniques.
- Works well in urban and suburban areas, thus complementing GPS-based geolocation.

It is important that the D-TOA and D-TDOA techniques selected for ASLAT use the network only to provide the data about base station locations and other network parameters. All measurements and calculations should be completed in the mobile device.

Some disadvantages of D-TOA and D-TDOA are the requirement for at least three base stations, sending network data to the mobile device, indoor signal quality and base station synchronization.

Both D-TOA and D-TDOA require at least three base stations from which the mobile device is receiving good signals. This can be difficult in some rural areas. Fortunately, GPS works very well in rural areas and can mitigate this disadvantage.

Key network data needs to be made available to each mobile device for D-TOA and D-TDOA. This data is currently sent over a dedicated channel. This would create an additional load on cellular network resources if many mobile devices in a broadcast area simultaneously request location measurements. Potential impacts on radio resource utilization, network loading and battery consumption need further investigation. Similar to the A-GPS case, the feasibility of using cell broadcast channel for network data should also be analyzed further.

Cellular signals may be weak at some indoor locations. They may also be affected by multipath propagation, distorting TOA measurements. Although cellular signal quality is better than GPS signal quality indoors, there will still be some locations where D-TOA and D-TDOA measurements would not be possible.

Finally, synchronization of base stations is required for D-TOA and D-TDOA. If not already implemented, this adds to the development and deployment cost of the system.

7.3.2.3 Wi-Fi Proximity

For some indoor locations, both GPS and cellular signals may be weak. However, proximity techniques utilizing the increasing density of the Wi-Fi systems may provide a complementary alternative. As mentioned previously, sophisticated geolocation techniques using location services from commercial vendors (e.g., Google, Navizon, AlterGeo, Skyhook Wireless) is not suitable for ASLAT due to privacy and network loading issues. Therefore, the simplest feasible approach for indoors would be broadcasting the Wi-Fi AP geolocation to mobile devices in its range. Each mobile device would then use the location of the Wi-Fi AP with the best received signal as its own geolocation. This will require additions to the 802.11 standards, but the actual implementation should be relatively simple. Instead of depending on AP broadcasting, geolocations of key Wi-Fi APs can also be manually input to the mobile device by the user. Then the relationship between the SSID (that the mobile device can see) and geolocation allows the mobile device to estimate its location with reasonable accuracy. More sophisticated schemes using the geolocations of multiple Wi-Fi

APs and the corresponding signal strengths can also be developed for increased accuracy. However, ASLAT accuracy requirements may be met with the basic Wi-Fi AP technique, and the additional cost may not be justified.

7.4 Recommendations, Basic Architecture and Enhancements

The above discussion suggests that GPS, mobile-device-based TOA/TDOA and Wi-Fi proximity provide three complementary techniques for mobile device geolocation. GPS is a good solution in rural and suburban areas and is the primary technique with minimal network involvement. TOA/TDOA techniques are good in urban and suburban areas. Finally, the Wi-Fi proximity-based techniques could support indoor locations. There are also regions where multiple techniques are suitable.

A key recommendation is to use these three types of techniques in an overall solution. This solution should also include simple mitigations discussed earlier. If an alert arrives and the mobile device does not have its geolocation, then it would start multiple algorithms and a timer. If an algorithm provides the geolocation with sufficient accuracy before the timer expires, then the device would use the geolocation to decide if the user should be alerted. If the timer expires before the geolocation can be determined, then the device would alert the user just in case. This basic concept is detailed in Section 7.5.

Several simple enhancements should also be implemented. One example is starting the geolocation process when an alert arrives and shutting it off when the ASLAT algorithm completes, ensuring minimal drain on the battery. Another involves severe and extremely time-critical warnings, such as earthquakes and tornadoes. The latency requirements for these warnings may be too stringent to wait for geolocation. Also, the consequences of FNs are more serious than those of FPs. In these cases, the user should be alerted without even starting the geolocation and filtering processes. This would require that the alert message has the information for the device to decide if the alert falls into the "severe and very time critical" category.

As mentioned earlier, the use of dedicated versus cell broadcast channels for communicating satellite or network-related information from the network to the mobile device needs further investigation. Also, it is important to evaluate the need for the improvements provided by A-GPS (over GPS) for ASLAT.

Indoor locations without adequate Wi-Fi coverage pose serious challenges because all three types of techniques discussed may fail. One solution would be to deploy low-energy geofencing at the entrance to and exit from selected areas. Low-energy beacons at the entrances would provide geolocation information to the mobile device. This is another simple concept to implement; however, deployment benefits versus cost needs investigation.

7.5 Mobile Device Decision Process

In this section, we introduce a high-level ASLAT reference model to illustrate how a mobile device will be able to process WEA messages with ASLAT. Each received alert message is filtered based on the target area and the geolocation of the mobile device. The proposed reference model meets the recommendations discussed in the previous section. For example, the reference model allows multiple geolocation technologies to be used

simultaneously to minimize latency. It also aims to reduce consumed energy by shutting off the geolocation processing when not needed. The proposed reference model ensures that ASLAT does not interfere with the user's decisions regarding enabling or disabling the Wi-Fi interface or the GPS sensor of the device.

The proposed ASLAT reference model operates under the following list of assumptions:

- Mobile devices will implement ASLAT as a separate feature, which can be turned on or off by the user. If ASLAT is turned off, then received alerts will be handled as in current WEA.
- Alert messages without a target area polygon will be handled as in current WEA.
- If the mobile device already knows its geolocation due to another application, then a received alert will not trigger a new geolocation determination process, and the device will leverage the existing location information.
- When the mobile device needs its location for ASLAT, it will leverage all viable geolocation techniques to determine its location in the shortest time possible. This process is called the Multi-Modality Location Determination (MMLD).
- The ASLAT geolocation process is allowed a finite amount of time to complete, called the MMLD interval. This interval bounds the maximum latency and the maximum amount of energy consumption to determine the mobile device's geolocation for a WEA message. If the mobile device is not able to determine its geolocation within this interval, then it will resort to default WEA behavior by displaying the new emergency alert message to the user.
- The mobile device will maintain a list of displayed alerts as in current WEA. All received alerts that were displayed to the user as the result of ASLAT processing will be stored in this list in order to avoid duplicate notifications of the same alert during a retransmission. The mobile device may also maintain a second list of alerts to store received alerts that were not displayed to the user because of the ASLAT decision process. It may then check this list whenever its location changes and process any pending alerts in this list with the new location information.
- When the mobile device completes the geolocation processing by determining its current geolocation or when the MMLD interval expires, the mobile device will turn off GPS hardware and the Wi-Fi interface if they were turned on for ASLAT (i.e., not by another application).
- The ASLAT geolocation process will minimize communication with network services to avoid introducing additional network loading and congestion.
- The ASLAT geolocation process will mainly operate in passive sensing mode, where it only uses broadcast channels instead of dedicated channels. The only exception is when it has Wi-Fi connectivity and the user has explicitly consented for the ASLAT geolocation process to share information with the network or some third-party location services. In this case, network congestion will not be an issue due to the Wi-Fi connection, so the device can be allowed to use Wi-Fi connectivity to access network location services.

Figure 32 displays a flow diagram describing the ASLAT reference model decision process. As depicted in the figure, whenever a mobile device is powered on and operating in standby mode, it constantly monitors the cell broadcast channel for WEA messages. When a WEA message is received, the mobile device determines whether this is a new alert or a repeated alert that was displayed to the user previously. If the message is identified as a new alert, then the mobile device verifies that the ASLAT feature was enabled by the user and the new alert contains a target area polygon. If these conditions are true, then the mobile device proceeds with location determination; otherwise, it displays the alert to the user by default. If the mobile device's location is already known, then the existing location is used to determine whether the mobile device is inside the target area or not. If the current location of the device is not known, then the device starts an MMLD timer and initiates all available techniques to determine its current location.

The figure assumes that the mobile device supports GPS and mobile-device-based trilateration techniques such as OTDA and Wi-Fi AP proximity techniques. If the MMLD timer expires before any of these geolocation methods succeeds in determining the device's location, then the alert message is displayed to the user by default. Conversely, if any of the geolocation techniques determine the current location before the timer expires, then all other geolocation techniques are suspended and all geolocation hardware that was enabled by ASLAT logic is turned off. In this case, the mobile device's geolocation is used to determine if it is inside or outside the target area. If the mobile device is inside the target area, then the message is displayed to the user and the list of received alerts is stored in the memory. If the device is located outside the target area, then this message is ignored and considered as if it was never received.

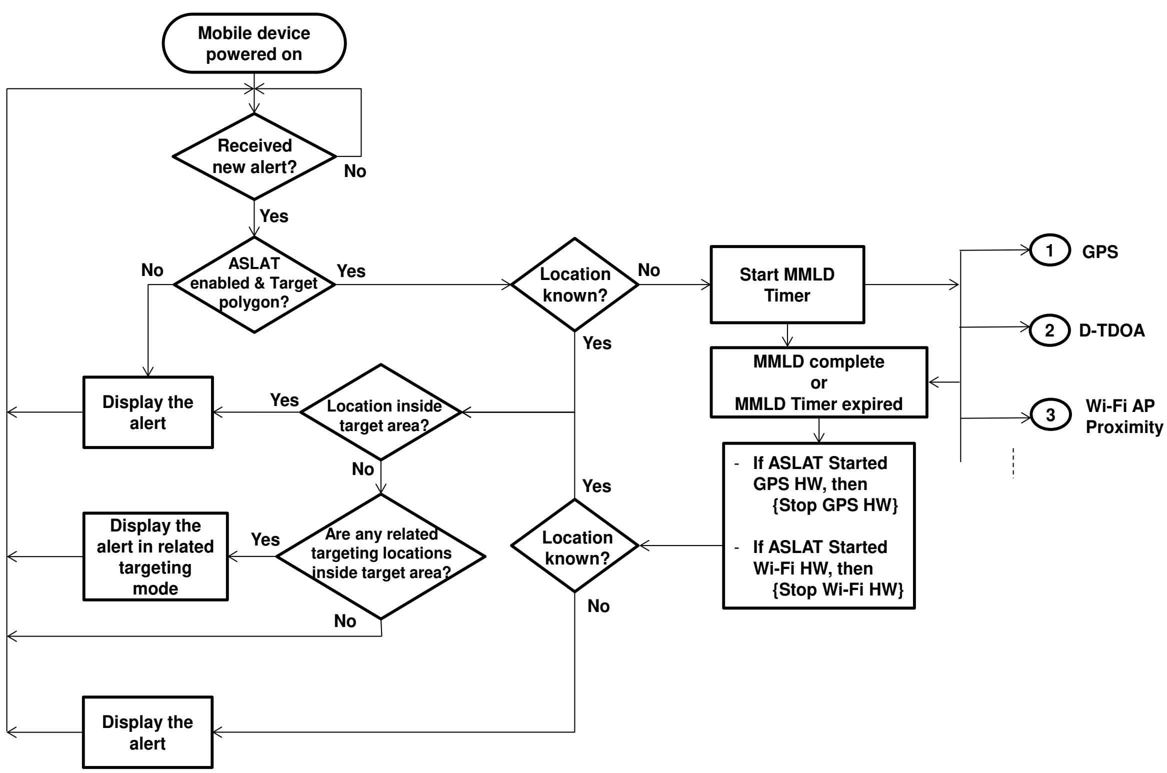


Figure 32: ASLAT Flow Diagram

8 REQUIRED CHANGES TO EXISTING STANDARDS

Sections 6 and 7 discussed the new functionality required in the cellular network and in the mobile device to support ASLAT. Implementation of this functionality would require some changes to existing standards, as explained in the remainder of this section.

8.1 WEA Standards

Some changes to WEA standards would be required to support transmission of polygon data to the mobile device and interpretation of this data by the mobile device. Polygon transmission is already supported by the CAP and CMAC protocols, so no modifications are necessary for those standards. Modifications would only be needed to the standards governing the CMSP network and the mobile device behavior.

8.1.1 CMSP Network

The ATIS Standard 0700006 describes broadcasting WEA messages over the GSM or UMTS networks.[29] Similarly, ATIS Standard 0700010 describes broadcasting WEA messages over LTE networks.[31] Both of these standards specify Cell Broadcast Center (CBC) requirements for WEA. For ASLAT support, the CBC requirements should be extended to include polygon compression and polygon transmission. The limitation of the broadcast message size to a single page should be removed so that WEA messages with ASLAT can have multiple pages to carry the polygon information. A polygon compression algorithm, similar to the one described in Appendix A, should be specified in these standards so that CBCs and mobile devices from different vendors remain compatible.

The standards should describe a new CBC function, which determines whether to broadcast polygon information based on the urgency of alerts, as conveyed in the message. The CBC should not include any polygon information in the message for extremely urgent alerts (e.g., alerts with the <urgency> field equal to "Immediate"), so that the mobile device would display these alerts immediately without first checking their locations.

ATIS Standard 0700007 describes implementation guidelines and best practices for cell broadcast services.[7] Guidelines described in this standard should be extended to cover multiple-page WEA messages.

8.1.2 Mobile Device

The joint ATIS/Telecommunications Industry Association (TIA) Standard J-STD-100 defines a common set of requirements for WEA-capable mobile devices.[32] ASLAT support does not change any of the existing requirements in this standard, but some new requirements should be added to specify ASLAT message processing and geolocation use.

The standard should mandate receiving and processing multiple-page cell broadcast messages for mobile devices with ASLAT support. It should also describe the polygon format and the decompression algorithm, so that mobile devices can properly decode the compressed polygon data.

Requirements regarding the use of multiple geolocation techniques should be added to the standard. In particular, the standard should support using multiple techniques

simultaneously with an MMLD timer, as described in Section 7.5. It should prevent the use of any technique that will trigger a message exchange with the CMSP infrastructure, such as the network-based and hybrid techniques mentioned earlier. The mobile device decision process should also be specified, similar to the process described in Section 7.5.

A new requirement for preserving subscriber privacy should be added. This requirement should prevent revealing the device location without the subscriber's consent. New device configuration options should also be added to the standard, which would let the subscriber enable or disable ASLAT geotargeting and control the use of specific geolocation techniques for ASLAT.

8.2 Geolocation Standards

The recommendations in Section 7.4 include the use of GPS with or without assistance from cellular networks as the primary outdoor geolocation technique for the mobile device, supplemented by D-TOA and D-TDOA techniques for dense urban and suburban environments, and Wi-Fi proximity-based techniques for indoor environments. The current A-GPS, D-TOA and D-TDOA standards are driven by the need of E911 applications, where the PSAP needs to know the location of the calling mobile device. These standards need to be modified to make them more effective for the geolocation requirements of ASLAT, where the mobile device needs to know its own location.

8.2.1 GPS

GPS-based geolocation is a key technology in all navigation applications used in wireless mobile devices. As a result, GPS can be leveraged to provide geolocation for ASLAT. Standalone GPS does not require any changes for ASLAT. However, ephemeris or almanac data stored in the mobile device can be invalid as a result of an extended power off state, causing excessive TTFF delays. In order to minimize this delay, a mobile device with A-GPS capability can get assistance data (including ephemeris and almanac) from the network at a higher bitrate compared to the satellite channel.

A-GPS can be mobile device based (MB) or mobile device assisted (MA). In MB mode, the mobile device uses the assistance data supplied by the network to quickly synchronize with three or more satellites to calculate its own geolocation. In MA mode, the mobile device uses the assistance data supplied by the network to take measurements of satellite data. The measured data is then sent back to the network, which calculates the location of the mobile device. As discussed in Section 7.3, methods with significant network involvement and methods that can introduce privacy concerns are not suitable for ASLAT. Therefore, only the MB mode of A-GPS is considered.

GPS assistance data can be sent to a mobile device using either a dedicated channel or a broadcast channel in the MB mode. Driven by E911 and navigation applications, typical implementations of MB A-GPS use dedicated point-to-point channels. In such implementations, the mobile device requests assistance data from an assistance server, receives the data over a dedicated channel and then calculates its geolocation. For ASLAT, using this on-demand point-to-point delivery can significantly increase the network load and radio resource consumption, so it should not be used.

GPS assistance data delivery using a broadcast channel should be supported by the standards and be deployed in cellular networks for ASLAT to use A-GPS. With this approach, the network would periodically broadcast the assistance data without utilizing dedicated channels. The mobile device would then use the assistance data, as needed, to update the satellite information and achieve a short TTFF in response to an ASLAT alert. The Third Generation Partnership Project (3GPP) Cell Broadcast Service standard supports GPS assistance data delivery.[33] 3GPP UMTS Location Services (LCS) standards support sending GPS assistance data by broadcast [34][35][36]; however, this capability is left optional in the standards. Therefore, no change is required to the UMTS standards, but the optional broadcast capability has to be widely deployed, so that ASLAT can use A-GPS in UMTS networks.

The 3GPP LTE Positioning Protocol (LPP) supports the MB mode for A-GPS, but does not specify broadcast of the assistance data.[37] On the other hand, the Open Mobile Alliance (OMA) developed an LPP Extensions (LPPe) standard for LTE, which fully supports broadcast.[38] Including these extensions in 3GPP LTE standards would facilitate widespread deployment of this capability, and ASLAT would be able to use A-GPS in LTE networks.

The Position Determination Service for CDMA networks does not support broadcast of A-GPS assistance data.[39][40] ASLAT use of A-GPS in CDMA networks would require the addition of broadcast support to these standards.

8.2.2 D-TOA/D-TDOA

Similar to A-GPS, D-TOA and D-TDOA techniques can be used either in MB mode or MA mode. In both modes, the cellular network provides assistance data to the mobile device. The assistance data includes various types of information about the base stations and cell sectors. In MA mode, the mobile device performs some measurements and sends the results back to the cellular network for geolocation calculation. In MB mode, the mobile device performs both the measurements and the calculations to find its geolocation.

UMTS and LTE networks use the D-TDOA techniques. D-TOA is not used in UMTS and LTE because it requires synchronization between the base stations and mobile devices. The UMTS LCS standards support sending D-TDOA assistance data to mobile devices by broadcast, similar to the A-GPS broadcast support.[34][35][36] This capability is optional in the standards. Widespread deployment of this capability would enable ASLAT to use D-TDOA in UMTS networks.

3GPP LPP supports only MA mode for D-TDOA.[37] However, the OMA LPPe standard supports both MB mode and broadcast transmission of assistance data.[38] The OMA extensions should be included in the 3GPP LPP standard, so that they get widely deployed for use by ASLAT and other applications.

CDMA networks use the D-TOA techniques, since base stations and mobile devices are synchronized in CDMA.[39][40] However, MB mode and the broadcast transmission of assistance data are not specified in these standards. Support for these capabilities should be added to the CDMA standards, so that ASLAT can use D-TOA techniques.

8.2.3 Wi-Fi Proximity

As mentioned in Section 7.3.2.3, the simplest approach to Wi-Fi-based mobile geolocation is for each AP to provide its own geolocation to every mobile device within range. The mobile device would then pick the strongest signal and use the geolocation of the corresponding AP as an estimate of its own geolocation.

Specifications for Wi-Fi networks are defined in the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standard.[41] This standard provides a mechanism to make the AP location available to a mobile device within range; however, this capability is optional both for the AP and the mobile device. Without support for this mechanism, Wi-Fi proximity can only use a manual approach, where the user populates a database of local SSID to geolocation mapping. The mobile device needs to provide an Application Programming Interface (API) to develop such a database, and then use the manually-populated database in ASLAT message processing.

If the 802.11 location capability is supported by the AP and the mobile device, then Wi-Fi proximity can be fully automated. This would allow the mobile device to create the database of the SSID to geolocation mapping automatically, without involving the user.

9 CONCLUSIONS

This document describes a new geotargeting mechanism for WEA, called ASLAT, which is based on broadcasting the alerts to an area wider than the target area, but only displaying them to the user if the mobile device is inside the target area.

Performance analysis of ASLAT showed that it can improve the accuracy of the WEA geotargeting mechanism significantly, without consuming excessive mobile device power or radio resources. ASLAT would increase the alerting latency, but the amount of increase can be controlled. ASLAT can also be bypassed for highly delay-sensitive alerts, such as earthquake warnings.

ASLAT depends on a variety of geolocation technologies to determine the location of the mobile device. Mobile-device-based geolocation technologies such as GPS, TOA/TDOA and Wi-Fi proximity are suitable for ASLAT, since they do not introduce an additional load on the cellular network and they maintain user privacy. Although the required precision in WEA geotargeting is not well defined, most of these geolocation technologies were driven by E911, which requires high precision, so it is expected that they would be adequate for WEA.

ASLAT would require some changes to existing standards. Specifically, WEA standards that specify functionality in the CMSP network and mobile device behavior would require amendments to support ASLAT. Modifications to A-GPS, TOA/TDOA and Wi-Fi standards, and implementing new indoor location capabilities would enable ASLAT to fully utilize these geolocation technologies and further enhance its performance.

The new geotargeting mechanism and the related findings described in this document could affect important technical, programmatic and policy decisions regarding the evolution of the WEA system. The DHS S&T WEA Program Management Office should work with other stakeholders, including the FCC, FEMA, CMSPs, the Alert Originator community and state and local first responders, to determine detailed requirements on geotargeting accuracy and to analyze various alternatives to meet these requirements. Such an analysis of alternatives study would benefit from the findings presented in this document, but should also include the level of effort and cost required for each alternative as that was outside the scope of this effort.

10 REFERENCES

[1] "Geotargeted Alerts and Warnings," National Research Council Workshop Report, The National Academies Press, 2013.

[2] C. Woody and R. Ellison, "Maximizing trust in the wireless emergency alerts (WEA) service," Carnegie Mellon University Software Engineering Institute, Pittsburg, PA, Tech. Rep. CMU/SEI-2013-SR-027, February 2014.

[3] J. McGregor et al., "Best practices in wireless emergency," Carnegie Mellon University Software Engineering Institute, Pittsburg, PA (USA), Tech. Rep. CMU/SEI-2013-SR-015, February 2014.

[4] S. Banerjee, D. Mukherjee, and P. Misra, "'What affects me?': A smart public alert system based on stream reasoning," in Proceedings of the 7th International Conference on Ubiquitous Information Management and Communication, ICUIMC'13, Association for Computing Machinery (ACM), 2013.

[5] Common Alerting Protocol, Organization for the Advancement of Structured Information Standards, CAP-V1.2, April 2009.

[6] Joint ATIS/TIA CMAS Federal Alert Gateway to CMSP Gateway Interface Specification, ATIS/TIA Joint Standard J-STD-101, October 2009.

[7] Implementation Guidelines and Best Practices for GSM/UMTS Cell Broadcast Service, ATIS Standard 0700007, October 2009.

[8] S. Rich, "National SMS System Successful during Super storm Sandy," http://www.govtech.com/public-safety/National-SMS-System-Successful-During-Superstorm-Sandy.html, accessed on November 21, 2014.

[9] FCC Consumer Guide, "911 Wireless Services," http://transition.fcc.gov/cgb/consumerfacts/wireless911srvc.pdf.

[10] FCC Rulemaking on 911 Emergency Calling Systems Compatibility, http://www.fcc.gov/rulemaking/07-114.

[11] Wireless E911 Location Accuracy Requirements. A Proposed Rule by the FCC on 03/28/2014. http://www.gpo.gov/fdsys/pkg/FR-2014-03-28/pdf/2014-06618.pdf.

[12] Third Further Notice of Proposed Rulemaking, FCC, February 2014. https://apps.fcc.gov/edocs_public/attachmatch/FCC-14-13A1.pdf.

[13] R. Jensen, "E911 Phase II Location Accuracy Workshop," November 18, 2013.

[14] D. Furth, "Next Generation 911," APCO Broadband Summit, May 5, 2014.

[15] B. Fung, "New FCC proposal would require pinpoint location accuracy for 911 calls," The Washington Post, February 2014, http://www.washingtonpost.com/blogs/the-switch/wp/2014/02/20/new-fcc-proposal-would-require-pinpoint-location-accuracy-for-911-calls/.

[16] "Smartphone Penetration Tops 65% of the US Mobile Market in Q4 2013," http://www.marketingcharts.com/online/smartphone-penetration-tops-65-of-the-us-mobile-market-in-q4-2013-39595/.

[17] A. Malm, "GPS and Mobile Handsets," LBS Research Series from Berg Insight, http://www.berginsight.com/ReportPDF/ProductSheet/bi-gps4-ps.pdf.

[18] J. Sahagian, "Study: U.S. Smartphone Penetration Is at 74 Percent," October 2013, http://wallstcheatsheet.com/stocks/study-u-s-smartphone-penetration-is-at-74-percent.html/.

[19] A. Roxin, J. Gaber, M. Wack, A.Nait-Sidi-Moh, "Wireless Geolocation Techniques: A survey," IEEE Globecom 07, Washington, DC, 2007.

[20] J. Costabile, "Wireless Position Location," Presentation at Virginia Tech Wireless Symposium, June 2010.

[21] "Wireless Geolocation System Architecture," www.cwins.wpi.edu/publications/pown/chapter_14.pdf.

[22] G. D. Durgin, "Radiolocation in Cellular Networks," Georgia Institute of Technology.

[23] J. F. Bull, "Wireless Geolocation," IEEE Vehicular Technology Magazine, December 2009, pp 45 - 53.

[24] M. Kanaan, K. Pahlavan, "A Comparison of Wireless Geolocation Algorithms in the Indoor Environment," IEEE Wireless Communications and Networking Conference (WCNC), 2004.

[25] Y. Zhao, "Standardization of Mobile Phone Positioning for 3G Systems," Motorola, IEEE Communications Magazine, July 2002.

[26] K. Krizman, T. Biedka, and T. Rapaport, "Wireless Position Location: Fundamentals, Implementation Strategies, and Sources of Error," IEEE, 1997.

[27] E. J. Nnenna and O. H. Onyekachi, "Mobile Positioning Techniques in GSM Cellular Networks: A Comparative Performance Analysis," International Journal of Computer Technology and Electronics Engineering, Volume 2, Issue 6, December 2012, 21-29.

[28] S. Fischer, "Observed Time Difference of Arrival (OTDOA) Positioning in 3GPP LTE," Qualcomm Technologies, Inc., June 6, 2014.

[29] CMAS via GSM/UMTS Cell Broadcast Service Specification, ATIS Standard 0700006, March 2010.

[30] Cell Broadcast Entity (CBE) to Cell Broadcast Center (CBC) Interface Specification, ATIS Standard 0700008, March 2010.

[31] CMAS via EPS Public Warning System Specification, ATIS Standard 0700010, August 2010.

[32] Joint ATIS/TIA CMAS Mobile Device Behavior Specification, J-STD-100, January 2009.

[33] Technical Realization of Cell Broadcast Service (CBS), 3GPP TS 23.041, v12.6.0, June 2014.

[34] Location Services (LCS) Service Description Stage 1, 3GPP TS 22.071, v12.0.0, October 2014.

[35] Stage 2 Functional Specification of User Equipment (UE) Positioning in UTRAN, 3GPP TS 25.305, v12.0.0, December 2013.

[36] Location Services (LCS) Broadcast Network Assistance for Enhanced Observed Time Difference (E-OTD) and Global Positioning System (GPS) Positioning Methods, 3GPP TS 44.035, v12.0.0, September 2014.

[37] LTE Positioning Protocol (LPP), 3GPP TS 36.355, v12.2.0, June 2014.

[38] LPP Extensions Specification, Open Mobile Alliance, OMA-TS-LPPe–V1_1-20121211-C, December 2012.

[39] Position Determination Service Standard for Dual Mode Spread Spectrum Systems, 3GPP2 Standard C.S0022-0, version 3.0, February 2001.

[40] Position Determination Service for cdma2000 Spread Spectrum Systems, 3GPP2 Standard C.S0022-B, version 1.0, February 2009.

[41] IEEE Standard for Local and Metropolitan Area Networks: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, IEEE Std 802.11-2012, February 2012.

[42] "About Wireless Emergency Alerts (WEA)," http://www.att.com/esupport/article.jsp?&sid=KB410692&cv=820#fbid=cqmyFSTlSFp, accessed on February 20, 2015.

[43] T-Mobile WEA Capable Cell Phones, http://www.t-mobile.com/cell-phones.wea-capable.html, accessed on February 20, 2015.

[44] "Wireless Emergency Alert Capable Devices," http://www.verizonwireless.com/support/wireless-emergency-alerts-compatible-devices/, accessed on February 20, 2015.

[45] "Survey Questions and Methodology," Pew Internet Spring Tracking Survey 2012, http://www.pewinternet.org/files/old-media/Files/Questionnaire/2012/SurveyQuestions_MobilePrivacy.pdf, accessed on February 20, 2015.

[46] Physical channels and mapping of transport channels onto physical channels (FDD), 3GPP TS 25.211, v12.1.0, December 2014.

[47] Channel coding and multiplexing examples, 3GPP TR 25.944 v4.1.0, June 2001.

[48] Evolved Universal Terrestrial Radio Access (E-UTRA); Physical channels and modulation, 3GPP TS 36.211 v12.3.0, September 2014.

[49] Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding, 3GPP TS 36.212 v12.3.0, December 2014.

11 ACRONYMS

3GPP	Third Generation Partnership Project
A-GPS	Assisted GPS
AP	Access Point
AOA	Angle Of Arrival
API	Application Programming Interface
ASLAT	Arbitrary-Size Location-Aware Targeting
ATIS	Alliance for Telecommunications Industry Solutions
BCCH	Broadcast Control Channel
CAP	Common Alerting Protocol
CBC	Cell Broadcast Center
CBCH	Cell Broadcast Channel
CDMA	Code Division Multiple Access
CMAC	Commercial Mobile Alert for C Interface
CMSP	Commercial Mobile Service Provider
CTCH	Common Traffic Channel
D-TDOA	Downlink TDOA
D-TOA	Downlink TOA
DHS	Department of Homeland Security
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FIPS	Federal Information Processing Standards
FN	False Negatives
FP	False Positives
GPS	Global Positioning System
GSM	Global System for Mobile Communications

IEEE	Institute of Electrical and Electronics Engineers
IPAWS	Integrated Public Alert and Warning System
IPAWS-OPEN	IPAWS Open Platform for Emergency Networks
JHU/APL	The Johns Hopkins University Applied Physics Laboratory
LCS	Location Services
LPP	LTE Positioning Protocol
LPPe	LPP Extensions
LTE	Long Term Evolution
MA	Mobile-device Assisted
MB	Mobile-device Based
MMLD	Multi-Modality Location Determination
NWS	National Weather Service
OFDM	Orthogonal Frequency Division Multiplexing
OMA	Open Mobile Alliance
PDSCH	Physical Downlink Shared Channel
PRB	Physical Resource Block
PSAP	Public Safety Answering Point
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RRU	Radio Resource Unit
S&T	Science and Technology Directorate
S-CCPCH	Secondary Common Control Physical Channel
SIB12	System Information Block 12
SSID	Service Set Identifier
TDOA	Time Difference Of Arrivals
TFCI	Transport Format Combination Indicator

TIA	Telecommunications Industry Association
TOA	Time Of Arrivals
TTFF	Time To First Fix
UMTS	Universal Mobile Telecommunications System
WEA	Wireless Emergency Alerts

APPENDIX A: POLYGON COMPRESSION ALGORITHM

This appendix explains the details of the polygon compression algorithm developed by the project team.

In WEA, a polygon is defined by an ordered list of latitude-longitude values,

$X_1,Y_1,X_2,Y_2,X_3,Y_3,\ldots,X_{N+1},Y_{N+1}$

where X_i (i=1, 2, …, N+1) are the latitudes of the vertices and Y_i (i=1, 2, …, N+1) are the longitudes of the vertices. A polygon with N vertices is defined by 2(N+1) numbers, where the first point is repeated at the end, i.e. $X_1 = X_{N+1}$ and $Y_1=Y_{N+1}$.

As an example, a four-point polygon is given by

32.231,-88.426,32.233,-89.321,32.927,-89.317,32.922,-88.337,32.231,-88.426.

For polygons in the United States, including Alaska and Hawaii, the latitude values lie between 18.91 and 71.39, and the longitude values lie between -179.14 and -66.95.

Steps taken for polygon compression are explained below:

1. Convert polygon coordinates to integers by keeping two decimal points and multiplying by 100. After this step, the numbers in the sample polygon become:

- 3223, -8843, 3223, -8932, 3293, -8932, 3292, -8834, 3223, -8843

2. Remove the negative sign from longitudes and remove the last two numbers, which are always the same as the first two. After this step, the numbers in the sample polygon become:

- 3223, 8843, 3223, 8932, 3293, 8932, 3292, 8834

3. Subtract a fixed value, 420, from all latitudes, and subtract another fixed value, 4000, from all longitudes. This step positions the United States approximately in the middle of all possible latitudes and longitudes that can be represented by the algorithm.

- Denote the numbers after this step by $U_1,V_1,U_2,V_2,U_3,V_3,\ldots,U_N,V_N$. These numbers are related to the original coordinates by

$$U_i = \text{round}(X_i \text{ x } 100) - 420 \quad (i = 1, 2, \ldots, N)$$

$$V_i = -\text{round}(Y_i \text{ x } 100) - 4000 \quad (i = 1, 2, \ldots, N)$$

- After this step, the numbers in the sample polygon become:
- 2803, 4843, 2803, 4932, 2873, 4932, 2872, 4834

4. Calculate differences between subsequent latitude numbers,

- $S_1 = U_1$; $S_i = U_i - U_{i-1}$ (i =2, …, N).
- Similarly, calculate differences between subsequent longitude numbers,

- $T_1 = V_1$; $T_i = V_i - V_{i-1}$ (i =2, …, N).
- After this step, the numbers in the sample polygon become:
- 2803, 4843, 0, 89, 70, 0, -1, -98
- Note that the first two numbers are not modified by Step 4, but in general the rest of the numbers reduce substantially in absolute value. This reduces the number of bits required to represent each vertex.

5. Represent the number of points in the polygon by 7 bits. The sample polygon has four points, which is represented by the bit sequence "0000100."
6. Represent the first latitude, S_1, by 13 bits, and represent the first longitude, T_1, by 14 bits. There are approximately 5250 possible S_1 values corresponding to the latitudes in the United States, which can be represented uniquely by 13 bits. Similarly, there are approximately 11220 possible T_1 values corresponding to the longitudes in the United States, which can be represented uniquely by 14 bits.

- For the sample polygon, 2803 is represented as the bit sequence "0101011110011" and 4843 is represented as the bit sequence "01001011101011."

7. Calculate the number of bits required to represent the largest difference found in Step 4, excluding the first pair of numbers. This is given by

- $B = \mathrm{Floor}(\log_2(\max[\max\{|S_i|\}, \max\{|T_i|\}])) + 1$ (i =2, …, N).
- Here, "$\log_2$"is the base-2 logarithm, "$|x|$" is the absolute value of x, and "Floor (x)" is the function that returns the largest integer not exceeding x. For the sample polygon,
- $B = \mathrm{Floor}(\log_2(98)) + 1 = 7$

8. Represent "B" found in Step 7 by 4 bits. For the sample polygon, 7 is represented by the bit sequence "0111."
9. Represent each difference, S_i and T_i (i =2, …, N), found in Step 4 by the number of bits, B, found in Step 7 plus one sign bit. For the sample polygon each difference is represented by 7+1 = 8 bits.
10. Concatenate the bit sequences found in steps 5, 6, 8, and 9. For the sample polygon, steps 5, 6, and 8 result in 38 bits. In Step 9, each of the six differences is represented by 8 bits, resulting in an additional 48 bits. Therefore, the sample polygon is compressed to a total of 86 bits (11 bytes).

The decompression operation to reconstruct the polygon from the compressed bit stream is simply done by reversing the steps.