Crowd Analyzer using Trilateration and Keep Alive Signals

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Abstract

Tracking mobile phones in a specific area is crucial for assessing population density and understanding crowd dynamics. Traditional methods rely on Wi-Fi and GPS, but offline techniques like cell tower triangulation offer valuable insights even in areas with limited connectivity. By analyzing the number of mobile phones present, estimated through trilateration using signals from the phone's keep-alive signal, one can accurately estimate the crowd size. This information aids in urban planning, transportation management, event organization, and business strategies. Empowered with such data, decision-makers can optimize resource allocation, enhance safety measures, and improve overall societal well-being through informed decision-making.

Keywords: GPS, Wi-Fi, Trilateration, Cell Tower, Keep Alive Signals

1. Introduction

The excessive population density in certain areas diminishes the enjoyment of exploring and often leads to stress, as people typically visit famous places during leisure time to relax. While controlling the overall population may not be feasible, the study proposes a solution to analyse crowd levels in specific locations remotely, without physically going to the place. This is achieved by leveraging the ubiquity of mobile phones. The approach involves analysing crowd density using a trilateration technique employed by cell towers. Each phone acts as the centre of its location, and the signal strength received from various towers is used to track the phone's location. If a particular location has a high number of phones, it is deemed crowded. This information can be utilized to plan schedules based on crowd levels, providing individuals with the ability to make informed decisions about their activities.

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2. Related Work

The various varieties of existing system in this technology are discussed below [1] The algorithmic approach relies on the Strongest RSS and Weighted Centroid algorithms for cell tower localization using received signal strength (RSS) data from wardriving. To boost accuracy, preprocessing steps include tower-based regrouping for identifying cells belonging to the same tower, boundary filtering to eliminate spatial outliers, and RSS thresholding to discard weaker signals. An essential optimization involves merging traces of cells sharing a tower, improving the estimation of the tower's location. These methods collectively address challenges with neighbouring cells, measurement biases, and spatial relationships significantly enhancing the accuracy of cell tower localization.[2] In the presented mobile subscriber locating method, multiple Base Transceiver Stations (BTS) in a GSM network are used to triangulate signal strength information. The system is based on GSM infrastructure and uses location estimation with Network Measurement Reports (NMR). The signal fingerprinting approach introduces a constant 'k,' computed by k=(2*i*v)/d, where 'i' is the velocity of the signal, and 'v' is the distance between sender and receiver. Although the study talks about the broad link between signal intensity and distance, it doesn't specifically give particular technology details or elaborate on complex mathematical procedures for triangulation. The overall architecture of the system and the use of signal strength information for positioning are highlighted.[3] The goal of the research project is to create a three-step algorithm for the cost-effective strategic placement of cell towers to improve network coverage. Geographic Information Systems (GIS), population density statistics, and satellite imagery are used by the algorithm to find possible tower locations, pick essential ones based on a number of factors, and calculate the ideal height and position for each location. Considering aspects like topography and building expenses, the suggested strategy aims to offer a workable and feasible response to the growing need for cell phone coverage in both urban and rural locations.[4] In order to help government management, Internet service providers, and mobile consumers, this research attempts to comprehend metropolitan mobile traffic trends. A model that incorporates three-dimensional data from hundreds of towers is proposed by the authors. Five time-domain traffic patterns among 9600 towers are found empirically, and each pattern is associated with an urban region. According to frequency-domain research, tower traffic is represented by a linear combination of four components. All things considered, this method improves our comprehension of extensive cellular tower traffic patterns in city environments.[5]

Incorporating user, time, and location data, this study analyses urban functional zones using Open Information Dynamic Data (OIDD). Through patterns of human mobility, the Latent Dirichlet Allocation (LDA) model—which is enhanced by time and place data—identifies discrete urban functions. The final subjects are validated and mapped onto the city, which helps to provide educated urban planning based on mobile phone data and a deep understanding of spatiotemporal urban dynamics.[6] The Estonian study extracted commute patterns from cell phone data using a Hidden Markov Model. It demonstrated the potential of mobile data for comprehending urban dynamics by reconstructing trajectories. With an emphasis on Estonia's counties and municipalities, the study highlighted the value of mobile data in tackling transportation-related issues. In addition, the study looked at urban mobility patterns inside Tallinn, which shed light on population mobility. All in all, it demonstrated the usefulness of mobile data for studying urbanization and commuting.[7] Using simulations in LTE macro cells, the study examines two scenarios with varying numbers of users and usage patterns for smartphones. A burst model is used to generate keep-alive messages, which classify background traffic into lighter and heavier categories. The study looks into how changing the RRC inactivity timer affects PUCCH signalling overhead, peak resource use, and signalling efficiency. Simulations assess the performance indicators outlined in the study by taking into account a number of factors, including bandwidth, data rate, and inactivity timeout settings.[8] The study suggests a GSM localization technique based on Pearson's correlation coefficient and RSSI. To improve accuracy, it makes use of data from nearby cells and the serving cell. In real-world experiments, the algorithm reaches a maximum inaccuracy of less than 550 m, proving its resilience and surpassing Cell-ID. Applicable to popular mobile handsets, it provides a workable way to achieve precise GSM localization.[9] In order to address issues such as data processing tools and complex urban factors, this paper investigates the mobile traffic patterns of 9600 cellular towers in urban settings. A three-dimensional model that integrates time, tower locations, and traffic spectrum is the main contribution. Five time-domain traffic patterns are identified, each of which is correlated with a particular urban area. Furthermore, a frequency-domain analysis proposes the use of four main components associated with human behaviours in the construction of tower traffic. This paper deals with many more wide concepts of cellular tower covering the location and pattern from areas across the world [10] The paper outlines a methodology that takes signal route loss requirements into consideration while establishing the initial geographic distribution of GSM base stations. Path loss models such as Okumura, Hata, CCIR, Free Space, and COST 231 Extended Hata are introduced. Georeferencing and geometric translation to map coordinates are part of the model. To accurately map a picture to geographic coordinates, the Affine transformation is used. Limited path loss values and few base stations are the goals of the suggested model. The framework includes seven modules, such as base station selection and geographic allocation. The significance of precise modelling for effective GSM network planning is emphasised in the document. Georeferencing is done using reference points from map imagery. For mapping coordinates, the Affine transformation coefficients are computed. The model provides a thorough method for addressing both urban and non-urban.

3. Proposed Work

In the process of trilateration for mobile device location estimation, the method involves measuring the time of signal propagation from the mobile device to multiple cell towers, calculating distances based on signal speed, utilizing keep-alive signals for continuous connectivity, and defining spherical surfaces around each tower to identify potential locations. The crucial step lies in determining the intersection of these spherical surfaces, pinpointing the mobile device's possible location

3.1 Initial Steps

For a clearer understanding we imagine we are estimating the population present within the park. Initially, we should estimate the area of the park using G-map API/Google earth. Next, using the cell tower locations, we get the ids of cell towers that are nearer to the park and we store the distance of each tower from the park respectively. Now we are getting the device ids that are connected to the cell tower that are nearer to the park. Once we get the idea of all the devices, we apply triangulation (detail explanation given below) for each device respectively. If a device falls within the area of the park for more than five minutes, we consider that device is contributing to the population within the park

3.1.1 Geo-Fencing

Once the public place is chosen, using coverage map and cellular map we should identify the nearby towers and approximate the range of signal strength that respective towers offer to that place. And we should store the ranges of each tower for future calculation.

The algorithm categorizes scenarios into three cases:

Case 1: If the selected location is covered by 2 or more towers, triangulation is applied. If a device is within the range of all three towers, it is concluded that the device is within that area (e.g., a mall).

Case 2: If only 2 towers are present, triangulation is still applied, but with reduced accuracy.

Case 3: In the presence of only one tower, the algorithm retrieves information on other towers outside the range of the selected location. If the device connects to any of these other towers, it signifies that the mobile device is not present in the particular place.

3.1.2 Utilization of Real-Time Signals and IMEI Numbers

There are several factors have to be considered before using triangulation techniques. They are based on the number of towers near the park

Case 1: **Applying Triangulation for Location Coverage having 2+ Nearer Towers**

Multiliterate is a sophisticated technique used to improve the accuracy of this location determination. Using several reference locations, this particular type of trilateration refines the predicted location iteratively. Starting with initial coordinate estimates, iteratively updates coordinates based on discrepancies between calculated and real distances, computes distances from the current estimate to each tower, and continues until a stable solution is reached. The

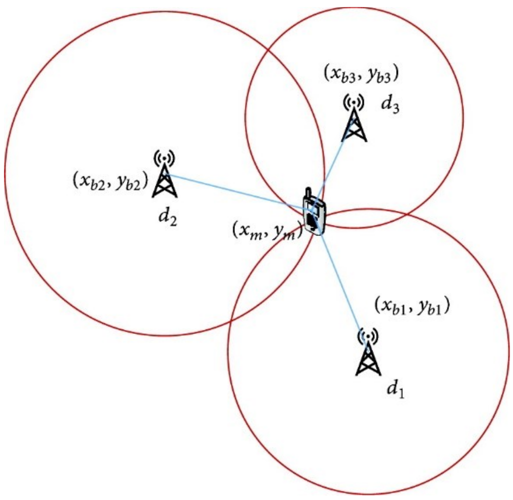

Figure1. Triangulation for Location Coverage

- **Starting Point:** Commence by making rough approximations of the mobile device's coordinates. The initial estimates will be represented as (x_0, y_0).
- **Determine Distances:** Determine how far each tower is from the present estimate. Using the Euclidean distance formula, given N towers, the distances d_i for each tower are calculated

$$d = \sqrt{(x - x_i)^2 + (y - x_i)^2}$$

where (x_i, y_i, z_i) are the coordinates of the i-th tower.

Step 1: The equations for all the circles are formulated below:
$(x – x_1)^2 + (y – y_1)^2 = r_1^2$
$(x – x_2)^2 + (y - y_2)^2 = r_2^2$
$(x - x_3)^2 + (y - y_3)^2 = r_3^2$
Step 2: Using basic math formula below
$x^2-2x+x_1^2+y^2-2y_1y+y_1^2=r_1^2$
$x^2-2x_2x+x_2^2+y^2-2y_2y+y_2^2=r_2^2$
$x^2-2x_3x+x_3^2+y^2-2y_3y+y_3^2=r_3^2$
Step 3: Subtract the equations
$(-2x_1+2x_2)x+(-2y_1+2y_2)y=r_1^2-r_2^2-x_1^2+x_2^2-y_1^2+y_2^2$
Subtract the remaining equations
$(-2x_2+2x_3)x+(-2y_2+2y_3)y=r_2^2-r_3^2-x_2^2+x_3^2-y_2^2+y_3^2$
Step 4: To make it simple lets use variables to store each equations
A1x+A2y=C
B1x+B2y=F
Step 5: The solution of this system is:
x=CB1-FA2/A1E-B1A2
y=CB1-A1F/B2A1-B1A2

- **Update Coordinates**

In order to reduce the difference between computed and measured distance, requires optimized algorithm which involves iterative optimisation procedure to minimize the error between the calculated distances d_i and the actual distances r_i.

Let's assume that E as the error function:

$$E= \sum_{i=1}^{N}(\mathrm{di} - \mathrm{ri})2$$

The goal is to find the coordinates (x, y, z) that minimize this error, typically using optimization techniques like gradient descent or Levenberg-Marquardt algorithm.

- **Iterate:** Carry this process until we get stable answer. Every time, the distance are recalculated using the coordinates we got recently, and also several adjustments are made to the coordinates to reduce error.

Once the stable location is identified and if the finalized location of a particular device falls under the area of the park which we calculated earlier then we consider that particular device is contributing to the population of a park.

- **Code**

main.py

```
#A function to apply trilateration formulas to return the (x,y) intersection point of three circles

def calculate_circle_intersection(x1_circle1, y1_circle1, r1_circle1, x2_circle2, y2_circle2, r2_circle2, x3_circle3, y3_circle3, r3_circle3):

A_coefficient = 2 * x2_circle2 - 2 * x1_circle1

B_coefficient = 2 * y2_circle2 - 2 * y1_circle1

C_term = r1_circle1 ** 2 - r2_circle2 ** 2 - x1_circle1 ** 2 + x2_circle2 ** 2 - y1_circle1   ** 2 + y2_circle2 ** 2

D_coefficient = 2 * x3_circle3 - 2 * x2_circle2

E_coefficient = 2 * y3_circle3 - 2 * y2_circle2

F_term = r2_circle2 ** 2 - r3_circle3 ** 2 - x2_circle2 ** 2 + x3_circle3 ** 2 - y2_circle2 ** 2 + y3_circle3 ** 2
```

x_intersection = (C_term * E_coefficient - F_term * B_coefficient) / (E_coefficient * A_coefficient - B_coefficient * D_coefficient)

y_intersection = (C_term * D_coefficient - A_coefficient * F_term) / (B_coefficient * D_coefficient - A_coefficient * E_coefficient)

return x_intersection, y_intersection

Apply trilateration algorithm to locate the phone

phone_x, phone_y = calculate_circle_intersection(tower1_x, tower1_y, tower1_radius, tower2_x, tower2_y, tower2_radius, tower3_x, tower3_y, tower3_radius)

Output phone location / coordinates

print("Phone Location:")

print("x-coordinate:", phone_x)

print("y-coordinate:", phone_y)

The algorithm's iterative structure guarantees that the estimated coordinates steadily improve until the computed and real distances to the towers are almost identical. The exact location of the mobile device is determined by this convergence.

Case2 : Bilateral Triangulation for Location Estimation with only Two nearer Towers

This is comparable to instance 1, but it differs in that there is an accuracy issue because just two towers are used, rather than the maximum number.

Same using the Euclidean distance formula, given N towers, the distances d_i for each tower are calculated

$d=(x-x_i)^2+(y-y_i)^2$ where (x_i, y_i, z_i) are the coordinates of the i-th tower.

Step 1: The equations for two tower circles are below

$(x - x_1)^2 + (y - y_1)^2 = r_1^2$

$(x - x_2)^2 + (y - y_2)^2 = r_2^2$

Step 2: Using basic formulas expand the above equations

$x^2-2x_1x+x_1^2+y^2-2y_1y+y_1^2=r_1^2$

$x^2-2x_2x+x_2^2+y^2-2y_2y+y_2^2=r_2^2$

Step 3: Subtract both the equations

$$(-2x_1+2x_2)x+(-2y_1+2y_2)y=r_1^2-r_2^2-x_1^2+x_2^2-y_1^2+y_2^2$$

Step 4: Finally, we get the location of x and y.

- **Iterate:** Carry out the steps again and again until the coordinates converge on a stable answer. Every time, the distances are recalculated using the most recent coordinates, and additional adjustments are made to the coordinates to reduce error. The process of iteration persists until the coordinate changes become insignificant, signifying convergence.

Once the stable location is identified and if the finalized location of a particular device falls under the area of the park which we calculated earlier then we consider that particular device is contributing to the population of a park

Case 3: Presence of a Single Tower (Rare Case)

This is an uncommon instance when only one tower is present nearer to the park, making it extremely difficult to determine whether the device is present inside the park or outside the park range. Unlike the above two cases the probability of finding the device location is reduced drastically here due to the lack of information we have right now.

But to overcome this scenario we came into a new ideology. In this, we again use the cell coverage map and get the details of towers which are far away to the park and don't provide coverage to the devices in the park. And we check whether the devices present in the nearer tower are present in these towers. If the device is present in those towers, it means that the particular device doesn't contribute to the population of the park. Only those devices which are not in the range of other towers will be counted. But it is less common and it also less accurate than other cases.

4. Methodology

4.1 Determining Location

Trilateration is a fundamental technique used in various applications, notably in cellular and wireless communication systems, to pinpoint the location of a mobile device. This process involves measuring the time it takes for signals to propagate between the device and multiple reference points, typically cell towers. By calculating the distance between each tower and the device based on signal propagation time and employing sophisticated geometric computations, trilateration narrows down potential locations of the device to a single point in space where the distances from all reference points align.

Key components include mobile equipment as the target device, reference points such as cell towers, and precise distance measurement methods like GPS or signal intensity. Trilateration algorithms analyse distance measurements from at least three reference points to determine the device's position accurately. This method offers a robust means of location determination, essential for various applications requiring precise spatial information.

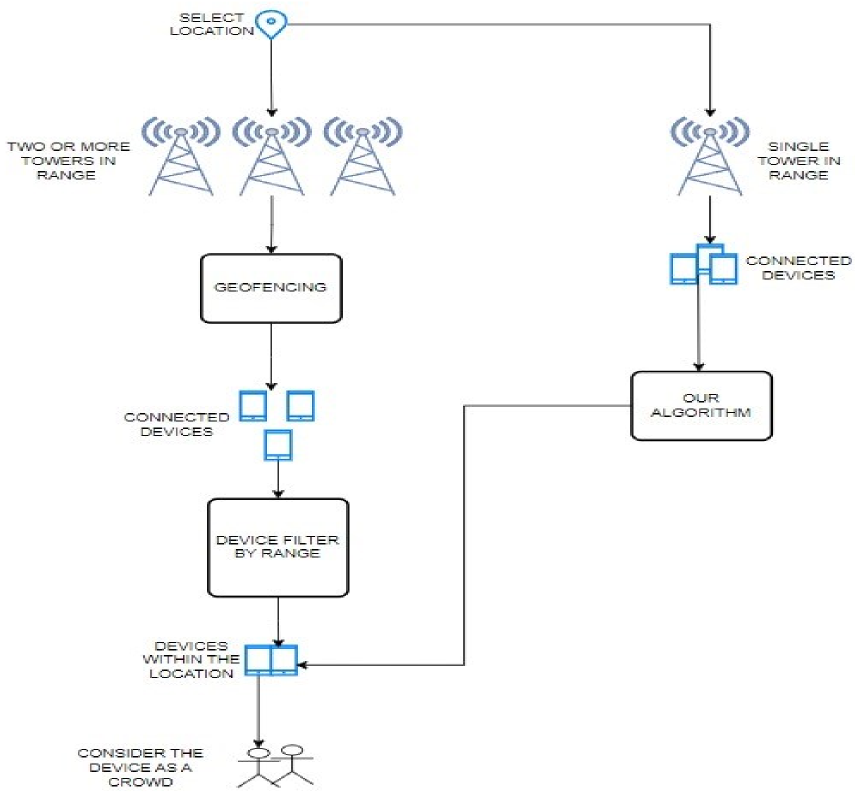

Figure 2. Determining Location

4.2 Connection Establishment

Upon device activation, the system initiates a sequence whereby the device transmits a keep-alive signal to nearby towers, verifying the connectivity status between the mobile device and the tower. Once connectivity is established, a confirmation message is relayed. Each mobile device is uniquely identified by its IMEI number, facilitating the tower's tracking of connected devices. The recurrent transmission of keep-alive signals ensures the continuity of the connection, with each signal serving to reaffirm connectivity status every second.

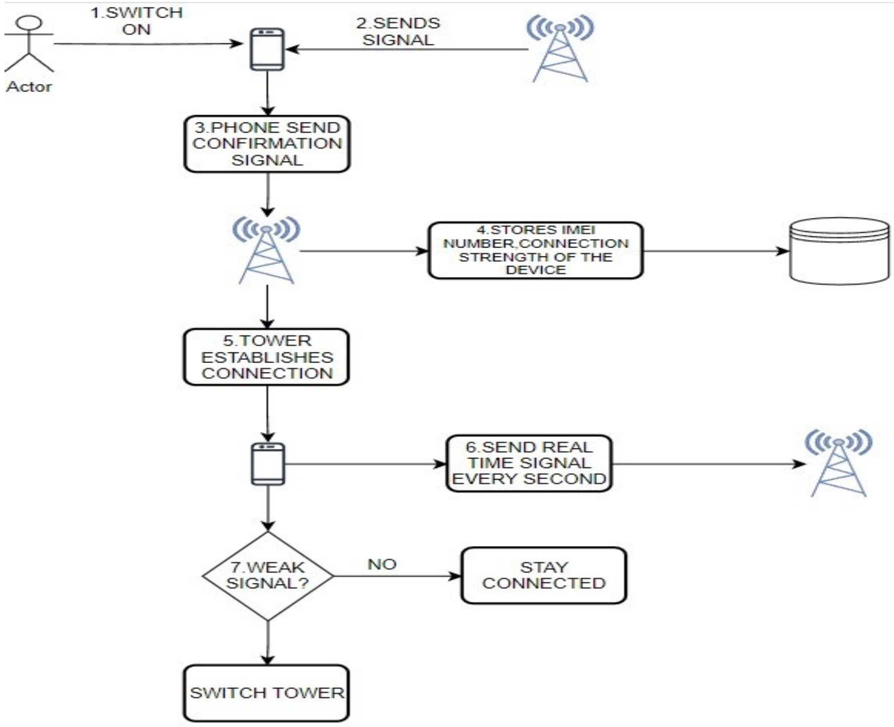

Figure 3. Connection Establishment

4.3 Components Used

- **Mobile Equipment:** The target device in trilateration is typically a mobile device, such as a smartphone or tablet, capable of connecting to the internet to access location-based services.

- **Points of Reference:** Trilateration involves geometric calculations based on the intersection of circles or spheres centered at established reference points. These reference points serve as the basis for determining the device's location. The radii of these circles or spheres correspond to the measured distances from the mobile device. Understanding the precise locations of these reference points is crucial for accurate trilateration.

- **Measurement of Distance:** Accurate distance measurement is fundamental to trilateration. Various technologies are utilized to estimate distances between the mobile device and reference points. These technologies include GPS signal reception, time-offlight methods (used in radar or ultrasonic systems), and signal intensity measurements (common in cell towers and Wi-Fi networks). Precise distance information is essential for achieving accurate location estimates.

- **Keep Alive Signal:** In addition to the above components, trilateration may also consider keep-alive signals emitted by the mobile device. Keep-alive signals are periodic data exchanges between the device and the network, ensuring continuous connectivity. These signals provide valuable data that can contribute to the accuracy of the trilateration process by aiding in tracking the device's location through cellular network data.
- **Signal Transmission to Tower:** Mobile devices continuously send signals to nearby cell towers to maintain network connectivity. These signals, often referred to as handshake or keep-alive signals, ensure that the device remains connected to the cellular network. By analyzing these signals along with other location data, such as GPS information and signal strength, trilateration algorithms can accurately determine the device's location relative to the surrounding cell towers.
- **Alphabet for Trilateration:** Trilateration algorithms analyze distance measurements from a minimum of three reference points to determine the position of the mobile device. These algorithms typically involve solving a system of equations using measured distances and known coordinates of reference points. The mathematical approach plays a primary role in determining the device's position during trilateration.
- **Compute Geometry:** Geometric calculations are central to trilateration, involving the intersection of circles or spheres centered at reference points. These circles or spheres are defined by the measured distances from the mobile device. By computing the intersections of these geometric shapes, potential locations of the device are identified. This process narrows down the device's position within a specific margin of error.

4.4 Discussion

Navigating the complexities of accessing IMEI data for identifying devices connected to mobile towers entails a strategic blend of legal compliance, ethical considerations, and professional collaboration. While privacy concerns necessitate careful handling of sensitive user data and adherence to relevant regulations, obtaining permissions from tower providers like Airtel is paramount for accessing such information in a lawful and ethical manner. Transitioning from theoretical submissions to real-time projects requires a commitment to professionalism, including the pursuit of formal agreements or partnerships with data providers. Exploring alternative approaches or data sources may offer viable solutions while ensuring project integrity and respect for user privacy remain central tenets of development efforts.

5. Conclusion

In response to the pressing need for efficient time management in today's fast-paced world, the proposed solution offers a sophisticated extension or application designed to seamlessly integrate with users' calendars. By harnessing real-time data on crowd density at specific locations, this innovative tool empowers users to make informed decisions about their schedule without disruption. By leveraging this technology, individuals can preemptively assess crowd levels, strategically plan their activities, and navigate their day with ease, thereby minimizing stress and maximizing productivity.

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Author's biography

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