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Cell Tower Localization Approach for Vehicles Tracking

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Abstract

Tracking systems are common tools for managing transportation, monitoring vehicles, and securing vehicles. However, current tracking systems depend on GPS technology, which necessitates hardware and communication with satellites, making power consumption higher and more costly. Besides, the functioning of GPS technology may be affected in regions with reduced visibility of satellites. For this reason, new localization systems have received much attention. The aim of this study is to design an IoT vehicle tracking system by using cell tower localization in lieu of the existing GPS-based tracking systems. The vehicle tracking system has been designed using the Raspberry Pi 3 model B, 4G LTE modem, Google Geolocation API, and Google Maps services. The cell tower IDs have been captured by using the LTE modem and transformed into geographical positions to track the vehicles in real time. For testing the performance, both the proposed approach and the GPS localization technique have been applied on the same path with ten predetermined points. Coordinates obtained in both localization methods were highly consistent within the test locations. An average positioning error was measured in meters by the Haversine distance between cell tower localization coordinates and GPS coordinates. As a result, an average positioning error of 1.48 m was calculated, with the minimal value being equal to 0.00 m and the maximum value being 4.98 m. The system successfully implemented vehicle monitoring and visualization of the vehicle location via a web interface. Experimental results show that the use of cell tower localization is a promising low-cost option for vehicle tracking in Internet of Things systems. While GPS localization is still the most popular method for positioning, it is evident that the suggested method produces equally accurate positioning results. In future studies, the use of hybrid localization methods will be examined.

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Introduction

The Vehicle Tracking System (VTS) has gained much popularity in today's transport sector and has become a very important part of logistics and fleet management systems and vehicle security. VTS helps monitor the position of the vehicle to make the process more effective and efficient, optimize routes, and also find stolen cars. With the emergence of new IoT technologies, there has been an increase in the demand for efficient and affordable vehicle localization systems that will be able to provide continuous position updates of the vehicle in different working conditions. Although there has been progress made in tracking technology, vehicle localization is still a difficult task, especially in urban areas (Calabrese et al., 2010; Hu et al., 2012).

The Global Positioning System (GPS) is the most popular solution for vehicle tracking because of its global coverage and relatively high precision (Zhou et al., 2012). Yet, GPS-based methods need to be equipped with hardware and maintain communication with several satellites, which leads to higher power expenditure and higher implementation expenses. In addition, there could be situations when GPS fails due to its poor signal in urban settings or tunnels. All these factors stimulate researchers to consider other possibilities of localizing objects using current communication technologies.

Cellular network coverage is quite extensive geographically and is present in almost all regions of habitation. Thus, cell tower localization has become a promising way of finding out the location of a mobile object, not depending entirely on satellite positioning systems. With the use of information retrieved from nearby cellular towers, the position of a moving vehicle can be found out and displayed on the map (Maaref et al., 2018).

The key contribution of this research is in developing an IoT-based system of vehicle tracking by means of cell tower localization as a replacement for the traditional system of vehicle tracking based on GPS localization. The suggested vehicle tracking system involves a Raspberry Pi hardware platform, a 4G LTE modem, the Google Geolocation API, and the Google Maps visualization service. Additionally, the research provides an experimental comparison of cell tower and GPS localization techniques under equal conditions.

The organization of this paper is as follows. Section II includes a literature review of the GPS and cellular-based location techniques that have been developed to date. Section III is devoted to methodology, where a description of hardware and software, and setup will be provided. The trilateration-based cell tower localization technique will be described in Section IV. In Section V, the implementation of the vehicle tracking system is described. System development is explained in Section VI, while results and their analysis, along with GPS comparison, are given in Section VII.

Literature Review

In recent times, there has been a surge in efforts towards achieving better accuracy in vehicle localization through cellular networks, Internet of Things systems, and hybrid localization methods that help overcome the deficiencies in GPS tracking technology (Yang et al., 2010). In this research, intelligent systems' application is being stressed for real-time detections and monitoring tasks, where lightweight computation models in embedded systems are used, which makes the feasibility of a Raspberry Pi-based tracking framework possible (Alrifaie et al., 2021; Iszaidy et al., 2016). Also, conventional IoT-based vehicle tracking systems that make use of Raspberry Pi and GPS/GSM modules have been extensively studied, focusing on cost-efficient solutions and real-time monitoring in transportation systems (Nalawade & Akshay, 2016; Shinde & Mane, 2015), and (Almishari et al., 2017). Nonetheless, these techniques depend heavily on satellite availability, hence the need for alternative localization techniques.

The latest developments in cellular-based localization techniques prove better precision and scalability of such approaches (Mistary & Chile, 2015). The article (Gao et al., 2024) provides scalable cellular localization techniques that prove the possibility of using telecom data for real-life location-based applications (Varandas et al., 2010; Zhou et al., 2024). It also expands on the idea of using cellular data by proving that the information about the serving cell tower is enough to perform transportation mode detection; thus, it proves that there is enough spatial information available from cellular signals (Mostafa et al., 2024). This finding supports previous research on the potential of LTE signals for vehicle tracking, even though the latest research makes improvements regarding scalability and precision (Driusso et al., 2016).

Some hybrid approaches to location-based systems have also been suggested by using the combination of GNSS, IMU, and cellular signals (Kassas et al., 2020; Laoudias et al., 2018). Furthermore, LiDAR and vision-based sensing technologies have also been discussed for position-related applications (Bian et al., 2019); however, they are mostly used in expensive autonomous systems rather than cheap IoT trackers. Finally, the paper shows that the optimization techniques may help improve the deployment of cellular infrastructure, which leads to better localization precision (Bharadwaj et al., 2022).

In general, it is evident from the literature that there has been a transition from the use of GPS-based systems to cellular and hybrid localization approaches, and current literature proves that LTE-based localization can produce highly accurate results. This proves that the proposed research will provide a viable solution for localization based on cell towers.

Methods and Materials

This particular vehicle tracking system was designed and tested through the use of a combination of embedded hardware, cellular connectivity systems, cloud-based location services, and web-based visualization tools. The idea was to evaluate the effectiveness of cell tower localization and GPS localization in similar environments.

Hardware Configuration

The design of the tracking device was carried out using a single-board Raspberry Pi 3 Model B computer, which had a 1.2 GHz 64-bit quad-core ARM Cortex-A53 processor, 1 GB RAM, Wi-Fi, and USB interfaces. In particular, the Raspberry Pi acted as the central processing unit for data acquisition, coordinate processing, recordkeeping, and transmission to the remote server.

For the cellular connection, a 4G LTE D-Link DWR series USB Modem with a standard SIM card was connected to the Raspberry Pi. The modem was used to provide the Internet connection and access to cellular towers needed for the localization process.

Additionally, a GPS receiver module was also connected for the comparative experiments to provide satellite positioning data. The power supply of the device was provided by a portable 10,000 mAh power bank and allowed continuous operation without the use of the car's electric power supply system.

Moreover, a 4 GB Toshiba USB Flash Drive was connected to the Raspberry Pi for local recordkeeping of collected data.

Software Environment

The Raspberry Pi used the Raspberry Pi Operating System (OS), which is Linux-based. All the modules responsible for localization and communication were coded in Python 3.x. The software solution consisted of modules for the following operations: Obtaining cellular tower information; Obtaining GPS coordinates; Data logging and storage; Communicating with the web server; Location update in real-time.

Google Maps Geolocation API was used to obtain the latitude and longitude coordinates based on cellular tower information. The locations of the vehicles were visualized using the Google Maps JavaScript API.

Experimental Procedure

Experimental verification was carried out in different urban areas within the study area. There were two methods used for experimentation: Cell tower localization and GPS localization.

In both cases, the vehicle moved along the same predefined path with ten reference points. In a moving vehicle, data about location was automatically gathered and updated every 10 seconds. Each record consisted of the following: latitude, longitude, timestamp, location name, and movement of the vehicle.

To enhance the reliability of results, experiments were done twice on two different days with the same operating conditions. Coordinates were automatically saved on a USB flash drive and also transferred to the web server for visualization.

Data Collection and Analysis

The localization data that was collected was imported into an Excel file for analysis. The coordinates gathered through both localization techniques were then analyzed for differences in similar places at similar times. Differences were measured for consistency of localization methods. Variables that could have caused variation in the localization were things like traffic on the network, access to cellular towers, weather, and visibility of satellites.

A Cell Tower Localization and Trilateration Model

The proposed localization technique determines the position of the car using the data provided by the cellular towers that surround the vehicle. Each tower's location is determined via the Google Maps Geolocation API by using the respective Cell ID. In case there are at least three towers available, the position of the car can be found using trilateration.

Equation (1) assumes that three neighboring cellular towers are located at known coordinates.

$$T_1(x_1, y_1), T_2(x_2, y_2), T_3(x_3, y_3) \tag{1}$$

and the distances between the vehicle and each tower are denoted by equation (2).

$$d_1, d_2, d_3 \tag{2}$$

respectively.

Estimation of the distance between the vehicle and the towers is done using the received signal strength indication (RSSI) based on the logarithmic path loss model. These equations are shown in equation (3):

$$RSSI = RSSI_0 - 10n\log_{10}(d) \tag{3}$$

Where

- $RSSI$ is the measured signal strength (dBm),
- $RSSI_0$ is the reference signal strength measured at a distance of 1 m,
- n is the path-loss exponent,
- d is the estimated distance from the tower.

Rearranging equation (4), the distance can be estimated as:

$$d = 10^{\frac{RSSI_0 - RSSI}{10n}} \tag{4}$$

After estimating the distances from the three towers, the vehicle position (x, y) is obtained by solving the following system of trilateration equations (5), (6), and (7):

$$(x - x_1)^2 + (y - y_1)^2 = d_1^2 \tag{5}$$
$$(x - x_2)^2 + (y - y_2)^2 = d_2^2 \tag{6}$$
$$(x - x_3)^2 + (y - y_3)^2 = d_3^2 \tag{7}$$

The meeting point of all three circles shows the estimated position of the car. In situations where there are more than three towers, the least squares estimation method can be used to minimize errors in positioning.

Algorithm 1: Vehicle Position Estimation

Input: Cell IDs and RSSI values from neighboring towers

Output: Estimated vehicle coordinates (x, y)

Step 1: Detect nearby cellular towers.

Step 2: Obtain Cell IDs and RSSI measurements.

Step 3: Retrieve tower coordinates using Google Geolocation API.

Step 4: Convert RSSI measurements into distance estimates.

Step 5: Construct trilateration equations.

Step 6: Solve the equations to estimate vehicle coordinates.

Step 7: Store latitude and longitude values.

Step 8: Display the estimated location on Google Maps.

Step 9: Repeat every 10 seconds for real-time tracking.

Algorithm 1 illustrates the process used in estimating the position of a car through data gathered from surrounding cellular towers. The process starts with the identification of the neighboring cell towers along with the gathering of their respective Cell ID and RSSI values. The coordinates of the towers are acquired using the Google Geolocation API, while the distance is obtained from the conversion of the RSSI values. With the obtained distances and coordinates, trilateration equations can be set up and solved to estimate the car's position. The outputted coordinates will then be saved, plotted in Google Maps, and refreshed every 10 seconds.

Vehicle Tracking System

In a cellular system, the term handover (or handoff) refers to when distributed mobile transceivers switch between cell frequencies during an ongoing call, without interruption and without a base station operator or manual switching. The mobile unit automatically switches from its current channel to a new channel, as provided by a new base station (Miao et al., 2017). The exact details of this move vary, depending on the system. You may have noticed that antennas on a cell tower are always arranged in a triangle (the reasons for this will not be detailed here). This enables a cell tower to distinguish which antenna is sending a signal. The location can be identified according to the triangulation concept, considering other objects and barriers. When the vehicle is located between more than one cell tower, it gives a greater chance of getting a more accurate location. The obtained signal should be converted into a format of (latitude, longitude) pair. This pair will be presented as a real location on a digital map by using Google Maps, as shown in fig. 1.

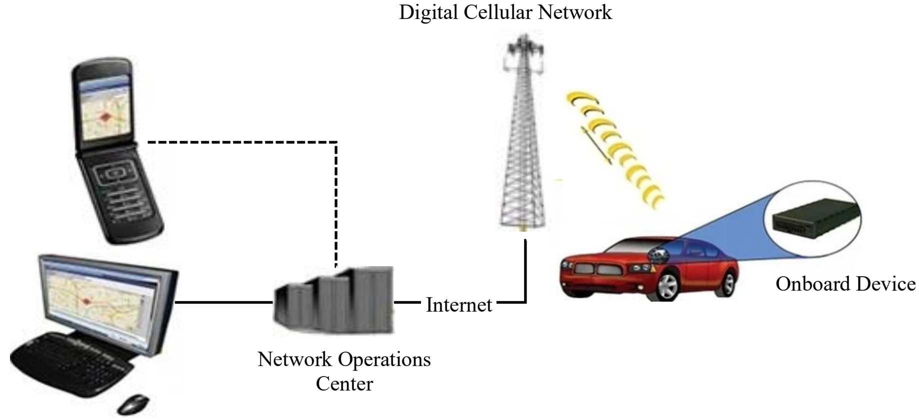

Fig. 1: Vehicle Tracking and Monitoring by Using Cell Tower Localization

To get the signal of the LTE, at first, the study has to get the cell ID and then the antenna in order to measure the position. Each LTE signal can be defined using time frequency networks for each antenna port represented by p, where each network element is mapped to Sp l [k] as a resource (RE) element. Whereas K is a subcarrier in OFDM, as shown in equation (8) (Driusso et al., 2016).

$$S_l^p(t) = \sum_{k=-\frac{N_{sc}}{2}}^{k=-1} \left(S_l^p[k + \tfrac{N_{sc}}{2}]\, e^{j2\pi k\Delta ft}\right) + \sum_{k=0}^{k=\frac{N_{sc}}{2-1}} \left(S_l^p[k + \tfrac{N_{sc}}{2}]\, e^{j2\pi(k+1)\Delta ft}\right),\ t \in [-T_{CP}, l, T_s] \qquad (8)$$

A GPS tracking system, on the other hand, uses GPS satellites, which circle the earth twice a day in a precise orbit. GPS devices can find the precise location of a satellite thanks to each satellite's unique signal and orbital parameters, thereby providing GPS receivers with information to locate a user. They do so by measuring the time it takes to receive a signal. With distance measurements from a few more satellites, the receiver can determine a user's position and display it electronically to measure a running route or locate a vehicle. A GPS tracking unit is a device that uses the Global Positioning System to determine the precise location of a vehicle or other asset to which it is attached. A GPS receiver is operated by a user on Earth; it measures the time taken by radio signals to travel from four or more satellites to its location, then calculates its distance from each satellite, and from this calculation, it determines the longitude, latitude, and altitude of that position. The tracking system uses measurements from several cellular base stations to precisely estimate the vehicle's location through triangulation or trilateration method (Chang, 2024), Shen et al., (2025). In this project, Raspberry Pi will be connected to a GPS receiver that operates with satellites by getting the signal and sending it to the web server in order to represent the location on the map.

System Development

Cell Tower Based Localization

The proposed system consists of three main elements: Raspberry Pi, USB LTE (a SIM card adapter), and a power supply (for this purpose, a power bank can be used, or the study can connect the components to the original vehicle's electricity).

For this experiment, the study used a power bank. In addition, a flash memory drive can be used to store the information and details (optional). For this proposed system, the study used a Toshiba 4GB flash memory drive. Fig. 2 shows how all the components are connected together.

Fig. 2: The Vehicle Unit is Embedded Inside the Vehicle

The SIM card adapter is very important for connecting the Raspberry Pi to the internet, so the study used a D-Link 4G modem for faster service and more efficient performance.

GPS Based Localization

This experiment is used to compare the results of the fundamental one to measure and decide which one is more efficient under the same circumstances. For this experiment, a Raspberry Pi will be used as an embedded system connected to a GPS receiver to get the current coordinates of the tracked vehicle and to send them to the web server to be represented on the map using Google Maps, and a sim card adapter will be used to connect the raspberry pi to the web server to represent the location. Furthermore, a pen drive can be used as a portable storage device to store the information obtained. Fig. 3 shows and clarifies all the connected components.

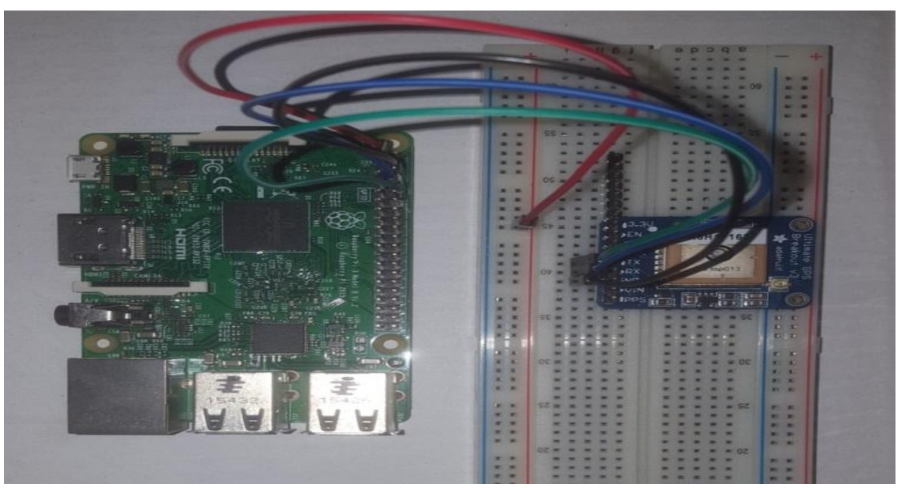

Fig. 3: GPS-based Localization Components

After the study connect the hardware unit to a power supply, this programming code will directly obtain the required information about the cellular tower. The information obtained will be stored temporarily to be converted later into latitude/longitude. The function get CellTowerInfo () has been written in Python to obtain the cell tower's ID, which is not a difficult process and can be done by various applications and even online by many websites. This information is regarded as the first stage of this work; depending on this information, the study can know the exact location of the cell tower, the number of sectors it serves, and the radius of each sector. This information should be converted into a latitude and longitude format to make it easier to identify the position of the vehicle, as shown in Algorithm 2, which clarifies the process of converting the obtained information into a latitude/longitude format.

Algorithm 2 Converting cell tower information to Latitude/Longitude format
Input: Brought information on the cell tower Output: Latitude/Longitude format information Start Step 1: Create an account on Google Maps Geolocation API. Step 2: Get a private key from the website to be used along with information Step 3: Enter the information you have obtained, such as the cell tower's ID, to get the pair of latitude/ longitude. Step 4: Repeat all steps every 10 seconds. End

From the latitude/longitude pair of the cell tower and the identification of the transmitter sector, the study can identify the radius of the sector to estimate the position of the vehicle. The chance of getting a more accurate position is increased when the vehicle is located by more than one tower, so that the concept of triangulation can be applied. The vehicle's location can then be estimated based on two or three towers that surround the vehicle. In fact, there are many applications and free websites that provide the location of cellular towers depending on the cell tower's ID. For this project, the study has used the Geolocation API of Google Maps to perform that function. A loop has been created every 10 seconds to make it a real-time tracking. This interval of time is approximately the time needed to get the information, store it, and get the real location in a latitude/longitude format. Once the information is in a latitude/longitude format, it is easy to represent it on the map to make it more attractive and easier to track by the tracker. For this purpose, the study has used JavaScript code to get the map from Google Maps and embedded it into this website to show the vehicle's location on it.

Results and Discussion

After installing the hardware unit inside the vehicle, multiple readings of the system results were recorded at different intervals and days to obtain more realistic results. A table in MS Excel was then created and saved automatically on the pen drive connected to the hardware unit as portable storage to store the results in columns. Each column refers to required data, such as latitude, longitude, place, and date/time of reading, as shown in table 1, which presents a sample of the recorded readings using a cell tower-based localization system. This data can be used as a historical report of movements. At the same time, these data were sent to the web server to be represented as real-time tracking on a digital map using Google Maps.

Table 1: Sample of Recorded Readings by Using Cell Tower Localization (1st try)

No	Lat	Lon	Address	Position Time
1	39.932798	32.878075	Dikimevi	22/11/2025 10:15
2	39.927838	32.867210	Kurtuluş park	22/11/2025 10:20
3	39.920683	32.853867	Güven park	22/11/2025 10:29
4	39.891628	32.853389	Atakule	22/11/2025 10:41
5	39.896141	32.845471	Dikmen vadisi	22/11/2025 11:03
6	39.925322	32.836858	Anıtkabir	22/11/2025 11:21
7	39.937766	32.839236	Dört mevsim parkı	22/11/2025 11:42
8	39.988914	32.644005	Göksu park	22/11/2025 12:04
9	39.987740	32.679739	75 yıl maliye ormanı	22/11/2025 12:16
10	39.980912	32.694720	Botanik metro istasiyon	22/11/2025 12:31

After obtaining the results of this scenario, the study then moved on to the second phase of this scenario. To achieve better and more realistic results, the study decided to repeat the implementation of Scenario A. Another test was conducted by visiting the same areas mentioned in the first stage, albeit at different times than those used in the first stage.

As stated in the earlier stage, the hardware unit was installed in the vehicle and launched towards the mentioned areas, as shown in table 2. The purpose of repeating the process was to make sure the results obtained in the first test were accurate, and to determine whether there would be a difference in the results or if the same results were repeated every time.

Table 2: Sample of Recorded Readings by Using Cell Tower Localization (2nd try)

No.	Lat	Lon	Address	Position Time
1	39.932770	32.878075	Dikimevi	24/11/2025 10:20
2	39.927844	32.867210	Kurtuluş park	24/11/2025 10:27
3	39.920683	32.853870	Güven park	24/11/2025 10:34
4	39.891628	32.853389	Atakule	24/11/2025 10:48
5	39.896162	32.845481	Dikmen vadisi	24/11/2025 11:10
6	39.925385	32.836869	Anıtkabir	24/11/2025 11:30
7	39.937776	32.839236	Dört mevsim parkı	24/11/2025 11:51
8	39.988914	32.644015	Göksu park	24/11/2025 12:11
9	39.987740	32.679751	75 yıl maliye ormanı	24/11/2025 12:25
10	39.980912	32.694720	Botanik metro istasiyon	24/11/2025 12:40

In addition to being stored on the flash memory connected to the hardware unit, the table simultaneously sends the required data to the website for the purpose of interactive presentation and representation in an easy manner that allows the user to track and control the vehicle smoothly. The data sent to the website is represented in real time on a digital map using Google Maps, including a message that appears next to the form of the vehicle showing some additional information that is useful in the monitoring and tracking process. These data include date/time, latitude, longitude, mileage, movement direction, and speed, as shown in fig. 4.

Fig. 4: Sniped Pictures from the Website for a Tracked Vehicle in Real Time by Using Cell Tower Localization

The multiple readings were measured later by drawing a comparison with the results of scenario A. An Excel table was then created and saved automatically on the pen drive, which is connected to the hardware unit as a portable storage device to store the results in columns, each referring to required data, such as latitude, longitude, place, and date/time of reading. Table 3 explores a sample of recorded readings using a GPS-based localization system. In this table, a sample of the readings recorded for the same areas visited in Scenario A was reviewed and found to be close to that recorded in the first scenario.

Table 3: Sample of Recorded Readings by Using GPS Localization (1st try)

No.	Lat	Lon	Address	Position Time
1	39.932760	32.878044	Dikimevi	22/11/2025 10:15
2	39.927850	32.867213	Kurtuluş park	22/11/2025 10:20
3	39.920683	32.853867	Güven park	22/11/2025 10:29
4	39.891628	32.853389	Atakule	22/11/2025 10:41
5	39.896115	32.845441	Dikmen vadisi	22/11/2025 11:03
6	39.925322	32.836858	Anıtkabir	22/11/2025 11:21
7	39.937763	32.839236	Dört mevsim parkı	22/11/2025 11:42
8	39.988914	32.644005	Göksu park	22/11/2025 12:04
9	39.987745	32.679724	75 yıl maliye ormanı	22/11/2025 12:16
10	39.980933	32.694700	Botanik metro istasiyon	22/11/2025 12:31

As shown in table 4, at this stage, the same process as in Scenario A will be repeated by retrying the test again using the GPS receiver and installing it on the hardware unit inside the vehicle. This time, the test will be conducted at different times than the first time in Scenario B. After obtaining the results, the study will have a better chance to analyze and compare them in order to obtain adequate answers to all the questions raised during the tests.

Table 4: Sample of Recorded Readings by Using GPS Localization (2nd try)

No.	Lat	Lon	Address	Position Time
1	39.932760	32.878044	Dikimevi	24/11/2025 10:20
2	39.927850	32.867213	Kurtuluş park	24/11/2025 10:27
3	39.920684	32.853824	Güven park	24/11/2025 10:34
4	39.891637	32.853389	Atakule	24/11/2025 10:48
5	39.896115	32.845435	Dikmen vadisi	24/11/2025 11:10
6	39.925312	32.836859	Anıtkabir	24/11/2025 11:30
7	39.937766	32.839256	Dört mevsim parkı	24/11/2025 11:51
8	39.988914	32.644015	Göksu park	24/11/2025 12:11
9	39.987725	32.679724	75 yıl maliye ormanı	24/11/2025 12:25
10	39.980973	32.694720	Botanik metro istasiyon	24/11/2025 12:40

Localization Error Analysis

For quantitative analysis of the localization algorithm's efficiency, the coordinates determined by cell towers were compared to those determined by GPS in the same places. The error of positioning was computed as the geographical distance between the two coordinate sets.

The error of localization E between two points is computed using equation (9):

$$E = \sqrt{(x_{GPS} - x_{Cell})^2 + (y_{GPS} - y_{Cell})^2} \qquad (9)$$

Where:

- x_{GPS} and y_{GPS} represent the latitude and longitude obtained from GPS localization,
- x_{Cell} and y_{Cell} represent the latitude and longitude obtained from cell tower localization.

In order to get a more accurate calculation of distances based on geography, Haversine formula was employed to translate differences in coordinates to meters, as shown in equation (10):

$$d = 2R\arcsin\left(\sqrt{\sin^2\left(\frac{\Delta\phi}{2}\right) + \cos(\phi_1)\cos(\phi_2)\sin^2\left(\frac{\Delta\lambda}{2}\right)}\right) \qquad (10)$$

Where:

- R is the Earth's radius (6371 km),
- ϕ is latitude,
- λ is longitude.

The results show the difference between the proposed methodology and GPS measurements.

Table 5: Positioning Error Between Cell Tower Localization and GPS Measurements

Location	Error (m)
Dikimevi	4.98
Kurtuluş Park	1.36
Güven Park	0.00
Atakule	0.00
Dikmen Vadisi	3.86
Anıtkabir	0.00
Dört Mevsim Parkı	0.33
Göksu Park	0.00
75 Yıl Maliye Ormanı	1.39
Botanik Metro Station	2.89
Average Error	1.48
Maximum Error	4.98
Minimum Error	0.00

In order to quantitatively assess the performance of the proposed method for the localization of the cell tower, the coordinates generated by the cell tower method were compared with those generated by the GPS method on the same test points. The localization error was measured in terms of the Haversine distance between the two sets of coordinates. It can be seen from table 5 that the errors in localization varied from 0.00 m to 4.98 m, with an average localization error of 1.48 m. The largest error occurred in Dikimevi, but there were a number of points where the two sets of coordinates were very similar.

All data recorded using a cell tower-based localization system were compared to data recorded using the GPS-based localization system. The comparison process was presented in the form of illustrative charts to show a better comparison of results. This difference may be due to several factors that are almost variable and not fixed at all. The change in these data may be due to climatic conditions and weather conditions, in addition to the time at which readings were recorded.

After comparing the results obtained in Scenario A, the study found that there is a clear difference in the coordinates between the first and the second attempts. This difference may be caused by a peak time difference for cellular networks, resulting in a different momentum on cellular communication towers. As shown in fig. 5, which represents a comparison of the results obtained using the proposed approach of cell tower-based vehicle localization.

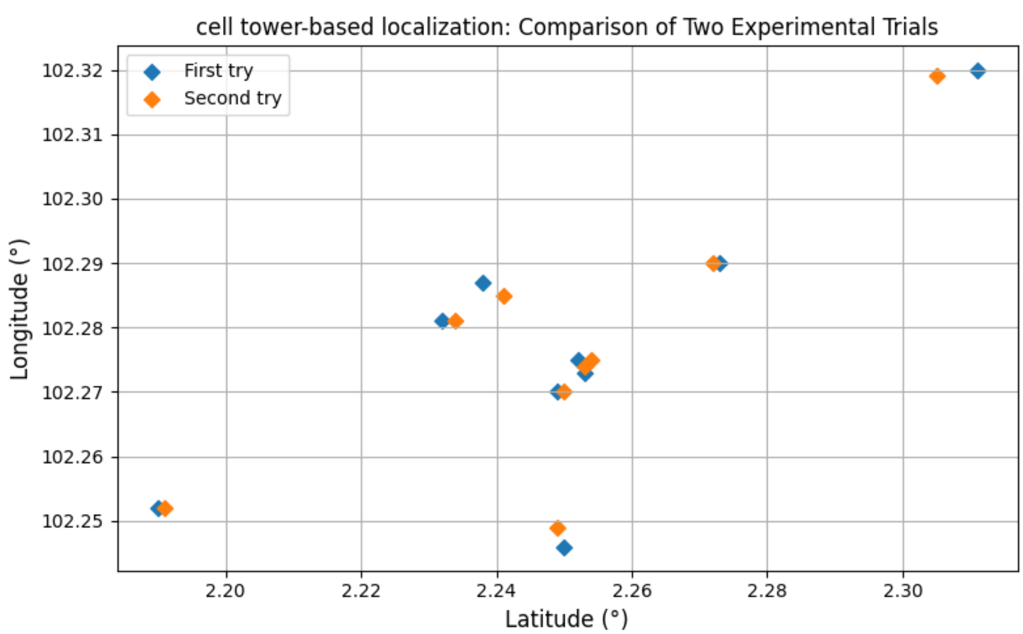

Fig. 5: **Comparison of Localization Coordinates Obtained from Two Experimental Runs Using Cell Tower-based Localization**

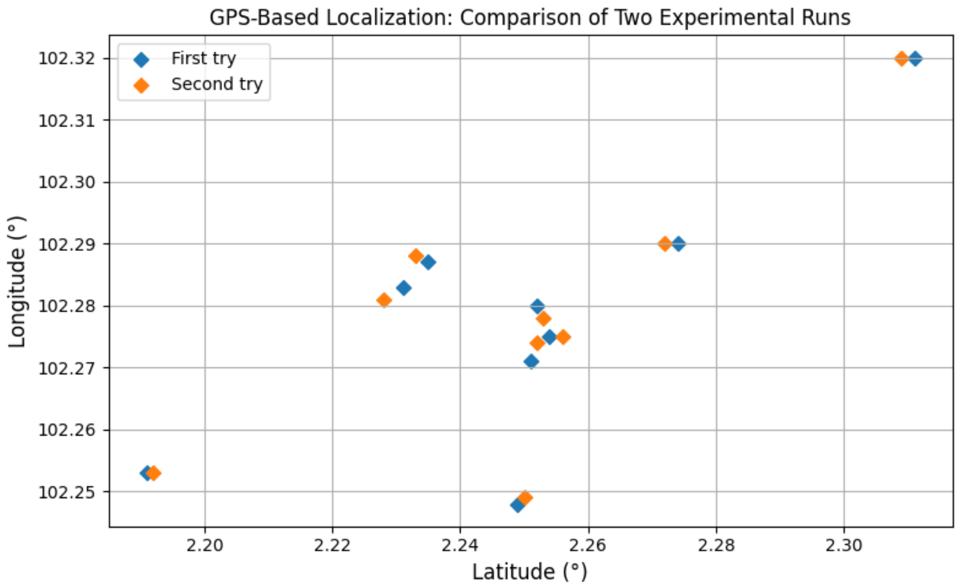

Fig. 6: **Comparison of Localization Coordinates Obtained from Two Experimental Runs Using GPS-based Localization**

As is evident in fig. 6, the x-axis represents latitude points, and the Y-axis represents longitude points. The points in blue represent the coordinates obtained as a result of Scenario A in the first attempt, in a neighborhood where the red dots represent the coordinates obtained as a result of Scenario A in the second attempt.

In scenario B, as shown in fig. 6 it also indicates that a difference exists in the results obtained by different coordinates received by the GPS receiver. As evident, the x-axis represents latitude points, and the y-axis represents longitudinal points. The points in blue represent the results of the first attempt in scenario B using the second method GPS based vehicle localization, whereas the red points signify the coordinates recorded from the results of the second attempt using the same method. After comparing the results of both attempts that were used in Scenario B by using GPS based vehicle localization, the study found that the outcome is similar to Scenario A in terms of varying outcomes from one attempt to another.

Conclusion

The IoT-based vehicle tracking system has been described in the above experiment with the use of cell towers localization as a substitute for traditional GPS-based vehicle tracking. The system comprised Raspberry Pi 3 board, 4G LTE modem, Google Geolocation API, and Google Maps. The main aim of this experiment was to test the viability of cellular network for vehicle localization instead of satellite-based positioning system. The experiments were carried out in ten preselected spots, and the tests were performed twice in order to determine the repeatability of the results obtained. The coordinates found through cell tower localization were compared to the coordinates determined through GPS localization under the same operating conditions. Analysis of the results of localization error estimation showed that the proposed method was capable of determining coordinates which were quite similar to GPS localization. Localization errors calculated varied from 0.00 m to 4.98 m, with the average error being 1.48 m. It is possible to conclude that the method of cell tower localization is able to provide reliable location estimates for the application of the technology in real time vehicle tracking systems. The developed system also managed to transfer location data to a web-based platform. Relevance of this study can be explained by the possibility to prove the applicability of exploiting cellular infrastructure for vehicle localization when GPS-based solutions cannot be applied due to their high price, energy consumption, and environmental limitations. While GPS is the more traditional and commonly used localization technique, the presented technique proved its viability under the considered circumstances and may be applied as an auxiliary tool for vehicle localization. Further research may deal with the development of hybrid localization methods that would make use of GPS, cellular network information, and some other sensors. Future studies could involve the analysis of big data, different geographic areas, signal strength-based localization algorithms, as well as machine learning techniques.

References

Alrifaie, M. F., Ismael, O. A., Hameed, A. S., & Mahmood, M. B. (2021, December). Pedestrian and objects detection by using learning complexity-aware cascades. In *2021 2nd Information Technology To Enhance e-learning and Other Application (IT-ELA)* (pp. 12-17). IEEE. https://doi.org/10.1109/IT-ELA52201.2021.9773589

Almishari, S., Ababtein, N., Dash, P., & Naik, K. (2017, August). An energy efficient real-time vehicle tracking system. In *2017 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM)* (pp. 1-6). IEEE. https://doi.org/10.1109/PACRIM.2017.8121884

Bian, J., Hui, X., Zhao, X., & Tan, M. (2019). A monocular vision–based perception approach for unmanned aerial vehicle close proximity transmission tower inspection. *International Journal of Advanced Robotic Systems*, *16*(1), 1729881418820227. https://doi.org/10.1177/1729881418820227

Bharadwaj, S., Dubey, R., Zafar, M. I., Tiwary, S. K., Faridi, R. A., & Biswas, S. (2022). A novel method to determine the optimal location for a cellular tower by using LiDAR data. *Applied System Innovation*, *5*(2), 30. https://doi.org/10.3390/asi5020030

Calabrese, F., Colonna, M., Lovisolo, P., Parata, D., & Ratti, C. (2010). Real-time urban monitoring using cell phones: A case study in Rome. *IEEE transactions on intelligent transportation systems*, *12*(1), 141-151. https://doi.org/10.1109/TITS.2010.2074196

Chang, S. (2024). Localization based on TDoA projection for autonomous vehicles in 6G cellular networks. *Ict Express*, *10*(1), 34-38. https://doi.org/10.1016/j.icte.2023.03.012

Driusso, M., Marshall, C., Sabathy, M., Knutti, F., Mathis, H., & Babich, F. (2016). Vehicular position tracking using LTE signals. *IEEE Transactions on Vehicular Technology*, *66*(4), 3376-3391. https://doi.org/10.1109/TVT.2016.2589463

Gao, R., Zhu, S., Li, L., Wang, X., Jiang, Y., Tan, N., ... & Tao, D. (2024). Real-world large-scale cellular localization for pickup position recommendation at black-hole. *IEEE Transactions on Mobile Computing*, *23*(12), 15114-15131. https://doi.org/10.1109/TMC.2024.3453596

Hu, J. M., Li, J., & Li, G. H. (2012, November). Automobile anti-theft system based on GSM and GPS module. In *2012 Fifth International Conference on Intelligent Networks and Intelligent Systems* (pp. 199-201). IEEE. https://doi.org/10.1109/ICINIS.2012.86

Iszaidy, I., Ngadiran, R., Ahmad, R. B., Jais, M. I., & Shuhaizar, D. (2016, November). Implementation of raspberry Pi for vehicle tracking and travel time information system: A survey. In *2016 International Conference on Robotics, Automation and Sciences (ICORAS)* (pp. 1-4). IEEE. https://doi.org/10.1109/ICORAS.2016.7872605

Kassas, Z. Z. M., Maaref, M., Morales, J. J., Khalife, J. J., & Shamei, K. (2020). Robust vehicular localization and map matching in urban environments through IMU, GNSS, and cellular signals. *IEEE Intelligent Transportation Systems Magazine*, *12*(3), 36-52. https://doi.org/10.1109/MITS.2020.2994110

Laoudias, C., Moreira, A., Kim, S., Lee, S., Wirola, L., & Fischione, C. (2018). A survey of enabling technologies for network localization, tracking, and navigation. *IEEE Communications Surveys & Tutorials*, *20*(4), 3607-3644. https://doi.org/10.1109/COMST.2018.2855063

Maaref, M., Khalife, J., & Kassas, Z. M. (2018). Lane-level localization and mapping in GNSS-challenged environments by fusing lidar data and cellular pseudoranges. *IEEE Transactions on Intelligent Vehicles*, *4*(1), 73-89. https://doi.org/10.1109/TIV.2018.2886688

Miao, G., Zander, J., Sung, K. W., & Ben Slimane, S. (2017). *Fundamentals of Mobile Data Networks*. Cambridge University Press. https://doi.org/10.1017/CBO9781316534298

Mistary, P. V., & Chile, R. H. (2015, December). Real time Vehicle tracking system based on ARM7 GPS and GSM technology. In *2015 Annual IEEE India Conference (INDICON)* (pp. 1-6). IEEE. https://doi.org/10.1109/INDICON.2015.7443571

Mostafa, S., Youssef, M., & Harras, K. A. (2024, October). ModeSense: Ubiquitous and accurate transportation mode detection using serving cell tower information. In *Proceedings of the 32nd ACM International Conference on Advances in Geographic Information Systems* (pp. 184-195). https://doi.org/10.1145/3678717.3691250

Nalawade, S. R., & Akshay, S. D. (2016, December). Bus tracking by computing cell tower information on Raspberry Pi. In *2016 International Conference on Global Trends in Signal Processing, Information Computing and Communication (ICGTSPICC)* (pp. 87-90). IEEE. https://doi.org/10.1109/ICGTSPICC.2016.7955275

Shinde, P. A., & Mane, Y. B. (2015, January). Advanced vehicle monitoring and tracking system based on Raspberry Pi. In *2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO)* (pp. 1-6). IEEE. https://doi.org/10.1109/ISCO.2015.7282250

Shen, J. M., Chen, H. M., Li, H., Lin, S., & Wang, S. (2025). 5G high-precision positioning in GNSS-denied environments using a positional encoding-enhanced deep residual network. *Sensors*, *25*(17), 5578. https://doi.org/10.3390/s25175578

Varandas, L. C. M., Vaidya, B., & Rodrigues, J. J. P. C. (2010, April). mTracker: a mobile tracking application for pervasive environment. In *2010 IEEE 24th International Conference on Advanced Information Networking and Applications Workshops* (pp. 962-967). IEEE. https://doi.org/10.1109/WAINA.2010.164

Yang, J., Varshavsky, A., Liu, H., Chen, Y., & Gruteser, M. (2010, September). Accuracy characterization of cell tower localization. In *Proceedings of the 12th ACM international conference on Ubiquitous computing* (pp. 223-226). https://doi.org/10.1145/1864349.1864384

Zhou, P., Zheng, Y., & Li, M. (2012, June). How long to wait? Predicting bus arrival time with mobile phone based participatory sensing. In *Proceedings of the 10th international conference on Mobile systems, applications, and services* (pp. 379-392). https://doi.org/10.1145/2307636.2307671

Zhou, X., You, L., Zhong, S., & Cai, M. (2024). From cell tower location to user location: Understanding the spatial uncertainty of mobile phone network data in human mobility research. *Computers, Environment and Urban Systems*, *111*, 102130. https://doi.org/10.1016/j.compenvurbsys.2024.102130