

Geospatial Analysis of Infrastructure for Wired Network Deployment: Leveraging GPS, GIS, Data Analytics for Optimal Connectivity and Deploying Shortest Path Algorithm

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Abstract

This Proposed word presents a comprehensive framework for assessing signal connectivity in urban environments by integrating Global Positioning System (GPS) coordinates, Geographic Information System (GIS) mapping, and advanced analytical algorithms. The primary objective is to evaluate user connection statuses by analyzing signal strength and interference factors to optimize signal transmission quality. The framework begins with retrieving user location data, utilizing both manual input and automated GPS acquisition to ensure precision. A robust database of nearby signal transmitting points is compiled, including geographical coordinates and technical specifications, visualized through GIS tools. By employing shortest path algorithms like Dijkstra's and A*, the framework calculates efficient routes from users to the nearest transmitters, factoring in obstacles such as buildings and terrain. Interference assessments consider the heights and materials of surrounding structures, utilizing 3D modeling to identify potential signal disruptions. Signal strength evaluations involve predicting coverage areas based on transmitter specifications and generating heat maps that illustrate varying signal strengths.

Keyword: Shortest path algorithm, signal strength, Dijkstra's algorithm, A* algorithm

1 Introduction

Concentrating GPS signal strength in urban areas is necessary because cities often have unique challenges that interfere with GPS accuracy and reliability. To check the signal strength for urban area is most preferable factor because in urban area there were tall building are constructed for the human utilization. These factors are blocking the signal strength and create the signal fluctuations. The highest

building are in cities were known as urban canyon effect. GPS signals may be blocked, distorted by these buildings. This leads to multi path errors on signals, and bounces off to an surface without reaching the receiver devices. This kind of confusion are creates the improper positioning of GPS devices. Then the signal is strong, herewith GPS will properly positioned. The next factor for blocking the signal is Obstruction; materials like concrete, metal, and glass in buildings and other urban structures can partially or fully obstruct GPS signals, resulting in weak or lost connections. Increasing signal strength can help signals penetrate or bypass these barriers, enhancing reception in densely built-up areas. The another factor is to High Demand and User Density, densely populated areas, more users depend on GPS for navigation, ride-hailing, logistics, public transport, and personal tracking. Stronger signals provide adequate coverage to support the high number of GPS-enabled devices, minimizing connectivity issues and delays.

The prime factor is to Augmented Reality and Location-Based Services. Modern applications, like augmented reality (AR) for navigation and precise location-based recommendations, require highly accurate GPS. Increased signal strength helps these services perform consistently, even in locations with restricted satellite visibility. To enhance GPS reliability in urban areas, technologies such as assisted GPS (A-GPS), ground-based signal boosters, and multi-constellation systems (which incorporate additional satellite networks like GLONASS and Galileo) are used to improve coverage and accuracy in locations where satellite signals alone may face challenges.

2 Objectives of the proposed work

The Proposed work involves implementing shortest path algorithms, such as Dijkstra's and A*, to determine optimal routes from user locations to the nearest signal transmitters, while considering geographic obstacles and terrain. The goal is to find the most efficient paths by accounting for real-world conditions, which may impact travel times and connectivity. In addition to route optimization, the project aims to assess potential signal interference from surrounding structures. This will involve analyzing the heights and materials of nearby buildings to model how they affect signal transmission. By constructing 3D models, it will be possible to visualize the impact of these structures on signal quality and better understand areas of interference.

Furthermore, the project will predict signal coverage areas based on the specifications of the transmitters, such as their power and range. By combining this data with geographic and environmental factors, heat maps will be generated to illustrate signal strengths across different regions. These visualizations will provide a clear representation of areas with strong, weak, or no signal coverage, aiding in the planning and optimization of signal placement and network efficiency. The integration of shortest path algorithms, 3D modeling, and signal coverage predictions will create a comprehensive approach to optimizing user connectivity in complex environments.

3 Related work

This Proposed work aims to enhance GPS reliability in urban environments, where signal strength and accuracy frequently suffer. The concept centers on integrating advanced signal-enhancement technologies and strategies to tackle the unique challenges found in urban areas.

In related with this concept, to review the many existing work done by various authors. The authors shared their opinion and experience about the proposed work has been discussed in the section. The geospatial analysis is widely applied in many decision making and resource optimization and improved infrastructure in urban area [1]. From the previous study the integration of GPS and GIS emphasize the planning of physical efficient infrastructure [2]. The GIS always allows for the mapping the individual location data accurately and also reveal the patterns deployment like population and traffic status [3], and physical obstructions [4]. Combining GIS data with GPS coordinates can enhance precision, particularly for planning network routes in densely built areas where accuracy is critical [5]. Most current GPS spoofing detection methods for UAVs are developed using simulation data or rely on the use of multiple UAVs [6][7]. The Carrier-to-Noise Density Ratio (C/N₀) [8] and Doppler frequency are important signal characteristics for GPS satellite [9] positioning that can be utilized to detect spoofing signals [10].

In the case of having only one GPS antenna, the attacker transmits messages containing the same current location data as the target[11]. By placing antennas at various locations within an airport[12], it becomes feasible to triangulate the sender's location and compare it with the location specified in the received message[13]. This unique combination effectively mitigates the effects of both jamming and spoofing, significantly enhancing the resilience and security of GPS systems against such threats. [14][15]. One of the buoy assets is a lamp, which carries a relatively high cost[16]. To ensure the safety of such assets, the buoy can be enhanced through the use of Internet of Things (IoT) technology[17]. IoT applications are extensively utilized across various industries, particularly in monitoring[18]. The technology being developed for IoT device[19] connectivity currently employs the LoRaWAN wireless network, enabling communication over long distances of more than 500 meters[20]. Detecting and preventing GPS spoofing attacks on UAVs is crucial for maintaining their safety and security. This survey paper examines the state-of-the-art [21] techniques based on artificial intelligence (AI) that have been proposed in the literature for identifying GPS spoofing attacks on UAVs[22]. We provide an overview of the UAV navigation system and then explore the concept of GPS spoofing, including its different types, such as soft and hard spoofing[23].

4 Needs of efficient signal strength in urban area

An interactive graphical user interface (GUI) enhances user engagement by displaying real-time data, allowing users to input their coordinates for immediate feedback on connection quality and recommended actions. This GUI also facilitates a reporting mechanism for users to communicate signal issues. The feasibility checking process systematically evaluates sources of signal interruption and proposes infrastructure improvements to enhance connectivity. By incorporating user feedback, the framework continuously refines its predictive models, ensuring accuracy and user satisfaction. This innovative approach not only empowers users with actionable insights but also supports network providers in optimizing infrastructure. Future directions include the application of machine learning for predictive analytics and collaboration with telecommunications partners for enhanced data sharing and infrastructure development. This framework ultimately aims to provide reliable and efficient connectivity solutions in increasingly complex urban landscapes.

5 Scope of this proposed work

The proposed system is designed to streamline the process of checking the feasibility of connectivity for new subscribers. Upon logging in to the homepage, subscribers can simply click a "check feasibility" link to initiate the process. Once clicked, the system will automatically capture the geographic coordinates of the subscriber's location using Global Positioning System (GPS). These coordinates are then plotted on a map-based Graphical User Interface (GUI), where the subscriber's position is marked in red, indicating a new user in the system.

6 Architecture of the proposed work

From the figure 1, to understand work procedure for the signal strength detection and decision making based on the frequency level of each network providers. Since the subscriber, find the location of subscriber node using the GPS provisions. Then the co-ordinate value are plotted into on Graphical User Interface map.

In the map co-ordinate plotted value is compared with existing node plotted value. Based on the plotted value is check with the existing network as stored in the data source which is already detected or noted into an location data to backend servers.

The node is at first time trying to connect with the node means, the plotted node is compared with the coordinate value may have one node or more than one node. The detection may done with one node means, it is called as detected node the connection is made up with only that specified node and extract the connection for the efficient signal transmission to avoid the un interrupted transmission between the server and clients.

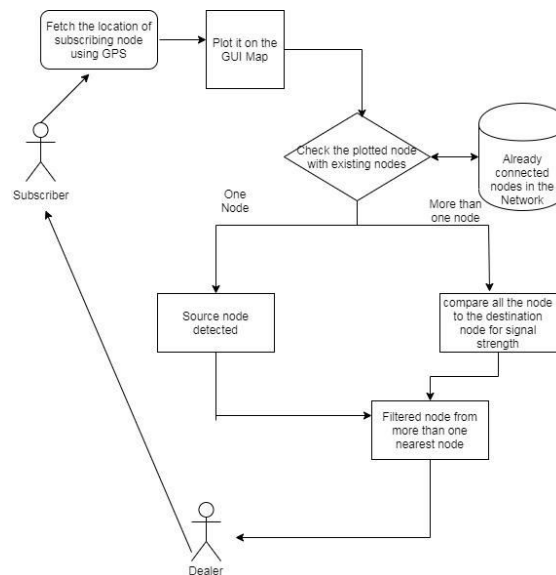


Figure 1 Architecture of the proposed work

Suppose the detection is made up with multiple node efficient provider means, to compare all node to the destination node for identifying the best signal strength. Then it detects is that node closest from the destination and make connection between them to allow the efficient data transmission. There is a direct communication between the dealer and network providers.

7 Methodology and algorithm

The novelty in the proposed research content can be identified through several innovative aspects, particularly in the integration of multiple technologies to create a streamlined and efficient system for connectivity feasibility checks. Key novel points include:

(i) Automated Feasibility Check Using GPS and GUI

The system allows subscribers to automatically check network feasibility by clicking a single link, which triggers the collection of their geographic coordinates using GPS. This automation eliminates the need for manual location entry or dealer intervention, providing a seamless user experience. The integration of a Graphical User Interface (GUI) that visually plots the user's location and existing network nodes further enhances the system's usability, making the process intuitive and highly interactive.

(ii) Visualization of Subscriber Locations on a Map

The system offers real-time visualization of new subscriber locations, represented as red markers on a map, alongside existing network nodes displayed as green markers. This color-coded representation allows dealers and network managers to easily distinguish between new and existing subscribers, enabling efficient network management. The use of visual mapping for real-time decision-making adds a unique layer to traditional connectivity solutions, which often rely on text-based data.

(iii) Shortest Path Algorithm for Optimized Connectivity

Incorporating a shortest path algorithm to determine the nearest node from a new subscriber's location adds an optimization layer that ensures efficient use of network resources. By automatically connecting users to the closest node, the system reduces latency and improves connection quality. This algorithmic approach is typically used in route planning but is being innovatively applied here for network connectivity, ensuring efficient service deployment.

From the previous work done by many authors, the two different algorithms are gave best accuracy and less loss function value. That algorithms are as follows.

- Dijkstra's algorithm
- A* algorithm

These two algorithms are implemented with the dataset which is downloaded from the network provider as on now. In the process has been done with four different levels.

Level 1: Concept Development.

In level 1, The proposed work has been analyzed about various factor. Considered as market analysis phase to check the benefits and scope of the proposed work. Next to check the feasibility of the proposed work, because every individual techniques used to simplify the human intervention and give an efficient outcome of the work. And cost of the work for implementation into an urban area has been analyzed and estimated properly for successful implementation.

Level 2: System Design

In level 2, the proposed work has been designed and concentrate about the sub system, refinement of design with make-buy analysis.

Level 3: Detail Design

In this level the system has been defined with the proper workflow and best simulator is used to control the quality of an proposed work in the urban area. In the basis the rural development is easy to carry but the urban area creates the little complication to implement with cost effectiveness and techniques.

Level 4: Test & Refine

In level 4, the work has been analyzed with various factors. To consider the testing for the issues in the field, how it can be adopt with the situation like fog and natural disaster and so on. It can be tested using the field testing phase.

The next level to test the proposed work with the regularity, because the work is not only for certain period. It could be works in future with efficient network provision without interruption of any other natural factors.

To know the implementation of efficient signal strength detection using the preferred algorithm like Dijkstra's algorithm and A* algorithm.

a) Dijkstra's algorithm

Dijkstra's algorithm is essential in Geographic Information Systems (GIS) for addressing a variety of pathfinding and routing challenges. It enables users to effectively determine the shortest or least-cost paths within spatial networks, including transportation systems, utility networks, and beyond. It employed in navigation applications to identify the shortest route between two locations on a map. This is vital for GPS-based navigation systems in vehicles, public transportation planning, and personal navigation applications. The shortest path has been calculated based on the distance and vector using the below mentioned formula.

$$\text{dist}(u) + \text{wei}(u, v) < \text{dist}(v) \rightarrow \text{equation 1}$$

In Equation 1, represent the set of all vertices (nodes) in the graph and E denote the set of edges that connect these vertices. Then the distance initialization has been done with every edge (u, v) with weight (u, v) representing the cost of traversing from node u to node v

b) A* algorithm

The A* algorithm is a popular pathfinding and graph traversal technique that excels in situations where finding the shortest path from a starting point to a target point is necessary, considering various cost metrics. It merges the advantages of Dijkstra's algorithm with heuristic-based methods, making it well-suited for applications such as signal strength detection in networks. It can help identify the best locations for Wi-Fi access points by calculating paths that optimize signal coverage according to the current signal strengths within the network. By leveraging dynamic signal strength data, A* can facilitate real-time routing of data packets, ensuring they take paths with the best signal conditions, thereby enhancing overall network performance. By using the A* algorithm, the signal strength can be calculated based on the following formula. The A* algorithm employs two primary cost functions:

$$f(n) = g(n) + h(n) \rightarrow \text{Equation 2}$$

In Equation 2,

$g(n)$: Represents the cost from the start node to the current node n

$h(n)$: A heuristic estimate of the cost from the current node n to the target node. This estimate may be based on factors such as signal strength predictions, geographical distance, or other relevant metrics.

$f(n)$: Represents the total estimated cost of the cheapest path through node n .

8 Dataset

In signal strength there are many dataset were available in network online repository such as kaggle, UCI learn and so on. Specifically the signal strength including atmospheric dataset is more comfortable with this proposed work. For the proposed work two different dataset were used one is provided by National Oceanic and Atmospheric Administration (NOAA) and another one dataset is provided by proposed work is implemented with the dataset named Geospatial topographic land dataset.

- National Oceanic and Atmospheric Administration (NOAA): NOAA provides spatial datasets that encompass environmental factors which may influence signal propagation.
- US Geological Survey (USGS): USGS offers topographic and land use datasets, which are valuable for analyzing signal strength alongside environmental features.

In the proposed work “MAG-L1b-GEOF(Table 1)” dataset were used for the signal strength detection to choose the highest peak level helps to choose the better node for individual network providers. The 4G trace dataset includes 135 traces, each lasting an average of 15 minutes, with throughput values ranging from 0 to 173 Mbit/s, recorded at a rate of one sample per second. The 4G measurement trials (unless otherwise specified) cover six different mobility patterns:

- Static: Indoor static trials.
- Pedestrian: Walking trials conducted around Cork city, Ireland.
- Bus: Trials spanning urban and suburban areas.
- Car: Trials conducted in both urban and suburban settings.
- Train: Travel routes between Cork-Dublin (240 km) and Cork-Farranfore (75 km), involving both 3G and 4G connections.

Coloumn	Description
Timestamp:	Sample timestamp.
NetworkMode:	Mobile communication standard (2G, 3G, or 4G).
CellId:	Identifier for the serving cell of the mobile device.
Operatorname:	Cellular operator name (anonymized).
Velocity:	Speed of the mobile device in kilometers per hour (kph).
Longitude and Latitude:	GPS coordinates of the mobile device.
RSRQ:	Represents the Reference Signal Received Quality, a ratio between RSRP and the Received Signal Strength Indicator (RSSI). It measures signal quality across all resource elements (RE), including interference from various sources (dB).
RSRP:	Represents the Reference Signal Received Power, which is the average power over cell-specific reference symbols within individual REs. It measures cell signal strength and coverage, aiding in cell selection (dBm).
RSSI:	Stands for Received Signal Strength Indicator, indicating wideband received power, including contributions from the serving cell, interference, and noise from other sources. RSRQ, RSRP, and RSSI collectively measure cell strength and coverage, supporting handover decisions (dBm).

Table 1: Represents the column and its description for the MAG-L1b-GEOF dataset.

In the Table 1 represents the list of columns and its description about the given dataset which is downloaded from the government site.

9 Implementation of the algorithm

The GUI displays a map of the specific area, with existing network nodes represented by green markers. These green markers symbolize locations with available connectivity or established links. When the system plots the red marker for the new subscriber, it automatically checks for nearby green markers

to identify the closest nodes that could potentially provide a connection to the new user. If there is more than one nearby link or node available, the system employs a shortest path algorithm to determine which node is closest to the new subscriber. This ensures that the user is connected to the nearest available node, optimizing network efficiency and resource allocation.

In cases where multiple nodes are at the same or a very similar distance, the system uses a "ping methodology" to assess the signal strength of each node. Ping methodology involves sending a small packet of data to each potential node and measuring the response time and signal quality. Based on this process, the system identifies which of the nearest nodes provides the strongest and most reliable signal. Once the node with the best signal is determined, that node becomes the target node for establishing a connection with the new subscriber. This process ensures that subscribers are connected to nodes with the best possible signal strength, minimizing connectivity issues and improving overall user experience.

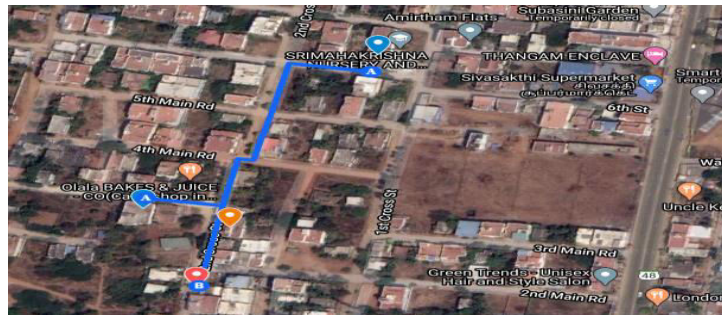


Figure 2: Signal strength identification

From Figure 2, the dealer's perspective, this system provides a highly efficient and automated way to handle new subscriber requests. By automating the process of capturing geographic coordinates, plotting them on the map, and checking for available links, the system reduces manual effort and increases the speed of service. The use of shortest path algorithms and signal strength checks further ensures that subscribers are connected in the most efficient manner possible, enhancing network performance and reliability.

Overall, the proposed system is a user-friendly, automated solution that simplifies the process of determining network feasibility for new subscribers. It ensures that users are connected to the best available nodes, taking into account geographic location and signal strength. By leveraging GPS for location tracking, graphical mapping for visualization, and advanced algorithms for pathfinding and signal assessment, this system provides a comprehensive and efficient solution for both subscribers and network dealers.

10 Result and discussion

The GPS system is committed to broadcasting signals in space with a daily global average user range error (URE) of 2.0 meters (6.6 feet) or less, with a 95% probability, across all active satellites in their designated constellation slots. However, actual performance often exceeds this standard. For example, on April 20, 2021, the global average URE across all satellites was 0.643 meters (2.1 feet) or less, 95% of the time.

11 Conclusions

The proposed system is an automated, user-friendly solution that streamlines the process of assessing network feasibility for new subscribers. It guarantees that users connect to the optimal available nodes, considering factors such as geographic location and signal strength. By utilizing GPS for location tracking, graphical mapping for visualization, and advanced algorithms for pathfinding and signal evaluation, this system offers a thorough and efficient solution for both subscribers and network providers.

12 References

- [1] S. Narain, A. Ranganathan and G. Noubir, "Security of GPS/INS Based On-road Location Tracking Systems," 2019 IEEE Symposium on Security and Privacy (SP), San Francisco, CA, USA, 2019, pp. 587-601, doi: 10.1109/SP.2019.00068.
- [2] K. Jansen, M. Schäfer, D. Moser, V. Lenders, C. Pöpper and J. Schmitt, "Crowd-GPS-Sec: Leveraging Crowdsourcing to Detect and Localize GPS Spoofing Attacks," 2018 IEEE Symposium on Security and Privacy (SP), San Francisco, CA, USA, 2018, pp. 1018-1031, doi: 10.1109/SP.2018.00012.
- [3] S. Wang, J. Wang, C. Su and X. Ma, "Intelligent Detection Algorithm Against UAVs' GPS Spoofing Attack," 2020 IEEE 26th International Conference on Parallel and Distributed Systems (ICPADS), Hong Kong, 2020, pp. 382-389, doi: 10.1109/ICPADS51040.2020.00058.
- [4] Eldosouky, A. Ferdowsi and W. Saad, "Drones in Distress: A Game-Theoretic Countermeasure for Protecting UAVs Against GPS Spoofing," in IEEE Internet of Things Journal, vol. 7, no. 4, pp. 2840-2854, April 2020, doi: 10.1109/JIOT.2019.2963337.
- [5] G. Panice et al., "A SVM-based detection approach for GPS spoofing attacks to UAV," 2017 23rd International Conference on Automation and Computing (ICAC), Huddersfield, UK, 2017, pp. 1-11, doi: 10.23919/ICAC.2017.8081999.
- [6] R. Calvo-Palomino, A. Bhattacharya, G. Bovet and D. Giustiniano, "Short: LSTM-based GNSS Spoofing Detection Using Low-cost Spectrum Sensors," 2020 IEEE 21st International Symposium on "A World of Wireless, Mobile and Multimedia Networks" (WoWMoM), Cork, Ireland, 2020, pp. 273-276, doi: 10.1109/WoWMoM49955.2020.00055.
- [7] A. Aravind, V. Ashwin, S. Chandee, P. S. S. S. Yasaswi, R. Gandhiraj and G. ShanmughaSundaram, "Enhancing GPS Position Estimation Using Multi-Sensor Fusion and Error-State Extended Kalman Filter", 2022 International Conference on Distributed Computing VLSI Electrical Circuits and Robotics (DISCOVER), pp. 201-206, 2022.
- [8] Ç. Tanıl, S. Khanafseh, M. Joerger and B. Pervan, "Kalman filter-based INS monitor to detect GNSS spoofers capable of tracking aircraft position", 2016 IEEE/ION Position Location and Navigation Symposium (PLANS), pp. 1027-1034, 2016.
- [9] Wenwei Liang, Kui Li and Qihang Li, "Anti-spoofing Kalman filter for GPS/rotational INS integration", Measurement, vol. 193, 2022.
- [10] Chang-Moon Lee, Kwan-Dong Park, Ji-Hyun Ha and Sang-Uk Lee, "Generation of Klobuchar coefficients for ionospheric error simulation", Journal of Astronomy and Space Sciences, vol. 27, no. 2, pp. 117-122, 2010.
- [11] Tao Wu, QiubaiZou, Jixiang Wu, Wenqiang Li and ZhenzeJia, "An evolutionary band-limited Gaussian noise jamming algorithm for LMS-based GPS", MATEC Web of Conferences, vol. 336, pp. 07009, 2021.
- [12] M. S. Sri Siddhartha, S. Saha and M. K, "Real Time Flight Timing Estimation at Airports Using Kalman Filter", 2023 International Conference on Advances in Electronics Communication Computing and Intelligent Information Systems (ICAECIS), pp. 520-522, 2023.
- [13] Y. Li, X. Guo, T. Zhang and Q. Sun, "GPS Anti-spoofing Algorithm Based on Improved Particle Filter", 2018 USNC-URSI Radio Science Meeting (Joint with AP-S Symposium), pp. 17-18, 2018.
- [14] S. Islam, M. Z. H. Bhuiyan, I. Pääkkönen, M. Saajasto, M. Mäkelä and S. Kaasalainen, "Impact analysis of spoofing on different-grade GNSS receivers", 2023 IEEE/ION Position Location and Navigation Symposium (PLANS), pp. 492-499, 2023.
- [15] G. Sriram Reddy and A.A. NippunKumaar, "GPS-Based Path Planning Algorithm for Agriculture Drones", Advanced Computational Paradigms and Hybrid Intelligent Computing . Advances in Intelligent Systems and Computing, vol. 1373, 2022, [online] Available: https://doi.org/10.1007/978-981-16-4369-9_25.
- [16] P.K. Eranti and B.D. Barkana, "An Overview of Direction-of-Arrival Estimation Methods Using Adaptive Directional Time-Frequency Distributions", Electronics, vol. 11, pp. 1321, 2022.

- [17] C. Vitale, N. Piperigkos, C. Laoudias et al., "CARMEL: results on a secure architecture for connected and autonomous vehicles detecting GPS spoofing attacks", *J Wireless Com Network*, 2021.
- [18] Simon Haykins, "Digital communication", disp, vol. 11, pp. 10, 2010.
- [19] T. -H. Kim, C. S. Sin, S. Lee and J. H. Kim, "Analysis of effect of anti-spoofing signal for mitigating to spoofing in GPS L1 signal", 2013 13th International Conference on Control Automation and Systems (ICCAS 2013), pp. 523-526, 2013.
- [20] Oliver Montenbruck and Belén González Rodríguez, "NeQuick-G performance assessment for space applications", *GPS Solutions*, vol. 24, no. 1, pp. 1-12, 2020.
- [21] Zhenjun Zhang, Xingqun Zhan and Hongliang Xu, "Development and Validation of a Low-cost GPS Spoofing Simulator", *Journal of Aeronautics Astronautics and Aviation*, vol. 46, no. 2, pp. 78-86, 2014.
- [22] SH. Seo, GI. Jee and BH. Lee, "Spoofing Signal Generation Based on Manipulation of Code Delay and Doppler Frequency of Authentic GPS Signal. Int", *J. Control Autom. Syst*, vol. 19, pp. 1026-1040, 2021.
- [23] T. Zhang, J. Gao and F. Ye, "Anti-spoofing algorithm based on adaptive Kalman filter for high dynamic positioning", 2017 Progress in Electromagnetics Research Symposium - Fall (PIERS - FALL), pp. 838-845, 2017.
- [24] K. D. Wesson, B. L. Evans and T. E. Humphreys, "A combined symmetric difference and power monitoring GNSS anti-spoofing technique", 2013 IEEE Global Conference on Signal and Information Processing, pp. 217-220, 2013.
- [25] G. Prabha and GA ShanmughaSundaram, "Estimation of DOA using a cumulant based quadricovariance matrix", 2016 10th European Conference on Antennas and Propagation (EuCAP), pp. 1-5, 2016.
- [26] Ferreira R, Gaspar J, P Sebastião and N. Souto, "A Software Defined Radio Based Anti-UAV Mobile System with Jamming and Spoofing Capabilities", *Sensors.*, 2022.
- [27] Xuefen Zhu, Zhengpeng Lu, Teng Hua, Fan Yang, Gangyi Tu and Xiyuan Chen, "A Novel GPS Meaconing Spoofing Detection Technique Based on Improved Ratio Combined with Carrier-to-Noise Moving Variance", *Electronics.*, vol. 11, pp. 738, 2022.
- [28] Huiqi Tao, Hailing Wu, Hong Li and Mingquan Lu, "GNSS Spoofing Detection Based on Consistency Check of Velocities", *Chinese Journal of Electronics*, vol. 28, no. 2, pp. 437-444, 2019.
- [29] Ruixiang Yang, Baodeng Hou, Weihua Xiao, Chuan Liang, Xuelei Zhang, Baoqi Li, et al., "The applicability of real-time flood forecasting correction techniques coupled with the Muskingum method", *Hydrology Research*, vol. 51, no. 1, pp. 17-29, February 2020.
- [30] J. Jetto, R. Gandhiraj, G.A. ShanmughaSundaram and K.P. Soman, "Software Defined Radio-Based GPS Spoofing Attack Model on Road Navigation System", *Soft Computing and Signal Processing. Advances in Intelligent Systems and Computing*, vol. 1340, 2022, [online] Available: https://doi.org/10.1007/978-981-16-1249-7_32.
- [31] Andrew J. Kerns, Daniel P. Shepard, Jahshan A. Bhatti and Todd E. Humphreys, "Unmanned aircraft capture and control via GPS spoofing", *Journal of Field Robotics*, vol. 31, no. 4, pp. 617-636, 2014.