JPPIPA 11(10) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

The Effect of Baseline Length and GSM Network Quality on the Geometric Accuracy of N-RTK Systems

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Received: August 19, 2025
Revised: September 03, 2025
Accepted: October 25, 2025
Published: October 31, 2025

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DOI: 10.29303/jppipa.v11i10.12765

Abstract: Network Real-Time Kinematic (N-RTK) positioning has become a fundamental tool in high-precision surveying. However, its accuracy is significantly affected by operational factors, such as baseline length and telecommunication network quality. This research aims to quantify the influence of these two factors on the geometric accuracy of the N-RTK system. Data was collected in a tropical peatland environment in Indonesia. Out of 661 test points, 495 were successfully measured using the N-RTK system with a geodetic GPS. At the other 166 points, however, limited GSM signal coverage in the field necessitated the use of a handheld GPS as an alternative solution to ensure the completeness of the spatial data. The results show that N-RTK accuracy decreases significantly with an increase in baseline length and a decrease in cellular network quality (4G to 3G). The 4G network provides higher accuracy, with a Circular Error 90% (CE90) value of 0.359 m at a 10-20 km baseline distance. At the same distance, the 3G network yields a CE90 of 0.472 m. An increase in distance up to 40-50 km further reduces accuracy, but the resulting accuracy still meets the standard for 1:2500 scale detailed maps. On the other hand, measurements using a handheld GPS yield a CE90 of 5.95 m, which is significantly lower and only suitable for general-scale mapping (1:25,000). This study underscores the importance of cellular network quality and optimal baseline planning to achieve maximum accuracy in N-RTK surveys, as well as highlights the need for alternative solutions in areas with signal limitations.

Keywords: Geometric Accuracy; GNSS; GSM Network; Real-Time Kinematic

Introduction

Here is the translated text: Global Navigation Satellite Systems (GNSS) have become critical infrastructure that enables global positioning and timing with high accuracy (Bong et al., 2023). In the field of surveying and mapping, various GNSS methodologies have been developed to meet diverse precision needs, ranging from DGPS to static methods and Real-Time Kinematic (RTK) (Irianto & Rassarandi, 2021; Pilot, 2023). Among these methods, N-RTK (Network Real-Time Kinematic) stands out for its high operational efficiency by eliminating the need for a base station in the field (Mikhaylov et al., 2023). N-RTK works by leveraging a network of permanent reference stations (CORS) that continuously record GNSS observation data and transmit it to a central server (Nord et al., 2021). This server then processes the data to generate differential corrections that can be accessed by users via cellular telecommunication networks, such as GSM (Marbawi et al., 2015). Although N-RTK offers significant advantages in efficiency and accuracy, its performance is highly dependent on two crucial factors that can influence the quality of the final position (Jimenez-Martinez et al., 2021). First, baseline length—the distance between the roving receiver and the nearest reference station—directly affects accuracy. As stated by Liu et al. (2023), a baseline length that positively correlates with increased uncertainty in ionospheric retardation modelling can worsen the impact of GNSS errors identified by Bhatta (2021). Gökdaş & Özlüdemir (2020) even quantified that a baseline length exceeding 42.8 km can significantly

How to Cite:
Mitrolia, R., M.S, S., & Rusdi, M. (2025). The Effect of Baseline Length and GSM Network Quality on the Geometric Accuracy of N-RTK Systems. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 166–170. https://doi.org/10.29303/jppipa.v11i10.12765

reduce N-RTK accuracy. Second, the quality of the GSM signal for transmitting correction data is a fundamental prerequisite (Jaya et al., 2022). Unstable or slow connections can lead to the loss of correction signals, which ultimately decreases accuracy or halts the measurement process. Sitohang et al. (2014) supported this argument by demonstrating the superiority of a 3G signal over EDGE in supporting N-RTK accuracy. In addition to these technical challenges, the implementation of N-RTK in the field often faces practical obstacles. Many survey areas, especially in remote regions or those with difficult topography, lack adequate telecommunication network coverage. This situation limits a user's ability to leverage N-RTK's high accuracy and necessitates the use of alternative methods that may have lower precision (Lim et al., 2025; Sitohang et al., 2014). This limitation becomes a significant hindrance in projects that require precise geospatial data. Therefore, although previous studies have acknowledged the importance of these factors (Gümüş & Selbesoğlu, 2019), there remains a gap in the literature regarding the specific and comprehensive quantification of the combined effect of cellular network quality (specifically the comparison between 4G and 3G) and baseline length on the geometric accuracy of N-RTK (Stephenson, 2016). This research aims to fill that knowledge gap by experimentally analyzing how these two factors influence the geometric accuracy of the N-RTK system and, at the same time, demonstrate its application limitations in areas without a signal by comparing it to an alternative solution.

Method

Research Design

This study uses a quantitative approach with a quasi-experimental design to analyze the accuracy of the N-RTK system. Spatial data was collected in a specific region, spanning six sub-districts in Aceh Jaya Regency, chosen for its varying telecommunication network conditions and peatland distribution. A total of 661 test points were established in a grid pattern of 250 m x 1000 m. This design aimed to collect systematic and representative data, allowing for a comprehensive analysis of the effect of baseline length and network quality on measurement accuracy. The research location in the peatland of Aceh Jaya Regency and the service radius of the BIG CORS in the same area are shown in Figure 1.

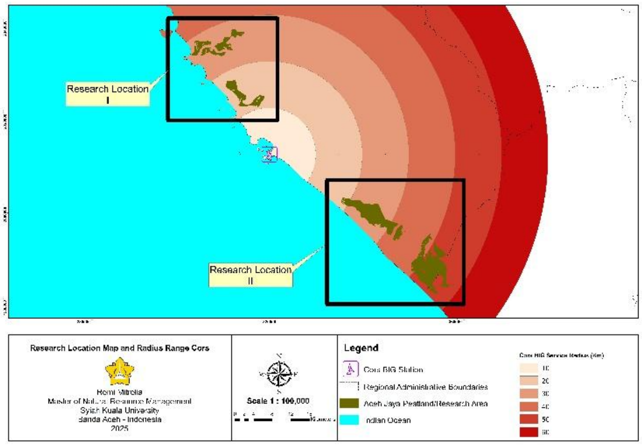


Figure 1. Research Location and BIG CORS Service Radius.

Data Collection

To ensure the completeness of the spatial data, a hybrid strategy was used for coordinate acquisition, adapted to the conditions in the field: N-RTK measurement, this was performed at 495 test points that had adequate GSM signal coverage (4G or 3G) (Karimidoona & Schön, 2023). The device used was a South Galaxy G1 Geodetic GPS. Data was collected in real-time by connecting to a CORS network operating in the study area; Alternative Measurement, at the remaining 166 points, where there was no GSM signal, coordinates were collected using a handheld GPS (Garmin 66s). This method was used as a practical solution to obtain position data in areas unreachable by the N-RTK method.

Accuracy Analysis

Horizontal geometric accuracy is evaluated using the Circular Error 90% (CE90) metric, as mandated by BIG Head Regulation No. 15 of 2014. CE90 is the horizontal error radius value that contains 90% of the tested sample points. The CE90 calculation is carried out by comparing the coordinates measured in the field with the reference coordinates that have been corrected and are considered correct as represented by Formula 1.

$$RMSE_r = \sqrt{\frac{\sum_{i=1}^{n} dx_i^2 + \sum_{i=1}^{n} dy_i^2}{n}} \quad (1)$$

Here, dx and dy are the coordinate differences in the x and y axes between the measured results and the reference data, and n is the number of tested points. This value was then converted to CE90 for further evaluation.

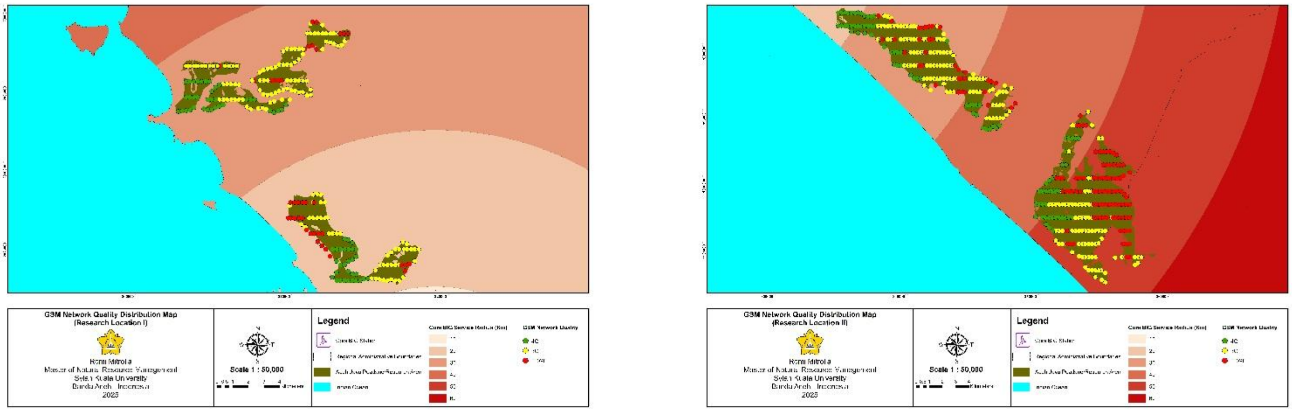
Test Variables

The independent variables analyzed were GSM network quality (4G and 3G) and baseline length, which were grouped into 10 km intervals (e.g., 10-20 km, 20-30 km, etc.) from the nearest CORS station. The dependent variable was geometric accuracy, measured in meters (CE90). The performance of the handheld GPS was also analyzed separately for comparison to evaluate its effectiveness as an alternative solution.

Results and Discussion

Out of a planned 661 test points, only 495 were successfully measured using the N-RTK method. The remaining 166 points, or approximately 25.1%, could not be measured with N-RTK due to the absence of a GSM signal at the research location. This condition directly highlights the system's fundamental dependency on telecommunication infrastructure, demonstrating that while superior in accuracy, this method cannot be universally applied in all areas with signal limitations.

Based on Figures 2, the maps illustrate the distribution of GSM network quality (4G, 3G, EDGE) in the research area in relation to the distance from the CORS station. The maps show that signal quality varies spatially, with stronger 4G and 3G signals found in certain areas, while other areas only have an EDGE signal or no signal at all. These maps serve as important visual evidence explaining why the N-RTK method could only be applied to some of the test points, and why other points had to be measured using a handheld GPS.



(a) (b)

Figure 2. GSM Network Quality Distribution Map: (a) Location I; and (b) Location II

The Influence of Network Quality and Baseline Length

The analysis of N-RTK performance showed a clear correlation between accuracy, network quality, and baseline length. The 4G network consistently provided higher and more stable accuracy than the 3G network over the same distances.

Table 1. The Influence of Network Quality and Baseline Length

Network	Distance (Baseline)	Average Accuracy (m)	Accuracy (CE90) (m)
4G	10-20 km	0.056	0.359
4G	20-30 km	0.106	0.494
4G	30-40 km	0.153	0.594
4G	40-50 km	0.174	0.632
3G	10-20 km	0.097	0.472
3G	20-30 km	0.150	0.588
3G	30-40 km	0.189	0.660
3G	40-50 km	0.206	0.689

As shown in Table 1, N-RTK accuracy decreases as baseline distance increases for both network types. The increase in distance from 10-20 km to 40-50 km resulted in a 43% decrease in accuracy on the 4G network and a 31% decrease on the 3G network. This decline is consistent with the theory that longer baselines amplify errors that cannot be fully modeled, such as ionospheric and tropospheric effects. Despite the decrease, N-RTK performance on the 4G network with a baseline up to 50 km still yielded a CE90 accuracy better than 1 m, which is ideal for detailed mapping.

Comparison with Alternative Solutions

For the 166 points lacking a GSM signal, a handheld GPS served as a practical solution (Chinnasamy et al., 2025; Othman et al., 2021). However, its performance fell far short of the N-RTK system. The analysis showed that the handheld GPS only achieved a CE90 accuracy of 5.959 m. This drastic difference in accuracy highlights that while a handheld GPS can provide position data in areas without a signal (Cabezas et al., 2022; Enge, 1994; Grenier et al., 2023; Lamsal, 2025; Patire et al., 2015), it's unsuitable for applications requiring high precision, such as land boundary mapping or infrastructure planning. Its function is limited to navigation or spatial data collection for general planning purposes.

Implications of the Results for Field Applications

These findings have significant implications for geospatial professionals. The reliance of N-RTK on the quality and availability of a GSM signal is a crucial factor in survey planning (Al-Attas et al., 2023; Niu et al., 2024). Projects requiring high accuracy in areas with variable signal cannot rely solely on N-RTK. Instead, a hybrid approach that combines N-RTK in areas where a signal is strong and stable with alternative high-accuracy methods (such as static GNSS surveys or UAV mapping) in "blank spot" areas is a more reliable and effective strategy. This approach not only ensures consistent accuracy but also allows for complete data coverage across the entire survey area, overcoming a fundamental limitation of N-RTK itself.

Conclusion

This study confirms that N-RTK system accuracy is highly dependent on baseline length and GSM network quality. The results show that accuracy decreases as the distance from the CORS station increases and when using a 3G network compared to 4G. While N-RTK can achieve sub-meter accuracy up to a 50 km baseline on a 4G network, its reliance on telecommunication infrastructure limits its universal application; at 25.1% of the test points, the lack of a signal necessitated the use of a handheld GPS, which provided a much lower accuracy (CE90 5.959 m) and was inadequate for precise mapping.

Acknowledgments
Thank you to University of Syiah Kuala

Author Contributions
R. M. and S. M.S. conceived and designed the experiments; R. M. and M. R. performed the experiments and conducted field investigations. R. M. and M. R. performed the formal analysis and curated the data. R. M. wrote the original draft preparation. S. M.S. and M. R. contributed to the methodology, writing—review and editing, and supervision. All authors have read and agreed to the published version of the manuscript.

Funding
Researchers independently funded this research.

Conflicts of Interest
No conflict interest.

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