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Current state of the art of connected car positioning technology in the 5G era

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Abstract. The Internet of Cars (IoV) has gained popularity in recent years as the number of vehicles on the road keeps increasing. With the development of 5G technology, positioning technology—which is essential to the implementation of IoV—has also started to gain popularity as a research issue. This paper summarises the development and current status of current Telematics positioning technology through the study of the optimization scheme of Telematics positioning technology based on 5G technology. It also clearly shows that the latency of the current Telematics positioning technology has been reduced to a certain extent, and the accuracy has been improved by describing the Telematics, positioning technology and the optimization of the positioning technology from shallow to deep. However, due to practical factors such as site, many technologies have not been further validated and used, and there is still much room for the development of positioning technology. However, with the further development of communication and transmission technologies, the positioning accuracy of Telematics will definitely be improved substantially.

Keywords: positioning technology, telematics, 5G.

1. Introduction

As the number of motor vehicles in China continues to increase, issues such as traffic safety and environmental protection are becoming increasingly prominent. The application of Telematics technology is an effective way to solve these problems. The Internet of Vehicles is an application of the Internet of Things in road traffic. With the help of advanced communication and computer technologies such as 5G and artificial intelligence, it enables information exchange between vehicles and vehicles, vehicles and people, vehicles and roads, and vehicles and control platforms, making traffic travel safer and more efficient for drivers [1]. Positioning technology is one of the key technologies to support Telematics applications. The ability to accomplish high-precision positioning determines whether Telematics can effectively perform vehicle navigation, traffic control, and case tracking [2]. Currently, GNSS positioning is the main means of positioning in Telematics [3]. As technology advances, people's requirements for vehicle positioning and navigation are increasing, which has led to continuous innovation in navigation and positioning technology. However, in many scenarios, the traditional satellite positioning technology does not meet the positioning needs well. There are problems such as unmet accuracy requirements, discontinuous positioning results, and long positioning time. [4]. At this stage, the Telematics industry is highly valued by China's national strategy, and the continuous favorable industrial policies are driving the rapid development of the Telematics industry in China [5]. With the development of 5G, the connectivity of Telematics has increased [6], and improved positioning methods based on 5G have been proposed, such as the combination of traditional satellite positioning and 5G [4]. These facts and changes show that in the 5G era, positioning technology, a key technology for Telematics, continues to develop, laying a solid foundation for the development of Telematics.

In recent years, scholars at home and abroad have conducted much theoretical research on vehicle network positioning and navigation. The literature [7]first proposed a Direction of Arrive (DOA) estimation method based on Sparse Bayesian Learning (SBL), which effectively overcomes the problem of low positioning accuracy of vehicles in places with weak GPS signals. Still, the positioning process has a large transmission delay. However, there is a large transmission delay in the positioning process. In [8], a new method of using Signal of Opportunity (SOP) from a single signal source for vehicle network positioning is proposed. This method can effectively improve the positioning accuracy to a certain extent. Still, the vehicle positioning accuracy cannot be effectively guaranteed when it is interfered by external signals and the environment. In the literature [9], a sensor fusion algorithm was proposed to locate the vehicle and predict its future trajectory. But the errors in direction and distance measurements can significantly impact the final position, and the positioning takes a long time. The literature [10] proposes a differential positioning mechanism-based vehicle networking positioning method, in which vehicles use a wireless medium to send their GPS observations to a base station. The base station fuses the received GPS data and local GPS observations to achieve high-accuracy vehicle tracking. However, the data transmission takes a long time and cannot meet the low latency requirements in practical applications. The literature [11] proposed a technical solution for Telematics navigation based on BDS positioning and edge computing to improve the positioning accuracy of Telematics nodes to a certain extent. The literature [12] proposes a positioning method based on field-end devices and 5G networks to provide reliable positioning information for vehicles in weak GNSS positioning scenarios, so as to pass special scenarios such as weak GNSS road sections normally. Literature [13]proposes a cloud-based technology for high-precision real-time monitoring of traffic vehicle location based on GNSS carrier phase single ephemeris RTK/5G, providing a cloud-based online high-precision solution for real-time full process monitoring of intelligent transportation vehicle location. In [14], a fusion positioning algorithm based on intelligent reflective surface (IRS) assisted BDS+5G is proposed, which can achieve accurate positioning of the target to a certain extent.

As a key technology in the Telematics business, high-precision positioning technology provides users with accurate and reliable location information, effectively improving vehicle driving safety and driving experience. However, in practical applications, there are still several problems, such as low positioning accuracy and long time consumption. With the emergence of 5G in recent years, more accurate and reliable positioning technologies have been proposed and verified. This paper will summarise some methods and briefly discuss positioning technology's development and the current status of Telematics in the 5G era. The application of connected cars will be able to improve the difficult travel situation partially. Coupled with the emergence of 5G networks, driverless technology, and intelligent vehicle-based systems are further upgraded [15]. At the same time, the combination of 5G and Telematics is also giving rise to more rational and efficient road planning, enhancing traffic safety supervision and emergency handling road management [16]. The upgrade of positioning technology will also promote the improvement of vehicle navigation capability and the emergency rescue capability of relevant departments [17].

2. Principle analysis

Positioning technology is one of the key technologies supporting Telematics applications. Various positioning methods support Telematics applications, and the technical characteristics, deployment costs and application prospects of different positioning methods vary. However, GNSS positioning is

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currently the main means of positioning for Telematics, so only GNSS-based positioning methods are discussed in detail in this paper.

2.1. Composition of GNSS

GNSS comprises three parts: the Space Segment, the Control Segment and the User Segment. Its structure is shown in Figure 1. The Space Segment consists of a constellation of satellites, mainly used for receiving and storing navigation messages, generating and sending signals for navigation and positioning, receiving ground commands and performing corresponding operations. The User Segment is the instrumentation, such as the user or receiver, that receives the information from the satellite or from the ground monitoring section [18].

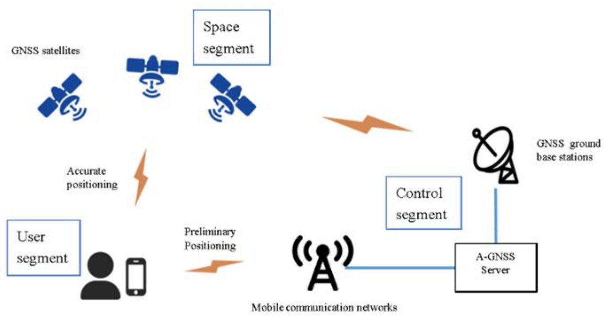

Figure 1. Structure of the GNSS system.

2.2. GNSS receivers and positioning principles

GNSS positioning starts with a signal from the satellite at a certain moment, called the transmitting moment. Then the local receiver captures the input signal with a replicated code slice to correlate it and obtain the correlation peak, which means finding the phase of the input signal and extracting this moment as the transmitting moment. The time at the receiver is then different from this transmitting moment, which can be noted as τ and is called the propagation time. This time multiplied by the light speed, is the distance between the receiver and the satellite. Assuming that the receiver time is known, use the above approach to calculate the distance between the receiver and the satellite, and then use the navigation message. The time received to find out the location of the satellite. At this moment, the satellite is the circle's center, and the distance is the circle's radius. The position of the receiver and its precise situation, as seen in Figure 2, can potentially be determined if the receiver can receive the signal from three satellites.

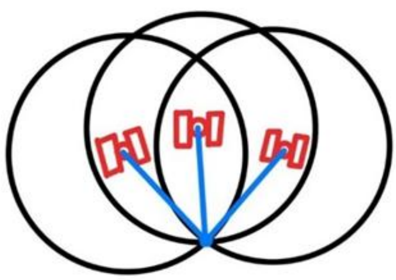

Figure 2. Schematic diagram of GNSS positioning technology.

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It should be noted that the receiver's real-time is unknown, so it needs to assume a receiver time, the real receiver time minus the hypothetical receiver time to obtain the clock difference Δt. Generally, the latest launch time is used as the receiver's reception time. The distance obtained by subtracting the launch time from the hypothetical reception time and multiplying it by the speed of light is not the real distance. Still, a pseudo distance allows us to calculate the final position and time. However, the receiver time is not known. Solving for the time also requires solving four equations using the observed quantities of the four satellites to obtain the three-dimensional coordinates and time of the receiver. However, as all observations are subject to error, least squares are used to avoid these errors as much as possible. If the satellite data used is not from the same system, attention should also be paid to the additional clock difference between the different systems, which is small but still needs to be noted. In this case, the positioning requires data from at least five satellites.

2.3. GNSS errors

2.3.1. Satellite ephemeris errors and clock errors. Satellite ephemeris and clock errors are caused by the inability of GNSS ground surveillance stations to calculate and estimate satellite orbits accurately and by satellite clock frequency drift. In classical standard single-point positioning, broadcast interim tables are typically used to calculate satellite coordinates. However, the orbits of satellites are subject to a variety of complex and currently incompletely understood influences that prevent ground surveillance stations from accurately calculating and estimating satellite orbits. Thus, satellite ephemeris errors occur. In addition, satellite clocks inevitably have temporal and frequency biases, leading to satellite clock errors. Precision back ephemerides or ultra-fast predictive ephemerides provided by IGs are extensively utilized for positioning and minimizing errors to the centimetre level in precise positioning.

2.3.2. Ionospheric delay errors. The ionosphere is the atmospheric layer between 60 km and 1,000 km from the ground. Due to the influences of sunlight and the universe's energetic particles, which are formed when the satellite signal passes through the area, refraction effects, and changing propagation speeds, this sector of the atmosphere has large concentrations of cations and free electrons. Additionally, the vacuum light speed vanishes and the propagation route is somewhat changed. The end result is an inaccuracy known as the ionospheric delay error that alters the distance between the satellite and the receiver.

2.3.3. Convective delay error. The tropics are an atmosphere with a surface height of fewer than 50km. The delay error caused by the neutral atmospheric differential signal as the signal passes from the satellite through the tropical region is called the tropical delay error. Unlike the ionospheric delay error, the convective zone delay error is independent of signal frequency, but is related to factors such as atmospheric pressure, temperature and humidity [19].

3. Specific discussions

3.1. IoT positioning technology based on single-calendar RTK/5G cloud-based monitoring system

The traditional GNSS receiver is the navigation module using pseudo-range single-point positioning technology. There is the disadvantage of low positioning accuracy. Mingduan Zhou and others use the GNSS receiver measurement function, using single-calendar RTK technology for processing and analyzing traffic vehicle location monitoring data, through 5G mobile communication technology for real-time online transmission of monitoring data, in order to achieve online high-precision traffic vehicle location Positioning [13].

In single-calendar RTK positioning, the fast and successful determination of the double-difference ambiguity parameter is the key to achieving high-precision GNSS dynamic positioning using carrier phase observations. Once the double-difference ambiguity is fast and correctly fixed, centimeter-level accuracy positioning results can be obtained [20]. Based on this principle, Mingduan Zhou et al. proposed a method for monitoring the position of traffic vehicles based on GNSS carrier-phase single-calendar RTK/5G, in which one GNSS receiver is set up as a reference station at a monitoring site with a wide field of view. Another GNSS receiver is fixed as a monitoring station at the top center of the vehicle for real-time dynamic monitoring of the position parameters of traffic vehicles during road driving (including 3D coordinate parameters and accuracy index information). The method corresponds to the working principle shown in Figure 3.

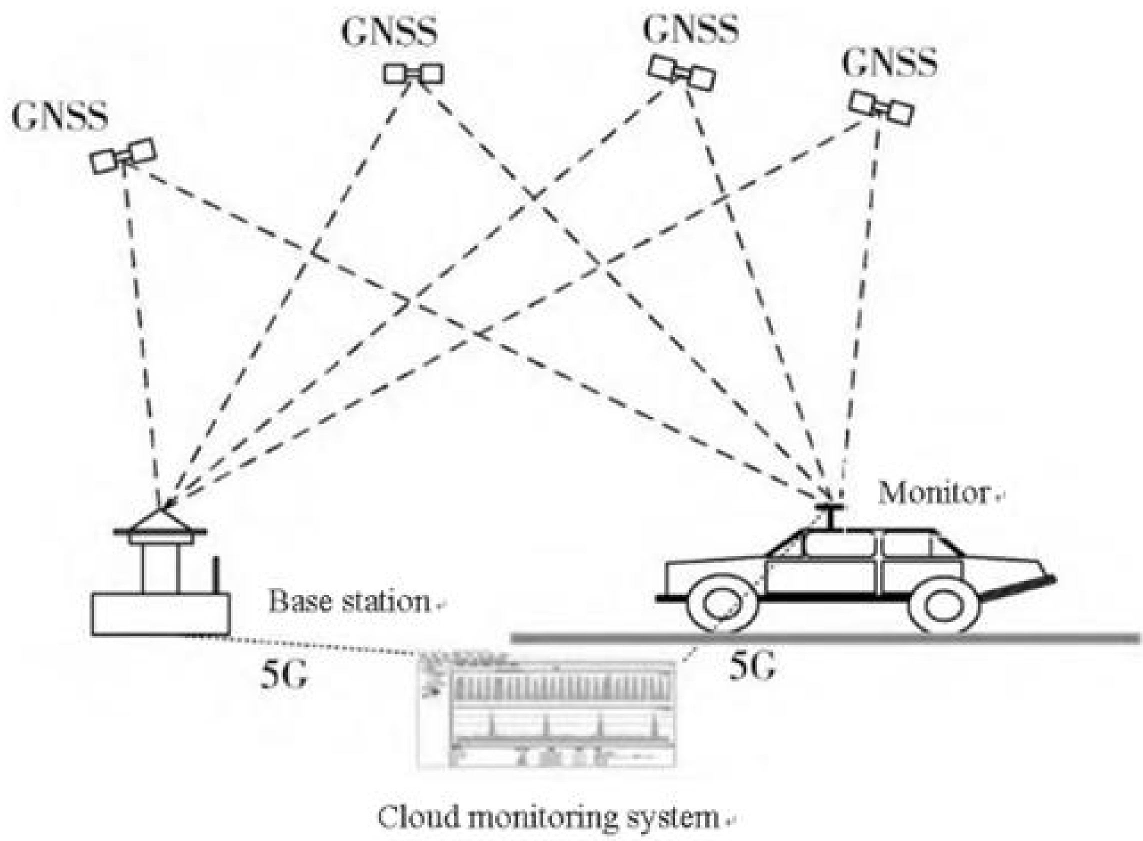

Figure 3. Single-calendar RTK/5G-based method for monitoring the location of traffic [13].

The vehicle's approximate position is then obtained by performing certain calculations based on the position parameters obtained. For the GNSS single-calendar element double-difference whole-period fuzzy degree fast determination algorithm, Mingduan Zhou et al. give a single-calendar element double-difference whole-period fuzzy degree fast determination algorithm (FARSE) based on the combination of DUFCOM and DC algorithm as an example, and this technical solution has applied for a national invention patent. The exact flow of the FARSE algorithm is shown in Figure 4. Thereafter, it then relies on real-time data transmission to achieve online monitoring of the location of traffic vehicles. Among them, 5G has significant advantages such as large data volume transmission and low latency, which plays a crucial role in this method [21].

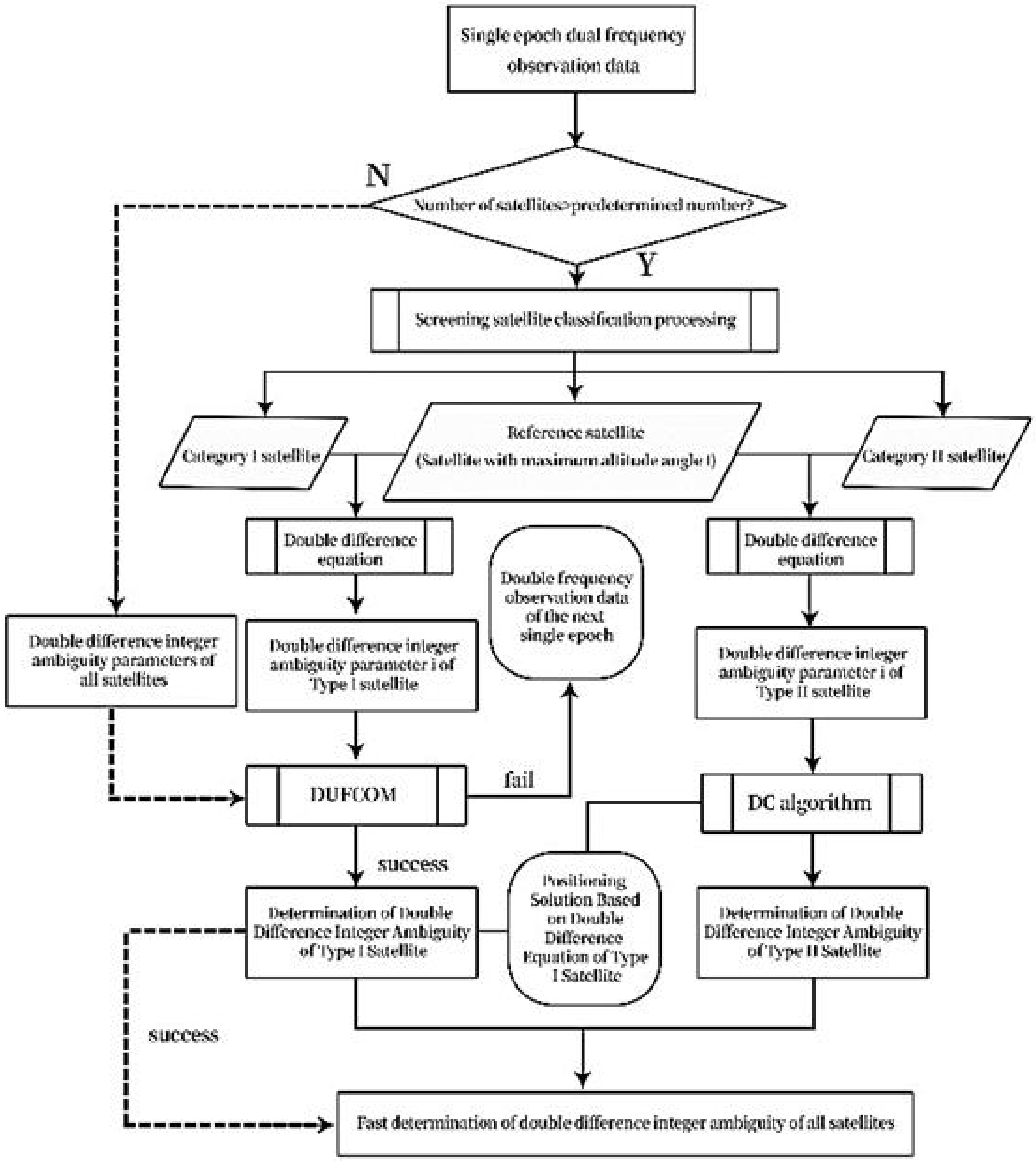

Figure 4. FARSE algorithm flow [13].

The NSS carrier-phase single ephemeris dynamic positioning model and 5G mobile communication core technologies were developed as a result. On this basis, the RTK/5G traffic vehicle positioning cloud monitoring system (GNSS ITMS) was built utilizing the VisualStudio2010 development environment and the C# programming language. ITMS system design mainly includes system hardware equipment assembly and system software development. Its overall development idea is: from one GNSS receiver as a reference station, another GNSS receiver as a vehicle monitoring station M constitute GNSS monitoring data acquisition device; from two 5G communication module and two 5G traffic card constitute GNSS monitoring data transmission device, the main role is to monitor data The main function is to transmit the monitoring data wirelessly and in real-time to a computer network cloud server Windows system platform with fixed IP (Tencent Cloud CVM is selected), and establish a SQL database (SQLSever2008 is selected) in the cloud server system platform by being able to seamlessly embed the RTK and 5G based traffic vehicle location accurate monitoring software developed in this paper; then build GNSS_ITMS server side, set up the traffic vehicle location data processing unit as well as the cloud online monitoring and analysis unit. On the GNSS_ITMS server side, a SQL database is used to manage the real-time high-precision position trajectory information (3D coordinate parameters and accuracy evaluation information) of the vehicle monitoring station and the information related to satellite signal tracking time. After that, the traffic vehicle client receives real-time broadcasts from the cloud-based online monitoring and analysis unit with high-precision position track information and satellite signal tracking information. As a result, it makes possible data exchange and synchronized traffic vehicle position monitoring between the server and client sides. Finally, after experimental validation, their results show that the online monitoring accuracy of the GNSS_ITMS system is better than 2cm for northbound RMS, 2cm for eastbound RMS and 5cm for elevation RMS, which verifies the correctness and effectiveness of their algorithms. The overall development process is shown in Figure 5.

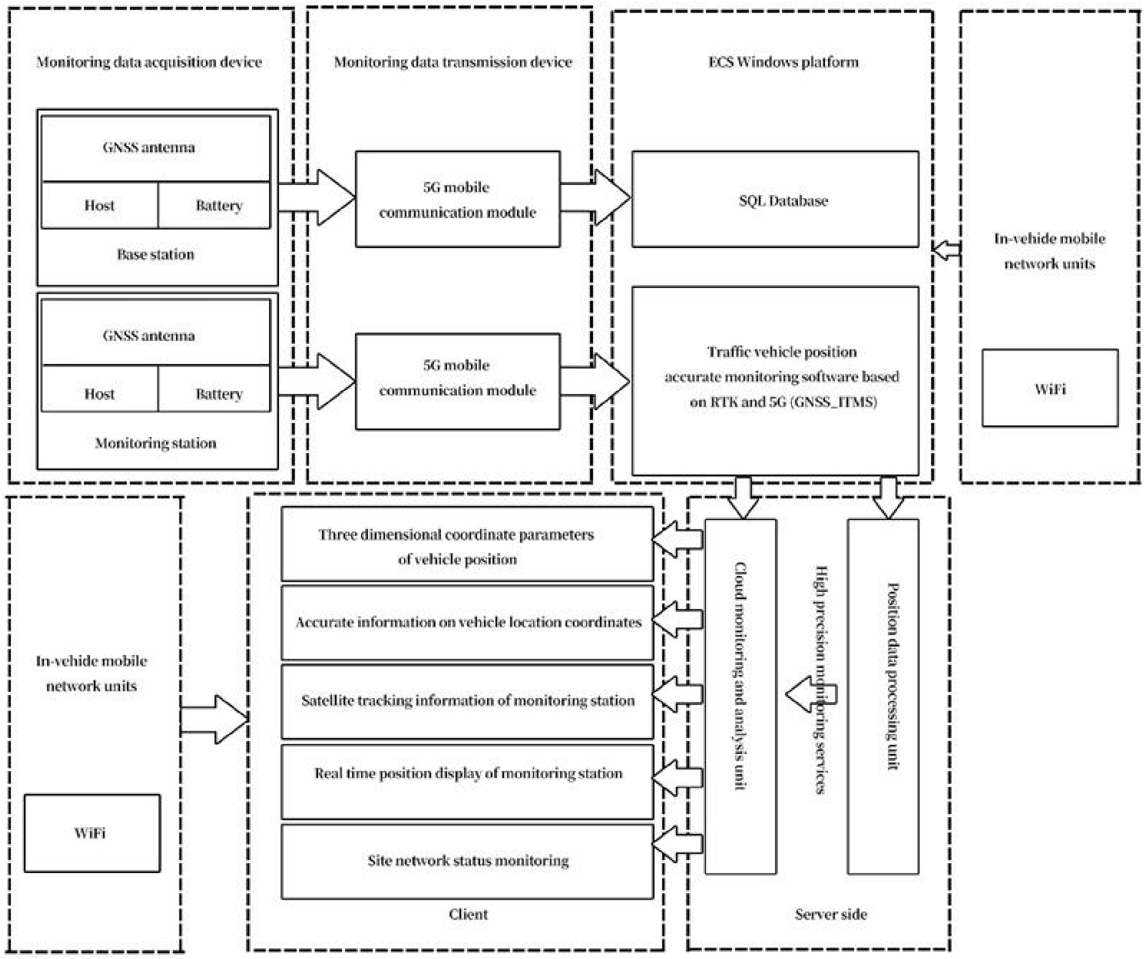

Figure 5. Overall system development process [13].

Finally, this technique was verified by simulation experiments, which are shown in Figure 6. This shows that the online monitoring accuracy of the GNSS_ITMS system is better than 2cm for northbound RMS, 2cm for eastbound RMS and 5cm for elevation RMS, which verifies the correctness and effectiveness of their algorithms. Finally, the monitoring performance of the GNSS_ITMS system is experimentally verified. It is concluded that the method of Zhou Ziduan et al. can provide a cloud-based online high-precision solution for real-time full process monitoring of vehicle location in intelligent transportation systems.

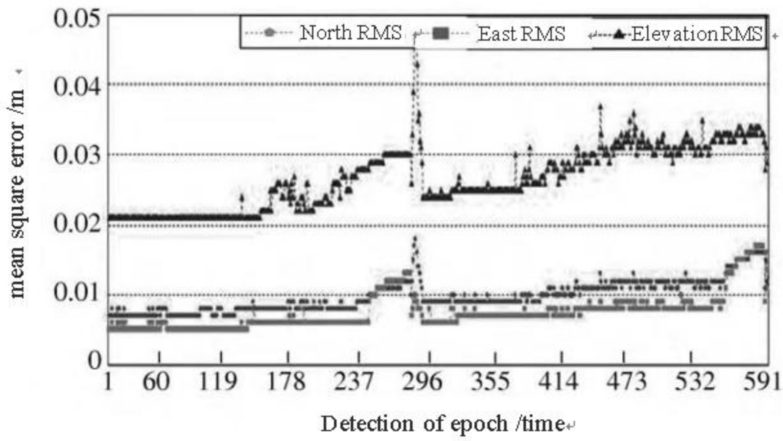

Figure 6. Evaluation of the positioning accuracy of the monitoring station [13].

3.2. A Beidou and edge computing based telematics positioning technology

Due to the transmission time delay of vehicle differential positioning data, which prevents the timely acquisition of high-precision positioning results in the scenario of a vehicle moving at a high speed, the traditional Telematics navigation system exhibits a certain deviation in vehicle positioning results. This led Zhou Qiping [11] et al. to develop a Beidou positioning and edge computing-based vehicle networking navigation technology method. This plan makes use of a better genetic algorithm to allocate resources for requests for terminal placement, significantly lowering the overall edge network's service latency. In order to increase the positioning accuracy of the Telematics nodes, this approach additionally employs an improved lossless Kalman filtering technique based on edge nodes.

The carrier phase difference approach is another name for the Real-Time Kinematic (RTK) method. The idea behind this method is to mount a receiver on a reference station and continually monitor the satellite's condition. The user station is then immediately updated with the observation data and station coordinates thanks to radio transmission technology. Using radio receiving equipment, the user station simultaneously gets the satellite signal and information from the reference station. In this manner, the relative positioning concept may be applied to determine the coordinates of the user station's location. Figure 7 depicts the architecture of the data center-based RTK differential positioning system (a). However, because the data center receives and processes terminal placement requests centrally, traffic congestion is readily caused by this technology. As a result, by incorporating edge computing technology into the positioning approach, the edge nodes may significantly minimize the computational load on the data center while still providing real-time and reliable positioning services.

Under normal circumstances, the use of conventional high-precision RTK positioning algorithms can obtain good vehicle positioning accuracy. However, due to the transmission delay of vehicle differential positioning data in high-speed mobile scenarios, there is a certain amount of positioning deviation in the vehicle positioning results. And high accuracy positioning results cannot be obtained in time, which will have a greater impact on vehicle navigation.

The 5G communication technology development has laid a solid foundation for integrating navigation and communication. Through integrated navigation and communication devices, mobile cellular network base stations are transformed and upgraded into reference stations used to observe satellite navigation signals. Edge computing networks are formed based on existing reference stations to provide navigation and positioning services to terminals [22].

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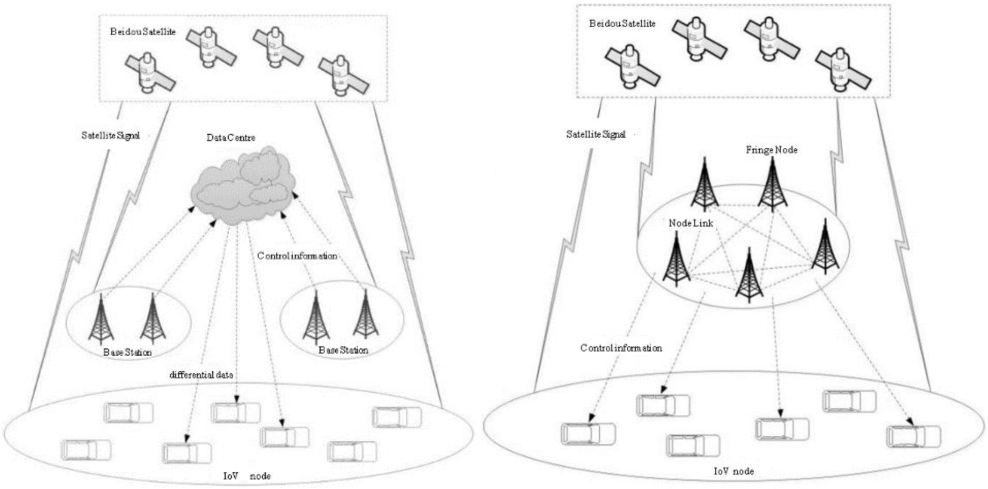

Figure 7. Positioning system architecture (a)RTK Differential Positioning system architecture based on data center (b)Positioning system architecture based on edge computing [11].

Edge computing is a computer technique that takes place at the network's edge, surrounding a tiny data center near the terminal. The base station, an essential component of the Telematics network, is in charge of connecting the terminal to cloud services. Using a base station on the terminal side as an edge node, a large number of deployed and geographically distributed Telematics terminal nodes with low latency, real-time interaction, and mobility support may be provided [23].

The high latency issue with centralized computing in data centers is intended to be fixed by the edge computing-based localization strategy. An edge node is the base station. The closest edge node responds to a location request from the terminal by receiving it, calculating the journey distance correction information, and sending it back to the terminal for resolution. Figure 7 depicts the architecture of the positioning system based on edge computing (b).

In the positioning algorithm based on 5G and edge computing, in order to effectively solve the service delay problem of terminal positioning requests and improve the efficiency of terminal positioning requests, this paper uses an improved genetic algorithm (GA) to ensure that the system service delay is minimized. Furthermore, to minimize the localization error, the team proposes an Enscented Kalman Filter Based on the Edge Node (EUKF) algorithm based on the Unscented Kalman filter (UKF) [24]. The algorithm is characterized by low computational effort and high localization accuracy and can achieve accurate target tracking by reducing the influence of errors on localization accuracy through filtering.

Finally, simulation experiments were carried out to validate the outcomes depicted in Figure 8. Figure 8(a) demonstrates how the EUKF method uses edge nodes in various contexts to eliminate system error, leading to results in vehicle localization that are more accurate. The placement algorithm based on edge computing will ease the load on the data center, as shown in Figure 8(b). The edge node near to the terminal handles the differential correction information, which alleviates the data center's issues with high computation, bandwidth constraints, and high throughput while also significantly lowering system service latency. Let's say the closest edge node receives the location request and, after initialization, determines the differential correction information. Because of the imbalance in terminal location queries, the service latency will then grow. Even yet, load balancing is still possible on GA's upgraded edge computing network, and requests for overloaded terminal locations on edge nodes will be reassigned, further lowering service latency.

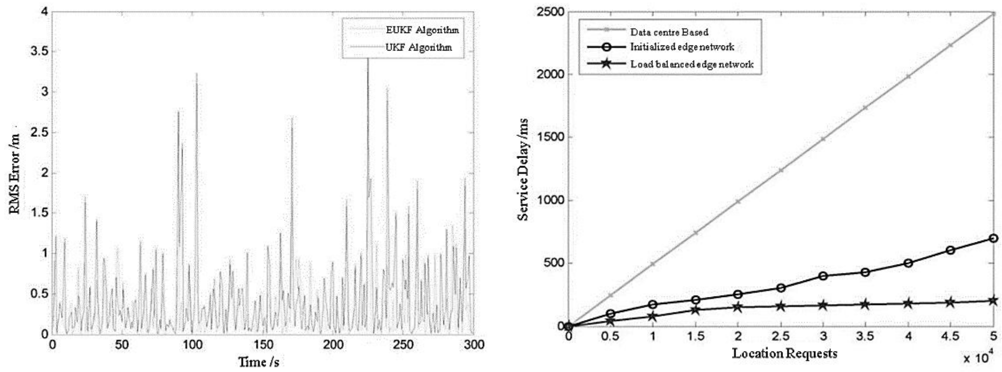

Figure 8. Diagram of the simulation results (a)Errors of dynamic positioning (b)Comparison of the different service delay [11].

3.3. A joint positioning system based on Beidou+5G

In order to solve the problems of unsatisfied accuracy requirements, discontinuous positioning results and long positioning time, Xue Jia-chen [4] et al. proposed a joint positioning system based on BeiDou satellite navigation system and 5G positioning technology, which mainly consists of 3 parts: 5G positioning network, time synchronization equipment and receiving terminal. In terms of algorithm, the mathematical model of joint positioning is established based on the positioning equations of BeiDou and 5G, and the Gauss-Newton method in least squares is used to convert the non-linear equations into linear equations, and the terminal positioning results after iteration are obtained through the derivation of equations.

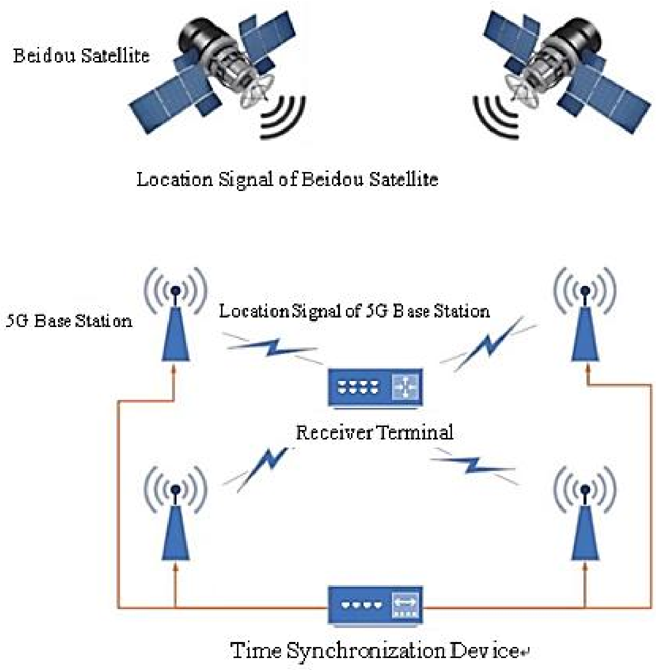

Figure 9. Composition of Beidou+5G joint positioning system [4].

The joint BDS+5G positioning system mainly consists of 3 parts: 5G positioning network, time synchronization equipment and receiving terminal. The structure is shown in Figure 9. Firstly, a 5G positioning network is constructed in the test area, consisting of 5G base stations, one of which is the reference base station. The base station is used to establish a Cartesian coordinate system in the test area, and the receiving terminal is placed within the test area. By receiving the positioning data from the 5G base station, the relative positioning data is decoded in real-time and then fused with the coordinates decoded from the simultaneously received BDS satellite signals to obtain the final positioning results. Among them, the time synchronization equipment ensures the consistency of positioning among 5G base stations to prevent the time difference from causing the positioning to be out of sync and the positioning results to produce errors [25].

Secondly, there are many positioning methods based on 5G technology, and this system uses the positioning method based on TDOA in trilateral positioning. It is one of the widely used position estimation algorithms in relative positioning technology, and TDOA technology based on cellular systems has become increasingly mature.

Rel-16 completes the standardised definition of a PRS dedicated to downlink positioning. The dedicated PRS enables a terminal to receive signals from multiple base stations simultaneously, thereby using the triangulation principle to calculate the terminal's location. To address the problem of neighborhood interference, the 3GPP standard coordinates PRS signals from neighboring cells in the frequency and time domains via PRS, respectively, in order to reduce mutual interference from PRS emitted by different base stations.

Finally, the system is simulated and tested. The experiments show that the average error of static positioning is around 3.14m, and the error of dynamic positioning is around 4.51m when choosing the positioning method of 2 stars + 3 stations and 3 stars + 2 stations. It is also verified that the 5G positioning technology can achieve a certain accuracy range when the signal quality of the BDS satellite is poor, which can further extend the positioning range to some extent and has certain application prospects.

However, there is still room for further improvement in system performance. In addition to the 5G signal measurement errors analyzed above, there are also issues such as the possibility of further optimization of the joint positioning algorithm, the possibility of precision single-point positioning of the BDS satellite receiver to improve accuracy and the elimination of time scale deviations between the system and the RTK reference device in dynamic testing.

4. Conclusion

With the emergence of 5G technology, the problems of low positioning accuracy and long time-consuming positioning in the vehicular network have been solved to some extent. As mentioned in the paper, all three methods effectively improve positioning accuracy and reduce Telematics's positioning latency. However, there are some limitations to the feasibility of optimizing the positioning technology for Telematics, including these three methods. Firstly, many of these optimization methods cannot be tested due to practical factors. While simulation results show that it is effective in optimizing positioning techniques, there is no guarantee that the same results will be achieved in real-world use. Secondly, research into communication technologies is still ongoing and 6G may have higher performance than 5G. Therefore, there is still a lot of room for improvement in the development of location technology for Telematics. Furthermore, concepts such as edge computing have been proposed for a relatively short period of time, and there is limited research and conclusions related to them. At this point, applying edge computing to Telematics requires more experimental data to prove its usability. Finally, for some approaches that use improved algorithms to improve localization accuracy, how to balance the latency associated with improved algorithms with improved accuracy is a key. In summary, although connected vehicle location technology is a popular area of research today and has been optimized to a certain extent, more theory and practice is still needed to drive its development.

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