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The Role and Exploration of Mobile IP Technology in Highways

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Abstract: With the nationwide promotion of ETC applications, congestion at highway toll gates has significantly decreased. However, some highway toll gates still experience frequent congestion due to mismatched passage capacity and demand. To address this issue, an innovative approach is proposed to use mobile IP technology in combination with ETC and manual lanes to achieve zero congestion at highway toll gates. Mobile IP technology involves switching IP addresses across different sites to monitor user entry and exit from highways. This reduces congestion at toll gates and significantly saves time for users entering and exiting highways, eliminating the need to wait for barriers to rise or fall. This solution provides a reference for promoting intelligent highway travel.

Keywords: mobile IP, highways,toll gate congestion management.

1. Research Background

1.1. Traffic Background

With the continuous growth of global traffic demand, highways, as a crucial part of modern transportation systems, face increasing challenges in management and operation. Traditional manual management methods are inadequate in handling large-scale traffic flows. Manual toll collection and inspections are time-consuming and can easily create traffic bottlenecks, affecting road capacity and safety. Although most highways are equipped with ETC systems, these systems have the following limitations [1]:

1.High initial investment and maintenance costs: ETC systems require the installation of dedicated electronic tags and reading devices, which are expensive to install and maintain.

2.Low flexibility: ETC systems primarily rely on specific communication protocols and equipment, limiting their flexibility.

3.Bottlenecks under high traffic volume: In cases of heavy traffic, ETC systems struggle and can lead to congestion and failures [2].

Therefore, it is essential to find a more efficient and reliable automated management method. With the rapid development of mobile internet and 5G communication technologies, achieving unattended automatic entry and exit on highways has become possible. Mobile IP technology, which supports seamless switching between different networks, offers a new solution to this problem.

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1.2. Technical Background

1.2.1. Mobile IP Technology

Mobile IP technology allows devices to maintain continuous and stable connections while moving between different networks. In the context of highways, mobile IP technology ensures smooth switching between different base stations, providing stable communication support. This not only enhances communication reliability but also provides a solid foundation for real-time data exchange and decision-making support [3].

1.2.2. IP Address Change Detection

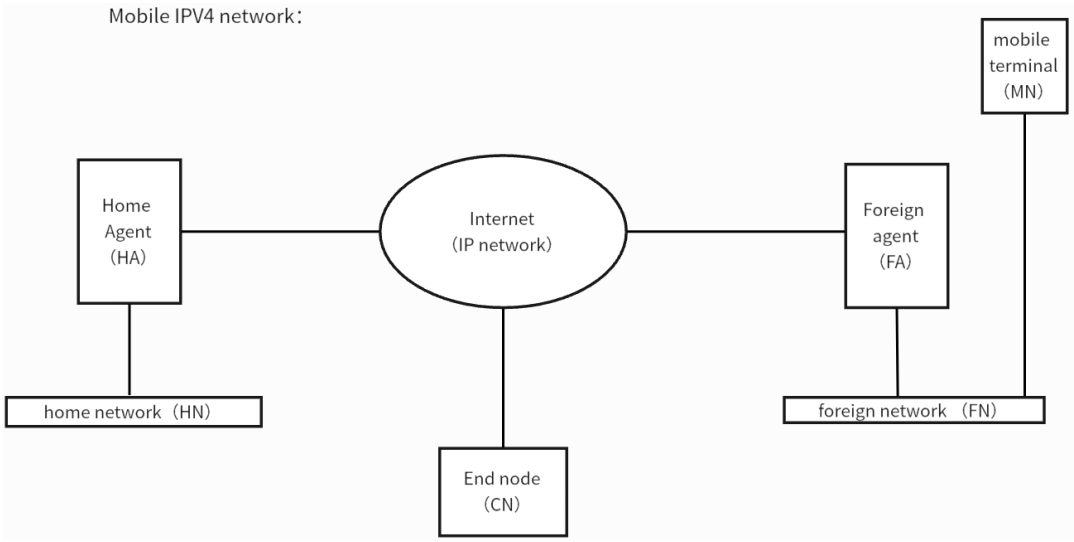
When a vehicle moves from a city network to a highway network or vice versa, the IP address of the mobile phone changes. This change serves as a key indicator of the vehicle's entry and exit from the highway. By monitoring these changes, the system can infer the vehicle's status and achieve automated management of highway entry and exit. This method has the advantage of not requiring additional hardware and can be implemented using existing mobile network infrastructure.

2. Research on Mobile IP Technology

2.1. Mechanism of Mobile IP

In mobile IP, there are four main functional entities and two types of addresses: Mobile Node (MN), Home Agent (HA), Correspondent Node (CN), Foreign Agent (FA), Home Address (HoA), and Care-of Address (CoA). The HA is located in the home subnet and is responsible for recording the current position of the MN and forwarding data packets to the MN's current location. The CN is the node communicating with the MN. Each MN has a fixed HoA, which is independent of its current internet access location. When an MN moves to a foreign subnet, it needs to configure a CoA with a foreign network prefix and provide its current location information through the CoA [4].

As shown in Figure 1, the mobile node MN registers with its Home Agent (HA), allowing the HA to manage the latest position of the mobile nodes within its subnet. When other nodes need to communicate with the mobile node, they first send data packets to the home network of the mobile node MN, which are received by the corresponding HA. The HA looks up the CoA registered by the mobile node and then encapsulates and tunnels the data packets to the MN. When the MN sends data packets, they can be directly sent to the correspondent node CN.



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2.2. Principle of Cell Tower-Based Phone Localization

When a mobile phone is turned on, it exchanges information with nearby cell towers. Through the transmission and reception of signals by the cell towers, the backend data processing center can determine the position coordinates of the phone. The specific calculation process is as follows: Assuming the total time for each radio pulse signal emitted by the cell tower to be received is tt, and the propagation speed of the radio pulse is known as VV. According to the formula d=V×t2d=V×2t, the one-way distance dd between the phone and the cell tower can be calculated. According to geometric principles, three circles can determine a unique point on a plane. When a mobile phone enters the coverage area of three or more cell towers, the three-point positioning method can be used to draw three circles, and the intersection of these three circles is the position of the phone. Let the coordinates of the three cell towers be (x1,y1,z1),(x2,y2,z2)and (x3,y3,z3) ,the coordinates of the phone be (x,y,z). For one of the cell towers, the data processing center calculates the spatial distance d1d1 between the phone and cell tower 1 based on the round-trip time of the radio pulse. According to the Pythagorean theorem, in a spatial coordinate system, the following three-dimensional quadratic equation can be established:

(x−x1)2+(y−y1)2+(z−z1)2=d1(x−x1)2+(y−y1)2+(z−z1)2=d1

(x−x2)2+(y−y2)2+(z−z2)2=d2(x−x2)2+(y−y2)2+(z−z2)2=d2

(x−x3)2+(y−y3)2+(z−z3)2=d3(x−x3)2+(y−y3)2+(z−z3)2=d3

By solving these three three-dimensional quadratic equations, the backend data processing center can determine the position coordinates (x,y,z) of the phone, thus achieving precise phone localization.

2.3. Role of Base Station Selection and Mobile Switching Center

To determine which base stations are used for positioning, the mobile network relies on the coordination of the Mobile Switching Center (MSC). The MSC is the central node of multiple base stations, responsible for managing and controlling call and data transmission in the mobile communication network. When a user purchases a SIM card, all personal information is registered with a specific Home MSC. The Home MSC stores user-related information, including location and communication records. When a user leaves the coverage area of their Home MSC, a new MSC (called a Roaming MSC) takes over the service. The Roaming MSC communicates with the user's Home MSC to obtain the user's latest location information. The Home MSC always knows the region where the user is currently located and determines the user's position through the following techniques:

1.Periodic Location Update: User location information is updated periodically, usually at regular intervals.

2.Location Update Based on Base Station Handover: When a user passes a predetermined number of base stations, the location information is updated again.

3.Initial Position Registration: When a user turns on their phone, it registers with the nearest base station, updating the location information. The following example illustrates this process: Suppose user E calls user J. The call request is first sent to E's Home MSC. Once E's Home MSC receives J's phone number, it forwards the request to J's Home MSC. J's Home MSC checks the current MSC area of J:

If J is within the coverage area of the Home MSC, the call request is immediately sent to J's phone, and J's current status (such as whether they are on another call or if the phone is off) is checked. If everything is fine, J's phone will ring and the call will be connected.

If J is outside the coverage area of the Home MSC, J's Home MSC forwards the call request to the current Roaming MSC. The Roaming MSC uses the aforementioned methods (periodic location update, location update based on base station handover, or initial position registration) to locate J's phone and then establish the call connection. In this way, the mobile switching center effectively

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manages and coordinates user communication requests, ensuring smooth communication even when users are roaming [5].

3. Implementation of Automatic Entry and Exit on Highways Using Mobile IP Technology

3.1. Basic Requirements

1. Vehicle Enters Highway Entrance When a driver enters the highway entrance, nearby base stations use localization technology to determine the vehicle's position. The base station monitors changes in the IP address of the mobile phone, identifying that a specific IP address (representing a vehicle) has reached the highway entrance. The base station sends this information to the Mobile Switching Center (MSC), which records the IP address and begins continuous monitoring of its position changes.

2. Continuous Monitoring and Position Updates During the vehicle's journey, the base station continuously monitors changes in the IP address's position. Through periodic location updates and location updates based on base station handover, the vehicle's position information is kept up-to-date. Each time the vehicle passes a base station, the base station updates the vehicle's position information and sends it to the MSC. The MSC matches this position information with pre-stored highway segment information, recording the vehicle's travel path.

3. Vehicle Leaves Highway Exit When the vehicle leaves the highway exit, the base station detects a change in the IP address, indicating that the vehicle has left the highway. The base station sends this information to the MSC, which calculates the vehicle's travel distance on the highway based on the recorded travel path and time.

4. Automatic Billing and Notification The MSC sends the calculated travel distance to the backend computing system, which calculates the toll fee based on predefined standards. The backend computing system sends the fee information to the user's phone, and the payment is automatically deducted via a mobile payment platform. Users can view detailed billing information and travel records through a mobile application, ensuring transparency and convenience in the payment process.

3.2. Technical Implementation

1. Base Station Localization: By using the signal strength and time difference from multiple base stations, the system employs triangulation to determine the precise position of the vehicle.

2. IP Address Change Detection: When a vehicle moves from a city network to a highway network or vice versa, the IP address of the mobile phone changes. By monitoring these changes, the system can accurately determine the vehicle's entry and exit status.

3. Mobile Switching Center (MSC): The MSC manages multiple base stations, records and updates the vehicle's position information, and communicates with the Home MSC and Roaming MSC to ensure the accuracy and real-time nature of the vehicle's position information.

4. Backend Computing System: This system handles position information and billing logic, ensuring accurate and transparent fee calculations [6].

4. Conclusion

This paper explores the feasibility of using mobile IP technology to achieve unattended automatic entry and exit on highways. By analyzing the mechanism of mobile IP, the principle of cell tower-based phone localization, and the role of base station selection and mobile switching centers, the study enhances the efficiency of highway passage, reduces human errors, and improves user experience. It also provides new insights for the further development of intelligent transportation systems. Future research will continue to optimize technical performance, expand application areas, and seek policy support to promote the widespread adoption and development of this technology [7].

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