

Postprint: A Technical Discussion on Network Architecture for Autonomous Vehicles

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Abstract

It is foreseeable that automotive autonomous driving will bring about a revolutionary transformation in future automotive transportation paradigms. To achieve clean, green, and intelligent transportation, it is essential to rely on 5G technology and Internet of Things (IoT) technology to construct intelligent road infrastructure, highway IoT, and data and control information platforms, thereby establishing a national intelligent autonomous driving system. This paper proposes a conceptual framework for a national automotive autonomous driving road network system, integrating BeiDou global positioning and navigation, IoT and vehicle networking, 5G communication, big data and cloud computing, artificial intelligence, microelectronic chips, and other technologies to establish a national automotive autonomous driving and control road network system, thereby realizing true full vehicle autonomous driving.

Full Text

Discussion on Technology of National Autonomous Driving Network System

Abstract

It is foreseeable that autonomous driving represents a revolutionary transformation in future automotive transportation. To achieve clean, green, and intelligent transportation, we must rely on 5G technology and Internet of Things (IoT) technology to construct intelligent road infrastructure, highway IoT networks, and data and control information platforms, thereby establishing a national intelligent autonomous driving system. This paper proposes a conceptual framework for a national automotive autonomous driving network system, integrating BeiDou global positioning and navigation, IoV (Internet of Vehicles), 5G communication, big data and cloud computing, artificial intelligence, microelectronic chips, and other technologies to establish a national automotive au-

tonomous driving and control network system, enabling truly fully autonomous driving.

Keywords: 5G; Internet of Things; automotive autonomous driving; information interaction

With social development and technological progress, there are higher demands for efficient travel. Establishing a national super highway network for the information age, developing intelligent transportation, and promoting green transportation will help meet the people's ever-increasing material and cultural needs. Building a national intelligent transportation network system to achieve true autonomous driving represents a revolutionary transformation in future automotive transportation.

After the network is completed, it will enable China and countries along the "Belt and Road" to further deepen comprehensive cooperation in transportation infrastructure and regional integration. Ordinary highways will be revolutionarily upgraded into "super highways" that meet autonomous driving requirements, forming a new round of high-tech engineering construction output. Countries along the "Belt and Road" will accept China's high-value-added complete technology products ranging from intelligent road infrastructure and highway IoT to traffic control and information platforms, facilitating the transformation and upgrading of China's industrial economy and strengthening economic and cultural exchanges with neighboring countries to establish long-term partnerships.

The autonomous driving network system is a major systematic project benefiting people's livelihoods. When integrated with the new energy vehicle strategy in planning, construction, and promotion, it can effectively reduce pollution and achieve green development. Planning and constructing a national autonomous driving network system will create new economic growth points, enhance China's soft power, and become a new calling card surpassing China's high-speed rail under the "Made in China 2025" initiative, yielding enormous benefits in political, economic, social, and national strategic aspects. By taking the lead in formulating a package of technical protocols and related standards for the autonomous driving industry—promoting, using, and maturing them first—China can seize first-mover advantage, establish market leadership, suppress competitors, maintain its leading position, become a rule-maker, and stand at the top of the global value chain.

1. The Dream and Reality of Autonomous Driving

Information, materials, and energy are often hailed as the three essential elements of human civilization. The revolutions in new information technology, new materials, and new energy have propelled the development of the automotive industry, with the future direction being vehicles that use clean electric power and achieve autonomous driving.

According to the automotive automation levels established by the Society of

Automotive Engineers (SAE), levels L0 through L5 represent a progressive scale from manual driving to fully autonomous driving (see Table 1 for details).

Currently, the models introduced by mainstream autonomous driving research institutions focus on single-vehicle independent operation. These systems use video cameras, radar sensors, and laser rangefinders to obtain road traffic conditions and signal information, relying on specialized detailed electronic maps for navigation and mimicking human driving behavior to achieve autonomous driving on roads. At best, these approaches can only achieve Level 2 or Level 3 automation. The research approach dominated by individual companies and commercial institutions, due to its inherent limitations, has resulted in continuous major accidents causing casualties even in specific simplified testing environments. If most vehicles on the road were unmanned, traffic would become a disaster. While technology certainly needs improvement, the fundamental problem lies in the inherent flaws of this technical approach. Following the current technical route, achieving safe and convenient autonomous driving and advancing to Level 4 or even Level 5 will be an impossible mission.

Therefore, to truly realize fully automated driving, it is necessary to integrate all transportation elements—including passengers, vehicles, roads, and signals—to establish a globalized, systematic, networked, and intelligent autonomous driving architecture. This requires building a national automotive autonomous driving network system to achieve a revolutionary leap in automotive transportation.

2. System Architecture and Technical Functions

2.1 System Architecture Overview

Truly achieving safe, efficient, convenient, and comfortable autonomous driving that completely liberates drivers requires top-level design led by the state, establishing unified specifications and standards to build a national automotive autonomous driving and control network system.

The national automotive autonomous driving and control network system is an intelligent, information-based, and networked comprehensive management and control system for all dynamic, real-time elements of road traffic. It integrates advanced sensor technology, communication technology, data processing technology, network technology, automatic control technology, and information publishing technology. This autonomous driving network architecture operates under the BeiDou navigation system and a national road IoT network.

2.1.1 The System Consists of Seven Basic Modules:

1. **National Traffic Information Data Storage Exchange and Traffic Management Control Center:** This center collects, processes, and publishes information from traffic participants, and implements planning, control, and management of ground traffic.

2. **Vehicle Traffic Management-Centric IoT:** Following agreed communication protocols and data exchange standards, this IoT network connects all road traffic participants through wireless communication networks to enable real-time information exchange.
3. **Comprehensively Informatized Roads and Fixed Traffic Facilities Under IoT Coverage:** Through signal and system retrofitting and standardization, these facilities continuously collect information from road traffic participants and issue commands and feedback to them.
4. **Intelligent Traffic Participant Vehicles:** These vehicles possess independent assisted driving and emergency avoidance capabilities, with driving status precisely controlled by automotive chips and electromechanical systems. They feature emergency early warning functions for surrounding environment monitoring and have bidirectional mobile data exchange capabilities, enabling real-time upload of vehicle speed, acceleration, position, and direction to the nearest information exchange node via IoT.
5. **BeiDou Navigation System and BeiDou Ground-Based Augmentation System (BeiDou CORS):** This system achieves centimeter-level or higher precision vehicle positioning across all road surfaces.
6. **Navigation Electronic Maps:** As a crucial component of the fundamental geographic information system, electronic maps primarily enable route planning and navigation functions. Map navigation must work in conjunction with the BeiDou system.
7. **Registration and Management Institutions:** Vehicles operating on autonomous driving network roads require registration for refined management. Drivers “operating” vehicles in autonomous mode also need to pass training and examinations to register for this new type of driving qualification.

Upon completion of the national automotive autonomous driving and control network system, cloud storage, cloud computing technology, IoT technology, and positioning and navigation technology combining BeiDou with electronic maps will create a unified national ground highway traffic network. All traffic participants will operate in an orderly manner under unified command and dispatch. From the driver/passenger perspective, this will be fully autonomous driving that meets and exceeds Level 5 standards; from the perspective of vehicles on the road, vehicle operation will be under precise guidance and strict control.

2.2 Technical Functions of System Components

2.2.1 Electronic Maps Autonomous vehicles require high-precision electronic navigation map systems with accuracy of at least 10 centimeters to enable Level 5 autonomous driving. Currently available civilian electronic maps do not meet this precision requirement. It is necessary to conduct

high-precision map data collection for the national road system and establish nationwide 2D and 3D navigation maps.

Implementation can begin with pilot programs in satellite towns, completing high-precision mapping to establish high-accuracy map navigation zones for road testing, then gradually expanding the coverage.

2.2.2 BeiDou System and Ground-Based Augmentation Currently, there are four major global satellite navigation systems: the U.S. GPS, Russia's GLONASS, the EU's Galileo, and China's BeiDou (BDS). Global satellite navigation and positioning systems primarily provide location information, particularly three-dimensional data including longitude, latitude, and altitude, offering real-time, all-weather, and global navigation services. Electronic maps such as Baidu Maps and AutoNavi mainly provide location-based information services.

For establishing a national integrated autonomous driving network, the BeiDou satellite navigation system with independent intellectual property rights is the preferred choice, considering both national security and practical application requirements.

BeiDou positioning has now entered its third phase, with global services commencing on December 27, 2018, upon completion of the BeiDou-3 basic system. China will establish a global navigation and positioning system composed of 30 BeiDou satellites by 2020. After completing global network deployment, BeiDou's coverage and performance will be substantially enhanced.

The BeiDou ground-based augmentation system is the core of navigation applications, representing an integrated rapid, high-precision application service system based on BeiDou. It utilizes multi-base station network carrier phase differential technology to establish a Continuously Operating Reference Station (CORS) system. Currently, the BeiDou ground-based augmentation system has completed the development of its basic system, capable of providing users with wide-area real-time positioning accuracy at the meter, decimeter, centimeter, and post-processed millimeter levels. The basic scheme for the BeiDou navigation ground augmentation system has been determined, with hundreds of base stations to be built nationwide to achieve wide-area high-precision positioning across the country.

Based on the BeiDou satellite navigation system and BeiDou navigation ground augmentation system, centimeter-level high-precision positioning can be achieved on China's territory, providing positioning, speed measurement, and timing services. It can enable route planning, navigation, and turn-by-turn instructions, and when combined with sensors, can also support indoor navigation.

The integration of BeiDou navigation technology with ground augmentation technology and vehicle IoT can effectively enhance the accuracy of spatiotem-

poral information to meet the demands for high-precision, high-frequency spatiotemporal data.

2.2.3 National Highway IoT The highway IoT is an integrated network capable of enabling intelligent traffic management, intelligent dynamic information services, and intelligent vehicle control, representing a typical application of IoT technology in the transportation system domain.

Wireless communication between vehicles and other units on the road refers to short-range wireless communication between vehicles and roadside facilities and equipment, including vehicle-to-vehicle, vehicle-to-roadside device, vehicle-to-infrastructure, and vehicle-to-pedestrian communications. Through the highway IoT, a series of traffic information from the road converges at the traffic information center, enabling traffic participants to “see” each other and facilitating more rational traffic scheduling and arrangement to achieve intelligent transportation.

The information command and control nodes of the national automotive autonomous driving and control network system, under the premise of achieving high-precision vehicle positioning through the BeiDou system and combining high-precision fundamental geographic data from electronic navigation map systems, provide vehicles on the road with information about surrounding vehicles based on identification information, vehicle status data, and driving intentions sent back via the wireless IoT from each vehicle under their “jurisdiction.” Vehicles operating in autonomous driving mode have clear awareness of the distance to nearby vehicles within a certain range, as well as the driving direction angle, speed, acceleration, and route of surrounding vehicles, achieving “knowing both oneself and the enemy.”

Simultaneously, these information command and control nodes calculate driving instructions based on traffic status information within their “jurisdiction,” vehicle attribute information, and driving intentions. Vehicles then follow these instructions from the nodes and, under control of their own computerized electronic driving systems, smoothly navigate through dense traffic along designated lanes with specified direction angles, speeds, and accelerations.

The development of 5G and 6G will meet the diverse demands of advanced applications for the national automotive IoT. Conversely, developing the autonomous driving network system will also promote the development and application of 5G and 6G technologies.

2.2.4 Intelligent Infrastructure and Road System Retrofitting Road systems must be retrofitted to accommodate autonomous driving requirements and become part of the national highway IoT. Through intelligent transformation and construction of road infrastructure, non-motorized vehicles and pedestrians can be separated on roads, and comprehensive road flow perception can be integrated with traffic signal systems to enhance road operation efficiency

and safety levels. Electronic and visual information markers formed on roads provide vehicles with perception of their location and surrounding environment, enabling onboard computers to construct detailed small-scale 3D maps. Furthermore, such intelligent transportation facilities can extend into communities, buildings, and underground parking lots.

With unobstructed mobile network communication along roads, precise regional information—such as road construction work, traffic control restrictions, road accidents and their handling, and road obstacles—can be collected in real time and sent to the nearest higher-level traffic dispatch center node. Conversely, the higher-level traffic dispatch center node will distribute traffic information and control information relevant to certain road sections down to those sections. At that time, various traffic information will be clearly visible on automotive navigation electronic maps, enabling rational travel route planning.

Under this system, highway section toll stations can be eliminated. With intelligent highways, entry and exit times, routes, and points of entering/exiting highways plus intermediate key points (such as highway interchanges) will be automatically recorded, and electronic statistical toll bills will be automatically sent and deducted, improving logistics efficiency and liberating social productivity.

Even non-autonomous vehicles can benefit from various convenient traffic services provided by such intelligent highway systems.

2.2.5 Traffic Information Center and Traffic Control Center In the future, ground vehicles will travel along standardized paths, forming driving plans according to demand—much like riding a train—following the dispatch instructions of traffic control centers within the national automotive autonomous driving and control network system to reach their destinations.

Under the national network's central traffic control center, several large regional networks will be established across the country, with regional traffic control centers created for each. Within each region, provincial (municipal) level networks will be further divided, establishing provincial (municipal) traffic control centers, followed by district centers, sub-district centers, and finally dispatch nodes at certain intervals along roads. Relying on cloud computing and cloud storage, traffic planning calculations and storage/distribution of traffic data and command information will be realized.

Combining traffic information control systems with satellite navigation systems, electronic maps, and vehicle IoT systems can enable numerous functions such as vehicle tracking and traffic management.

2.2.6 Computerized Electronic Driving System The computerized electronic driving system referred to here is the system that controls vehicle operation according to driving instructions.

Relying on wireless automotive IoT and intelligent transportation facilities to provide traffic information and command signals, autonomous vehicles on the road follow the “approved” planned routes from the national network’s traffic control center. Under guidance from the BeiDou navigation and ground augmentation systems and with reference to electronic maps, they generate a series of driving instructions to complete actions such as starting, accelerating, turning, overtaking and lane changing, parking, refueling (charging), and inspection under control of the vehicle’s driving computer.

The core of the computerized electronic automatic driving system is the onboard driving control chip unit, which has the function of receiving external information, processing it, and issuing driving instructions to various vehicle control modules to control the vehicle. It also has communication capabilities with the onboard IoT chip unit, traffic control centers, and traffic information centers. This component requires full core intellectual property rights.

2.2.7 Auxiliary Driving Warning and Avoidance System To enhance safety, vehicles themselves must also possess independent detection, warning, and avoidance systems. Vehicles joining the autonomous driving network can be equipped with cameras, millimeter-wave radar, LiDAR (Light Detection and Ranging) devices, front-end processing units, and inertial navigation devices to achieve early warning and monitoring of road obstacles and emergencies, enabling timely control of the vehicle to take reasonable avoidance measures and enhance active safety.

Meanwhile, relevant emergency road condition information is also reported to the nearest traffic node via mobile internet. The traffic node then issues advance warnings to all nearby vehicles about the emergency situation, including obstacle type, location information, and danger level, allowing following vehicles to handle and avoid the hazard.

2.2.8 Vehicle Registration Management System Vehicles operating within the national autonomous driving network system must meet basic technical standards and be pre-registered to obtain qualification certificates.

When a vehicle is being developed and manufactured, it must obtain national autonomous driving network access qualification. The vehicle must be equipped with onboard control chips and vehicle IoT chips, and conduct wireless data communication and identification according to unified communication protocols and data exchange standards to meet the requirements for autonomous operation on national autonomous driving network system roads. Basic performance information of the vehicle must be registered, such as three-dimensional external dimensions, wheelbase, track width, minimum ground clearance, longitudinal passage radius, lateral passage radius, minimum turning radius, curb weight, seating capacity, braking parameters, fuel tank capacity (battery capacity), and fuel consumption parameters, among others.

The national automotive autonomous driving and control network system stores qualified vehicle models in a database. Only such vehicles can connect to the autonomous driving network IoT, achieving vehicle identification, positioning, and communication, and be permitted for road operation.

Newly purchased vehicles with autonomous driving network access qualifications must be registered before the autonomous driving function can be activated. Vehicle maintenance and annual inspection records, insurance information, ownership details, and authorized drivers are injected into the vehicle information chip and simultaneously stored on the national traffic information data storage cloud platform.

2.2.9 Personnel Registration Management System Every driver must obtain a chip-based driver's license ID. People need to learn how to use the autonomous driving system, pass the autonomous driving license examination, and store this information in the license chip ID, including the autonomous driving qualification type and other details. When driving, the driver's chip ID must be verified by the vehicle before it can be started. The chips are categorized into autonomous-only and autonomous-manual compatible types, granting people the ability to "drive" vehicles using different modes.

3. Daily Operation Management

3.1 Mobile APP for Daily Vehicle Management

In the era of autonomous driving, individuals can conveniently dispatch their authorized vehicles using mobile phones. After personnel and vehicles are registered in the national automotive autonomous driving and control network system, they can log in and authenticate through the national network's dedicated APP to achieve integration of people, vehicles, and the network.

Through the dedicated APP, users can locate vehicles online in real time, understand various vehicle conditions, and dispatch vehicles to designated locations.

3.2 Trip Planning

Drivers submit travel plans through the national autonomous driving network APP, using either automatic or manual methods for route planning.

Automatic Route Planning: The driver determines the starting point, destination, and intermediate rest stops, and the national network traffic control center's cloud computing platform automatically designs several optimal and alternative driving routes for the driver to select.

Manual Route Planning: The driver initially formulates the route independently, or relies on the onboard computer/mobile phone using navigation electronic maps for route design and planning. After manual route planning is completed, it is submitted to the nearest grassroots traffic control center of the

national network according to the proximity principle. Automatically planned routes, or manually planned routes approved after review, are injected into the vehicle's driving operating system as a "road book" before autonomous driving actions can be executed. Each driving route plan, containing various basic information, is submitted to relevant traffic information centers at all levels of the network and stored on the cloud platform. Traffic information centers and traffic control centers work closely together, each performing its own functions.

3.3 On-Road Driving

Each vehicle engages in real-time information exchange with intelligent road facilities, surrounding vehicles in motion, traffic control centers, and traffic information centers under the support of 5G networks, achieving intelligent traffic management, dynamically obtaining intelligent information services, and realizing fully autonomous driving.

After autonomous vehicles enter the road, they can accurately perceive their own position, establish dynamic 3D data models of surrounding traffic facilities and vehicles, and achieve civilized driving according to their driving intentions, performing actions such as queuing, overtaking, lane changing, accelerating, decelerating, and turning. Their driving intentions and series of action information are disseminated through the nearest grassroots traffic information platform and perceived by surrounding traffic participants.

3.4 En Route Management

During travel, temporary stops or route changes may be necessary to meet various basic needs of people or the vehicle itself, and plans may also change due to personal reasons or emergencies. En route, vehicles can receive new instructions from the driver or accept control instructions from the nearest traffic control center to adjust their missions.

After the national road vehicle IoT is established, information on various road facilities and ancillary resources can be queried through the traffic information service center, and allocation and occupancy can be applied for in advance, achieving refined and precise management.

The vehicle's self-inspection functions may issue various warnings, necessitating entry into service areas for inspection and maintenance when needed. During autonomous driving, passengers may board or alight mid-journey, or long trips may require periodic rest stops at service areas. Passengers can even disembark to rest, shop, or watch a movie before continuing their journey.

3.5 Arrival

Autonomous vehicles drive into above-ground or underground parking lots registered and marked in the navigation electronic maps and traffic information

center, after which occupants lock the vehicle and depart. Sometimes the destination (drop-off point) is a standardized area that accommodates temporary stopping and passenger alighting for autonomous vehicles. For example, boarding and alighting at intelligent parking islands with pick-up/drop-off operations: after the driver (passenger) exits the vehicle and confirms on the mobile APP, the car automatically drives to an automated parking lot or intelligent multi-level garage for parking.

4. Application Scenarios

Autonomous driving functionality will bring a revolution to the transportation field, much like the invention of the steam engine ushered in the railway era.

For road transportation in logistics enterprises, mining operations, urban public transit, intercity long-distance passenger transport, and fixed-route shuttle services, implementing autonomous driving can liberate drivers from laborious operations.

Changes in daily travel patterns: At the junctions between suburbs, non-central urban areas, and central urban zones, people can alight at drop-off areas while their vehicles automatically find parking spaces to wait or return home on their own. People can then transfer to mass public transportation or private rental vehicles to enter central urban areas. This fully utilizes various transportation resources, reduces the number of vehicles on roads, and provides people with more convenient and worry-free travel.

In central areas of large cities, reducing the number of vehicles on roads saves energy, reduces emissions, alleviates congestion, and improves ground vehicle utilization efficiency. If all vehicles are converted to new energy vehicles, air pollution in central urban areas can be reduced, significantly improving air quality.

For tourism or out-of-town travel, the experience will be as convenient as local travel. At distribution hubs such as airports and ports, whether or not people can drive, they can conveniently rent vehicles through self-service, achieving seamless connection with air and sea transport. In tourist cities and scenic areas, the concept of “self-driving” will change to renting autonomous vehicles for free travel according to personal plans and preferences. For medium-short distance travel or business activities, people can sit in the vehicle, enjoying the scenery or working while traveling to their destination, without the fatigue of driving.

If new energy vehicles combine with wireless power and energy supply, some vehicles can operate autonomously online for extended periods, improving utilization efficiency. Moreover, they would not need batteries or would only require small-capacity battery packs, reducing environmental pollution from battery disposal.

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Note: Figure translations are in progress. See original paper for figures.

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