Research on reliable communication network for data concurrent transmission based on intelligent network connection system

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Abstract. With the development of intelligent networking system for electric vehicles, the communication between intelligent electric vehicles has attracted more and more attention, and how to use multi-channel communication to realize data distribution is one of the research focuses. Firstly, the communication channel is modeled by Markov chain, and a discrete-time channel model is established, which is used for estimating and predicting the channel state. At the same time, using the idea of multi-channel and time synchronization, a concurrent transmission mechanism based on time synchronization is proposed to realize the synchronous transmission of data from multiple intelligent networks on multiple channels. Finally, the simulation results show that the average delay in the network can be reduced by about 30%. Therefore, the feasibility of the method is verified, and the method can effectively improve the performance of the communication network. This paper also gives a feasible solution to the overall architecture of vehicle communication network from the perspective of integration of WAVE and WiMAX technologies, and uses cross-layer integration design criteria and optimization methods to improve the performance of the new vehicle communication network.

1. Introduction
Intelligent network connection system, which integrates new energy vehicles, charging pile infrastructure, smart grid and urban intelligent transportation, is one of the key elements of smart city construction and development. The growth trend of new energy vehicles in Tianjin is analyzed: from 2018 to 2020, there will be about 20,000 new energy vehicles in Tianjin for three consecutive years. It is estimated that in the next five years, the electric vehicles in Tianjin will show a rapid development trend, and the number of electric vehicles will exceed 200,000. The use of new energy vehicles has positive significance for solving urban environmental pollution, adjusting energy consumption structure and facilitating residents' travel[1]. In the communication process of the intelligent network connection, after the physical layer completes the spectrum sensing and modulation, the most basic network resource facing the link layer and the upper layer is the wireless channel. There are many channels in the communication network of MAS[1]. Compared with single channel, multi-channel can make full use of spectrum resources to enhance the performance of the network and complete the concurrent transmission of data among multi-agents. It can realize the split processing of data and reduce the waiting time and...
data delay. However, multi-channel must deal with the channel allocation and coordination between nodes in order to achieve higher performance than single channel[3]. At the same time, time synchronization is an important part of communication among multiple agents, which requires more accurate time synchronization among agents in the concurrent transmission mechanism. In this way, when exchanging data, we can have a unified time to realize that the agents can receive the data sent by other agents synchronously, so that the agents can fuse the data in real time, otherwise it will cause the increase of power consumption and the loss of data.

Traditional concurrent transmission mechanism uses multi-channel technology to share the data load with multiple available channels, which reduces the channel occupation time and avoids data conflicts in the communication process. However, it does not involve how to improve the accuracy of time synchronization, and it is difficult to efficiently solve the problems such as node disappearance caused by multi-channels. At the same time, when the number of agents increases, it will cause poor real-time performance of data and increase node power consumption. The basis of multi-channel selection is firstly to monitor the channel state. Therefore, in this paper, firstly, Markov chain is used to model the channel, and considering the fading characteristics of the channel, the change of channel quality in communication network is accurately described. And this paper proposes puts forward a concurrent transmission mechanism based on time synchronization. In this mechanism, a reference node is used to broadcast a synchronization reference packet, all nodes receiving this reference packet record the receiving time stamp in local time[6], and then complete the synchronization of all nodes receiving the reference packet by exchanging time stamps. At the same time, multiple channels in the network are shared by multiple nodes by multi-channel technology. When some channels are occupied, nodes can switch to other idle channels, which ensures that the communication among multiple nodes is carried out at the same time, thus realizing synchronous and concurrent transmission of data. Finally, the effectiveness of this method is verified by simulation experiments.

The traditional vehicle communication network is usually only a closed communication network designed for highway billing and other purposes. The recent development makes the vehicle network support workshop autonomous communication to exchange safety information. Due to the defects in the network architecture, the existing system can only provide information exchange in local areas for vehicles traveling at high speed. The new generation in-vehicle network will provide universal services, including various vehicle safety message transmission, intelligent traffic information service, multimedia digital service, etc. Therefore, in the new generation of vehicular mobile network, how to realize real-time data service between vehicles and intelligent traffic control center (such as providing road condition information, map download service based on location information, etc.), and broadband wireless access of in-vehicle users to the Internet to obtain multimedia entertainment and information have become a very important and urgent topic in the research of in-vehicle mobile network. In view of this situation, this paper puts forward a vehicle mobile network architecture with heterogeneous wireless network convergence, they are mainly the vehicle self-organizing communication technology based on wireless access in vehicle environment WAVE) (IEEE 802.11p) and the vehicle broadband wireless access technology based on worldwide interoperability for microwave access (WiMAX) (IEEE802.16e), and the related key technologies are discussed and studied.

2. Establishment of communication channel model in intelligent network connection system

2.1 Basic theory of Markov chain
Markov chain is a discrete-time stochastic process with Markov property, in which the past is irrelevant to predict the future given the current information[4]. Markov model can be applied to the modeling and analysis of discrete communication channels, considering a random process \( \{X_n| n = 0,1,2,...\} \), the value range of this process is a non-negative integer, so the state in this process can be expressed as \( i = 0,1,... \). Whenever the process is in state \( i \), regardless of the state before state \( i \), the probability \( pij \) that the next state is state \( j \) is a fixed probability, then the process is called Markov chain. That is, all \( n > 0, i_{n-1}, i0, i, j \), have
\[ p_{ij} = \mathbb{P}(X_{n+1} = j \mid X_n = i, X_{n-1} = i_{n-1}, \ldots, X_0 = i_0) = \]  
\[ \mathbb{P}(X_{n+1} = j \mid X_n = i) \]  \hspace{1cm} (1)

2.2 A discrete-time Markov chain channel model
When using Markov chain to model a channel, the state model of the channel is used to describe different channel states, in which the channel states are represented by a discrete state set. In every time slot, the state set of the K-state Markov model of a discrete communication channel is \( S = \{s_0, s_1, \ldots, s_{K-1}\} \). K states are used to distinguish different degrees of channel conditions. For example, state \( s_0 \) is the best channel condition, state \( s_1 \) is the second best channel condition, and so on, and state \( s_{K-1} \) is the worst channel condition. Write the channel state of the nth time slot as \( S_n \), where \( s_n \). Let \( p_{ij} \) be the transition probability from state \( s_i \) to state \( s_j \), then:

\[ p_{ij} = p(S_{n+1} = s_j \mid S_n = s_i) \]  \hspace{1cm} (2)

At the same time, the characteristics of Rayleigh fading channel are considered. In Rayleigh fading channel, the signal-to-noise ratio \( \gamma \) is a probability density function of exponential distribution:

\[ p_{\gamma} (\gamma) = \frac{1}{\gamma_0} \exp \left(-\frac{\gamma}{\gamma_0}\right), \gamma \geq 0 \]  \hspace{1cm} (3)

Where \( \gamma_0 \) is the average signal-to-noise ratio. Note that \( \{\gamma_1, \gamma_2, \ldots, \gamma_K\} \) are signal-to-noise ratio thresholds, and they are arranged in ascending order, where \( \gamma_1 \) is 0 and \( \gamma_K \).

Transition probabilities \( P_{i,i+1} \) and \( P_{i,i-1} \) satisfy:

\[ \begin{align*}
  P_{i,i+1} &\approx \frac{N(\Gamma_{i+1})T}{\gamma_i} \\
  P_{i,i-1} &\approx \frac{N(\Gamma_i)T}{\gamma_i}
\end{align*} \]  \hspace{1cm} (4)

In which \( n(\gamma I) \) is the horizontal pass rate and \( p_i \) is the probability that the received signal-to-noise ratio falls into the interval \( [\gamma_i, \gamma_{i+1}) \). Then the state transition process of the channel can be completely described by the transition matrix \( P_c \):

\[ P_c = \begin{pmatrix}
  p_{00} & p_{01} & p_{02} & \cdots \\
  p_{10} & p_{11} & p_{12} & \cdots \\
  \cdots & \cdots & \cdots & \cdots \\
  p_{K-1,0} & p_{K-1,1} & \cdots & p_{K-1,K-1}
\end{pmatrix} \]  \hspace{1cm} (5)

The above models describe the discrete-time Markov chain channel model, which can not only reflect the user's occupation of the channel well, but also consider the fading characteristics of the channel, accurately describe the change of the channel quality in the communication network, and scientifically predict the idle channel with the highest probability in the future.

3. Concurrent transmission mechanism based on time synchronization

3.1 Time synchronization
In the communication process of the intelligent network connection system, the information transmission between the intelligent network connection bodies needs to be synchronized, so as to complete the real-time communication. Real-time communication between agents can be realized by
using the idea of time synchronization. The method eliminates the influence of transmission delay on synchronization accuracy and improves the accuracy of time synchronization. The specific process of time synchronization is as follows:

Step1: The reference node periodically broadcasts the synchronization reference packet.

Step2: Node I receives the $k$th synchronization parameter packet, and the receiving time recorded according to the local clock is $T_{ik}$; node J receives the $k$th synchronization reference packet, and the receiving time recorded according to the local clock is $T_{jk}$.

Step3: Continuously receive the synchronization reference packet broadcast by the reference node, and exchange information with the neighbor nodes, and get m different differences. According to these differences, the receiving time deviation between node $i$ and node $j$ is calculated:

$$
\text{offset}[i,j] = \frac{1}{m} \sum_{k=1}^{m} (T_{ik} - T_{jk})
$$

Step4: After a period of time synchronization between nodes, due to clock drift, the node time is gradually skewed. When the clock skew is considered, the time stamp is processed by linear fitting of least square method, and the clock deviation $\Delta T_{ij}$ between nodes is calculated.

$$
\Delta T_{ij} = a_0 + a_1 x
$$

$a_0$ represents the intercept after curve fitting, that is, the clock phase offset; $a_1$ represents the slope after curve fitting, that is, clock skew. Let $x$ be the abscissa and $y$ be the ordinate after curve fitting, then

$$
\begin{align*}
x_k &= T_{ik} \\
y_k &= T_{jk} - T_{ik} \\
a_0 &= \frac{\left(\sum_{k=1}^{m} x_k\right) / m - a_1 \left(\sum_{k=1}^{m} y_k\right) / m}{m} \\
a_1 &= \frac{m \sum_{k=1}^{m} x_k y_k - \left(\sum_{k=1}^{m} x_k\right) \left(\sum_{k=1}^{m} y_k\right)}{m \sum_{k=1}^{m} x_k^2 - \left(\sum_{k=1}^{m} x_k\right)^2}
\end{align*}
$$

Step5: Complete the synchronization between nodes according to the calculated receiving time deviation and clock deviation.

### 3.2 Concurrent Transmission Mechanism

Because multi-channel transmission has obvious advantages over single-channel transmission in network performance, concurrent transmission on multi-channel can effectively reduce congestion, achieve load balance and improve the utilization rate of network resources. At the same time, it can reduce data conflicts, realize data distribution and improve the performance of the whole communication network. The schematic diagram of concurrent transmission mechanism based on time synchronization is shown in Figure 1:
Figure 1 Concurrent transmission mechanism based on time synchronization

The specific flow of the concurrent transmission mechanism is as follows.

Step1: Generate a channel selection sequence for each node. The pseudo-random sequence algorithm is used to generate different pseudo-random sequences for each node as the channel selection sequence, and each node uses its own node number as the seed of the pseudo-random algorithm. Here, the linear congruence method is used to generate pseudo-random sequence, and its calculation formula is

$$x_i + 1 = (ax_i + c) \mod m \quad (i = 0, 1, 2, \ldots) \quad (9)$$

In which $a$ is multiplier, $c$ is increment, $x_0$ is seed and $m$ is module.

Step2: Determine the time slice selection sequence. Firstly, time is divided into multiple fixed-length time slices, and a superframe is composed of multiple time slices. The pseudo-random sequence algorithm is used to generate different time slice selection sequences for each node. According to the generated time slice selection sequences, the node selects a time slice in each superframe as its awakening period. Nodes listen to the channel status in each waking period and send and receive information.

Step3: The node broadcasts its own channel selection sequence and time slice selection sequence to neighboring nodes regularly, so that the nodes can know each other's channel selection information, awakening period and dormant period for communication.

Step4: At the initial time, all nodes stay on the first channel of each channel selection sequence. According to formulas (2) and (4), the state transition probability and channel fading condition of the channel are calculated and recorded as channel state set $S$ when a node has information to send, the node judges whether the channel is good or bad through the channel state set $s$. If the current channel is good, communicate directly on the current channel, and execute Step5. Otherwise, execute Step6.

Step5: Determine whether the awakening periods of the sending node and the receiving node are in the same time slice. When in different time slices, the data is sent directly. If the awakening periods coincide, wait for the next superframe. This avoids the problem of node disappearance.

Step6: Determining the next channel to be switched according to the channel selection sequence, if the channel is good, establishing a connection between the sending node and the receiving node in a three-way handshake mode, and executing Step5. Otherwise, continue to search for the next channel through the channel selection sequence, and judge whether the channel is good or bad until a suitable channel is found for communication.
Step 7: The reference node periodically broadcasts the synchronous reference packet, and a plurality of sending nodes receive the synchronous reference packet, determine the receiving time according to the local clock, and calculate the receiving time deviation and clock deviation by formula (6) and formula (7) to complete the synchronization between nodes.

Step 8: After communication, the node switches to its own default channel, thus completing the whole channel selection process and realizing concurrent transmission based on time synchronization.

4. Experimental analysis

4.1 Experimental process

In Experiment 1, the simulation results of channel state in partial time slots are given. Markov chain is used to analyze the channel state, and the channel state set is $s_0 \ldots 10$. In Figure 3, the channel state of two channels in partial time slots is selected.
Fig. 3 the state of each channel in different time slots

Experiment 2 tests the influence of traditional methods and this method on the performance of multi-agent communication network, and measures the network performance by using the performance index of average delay.

Fig. 4 Comparison of average delay between two methods

4.2 Experimental conclusion

Fig. 4 is a comparison of data by traditional method and method in this paper. Comparison of the influence of transmission delay performance. It can be seen from the figure that the average time delay can be reduced by using this method. At the initial time, that is, when the channel and network load are not heavy, the data is transmitted concurrently on multiple channels, and the average delay is small. When more and more data are sent, the channel and network are overloaded, and the waiting time between data queues gradually increases. Therefore, the average delay also increases relatively. However, on the whole, the average time delay is reduced by using this method.

5. Research on key technologies of new vehicle mobile communication network

5.1 Distributed Channel Scheduling and Channel Adaptive Coordination Mechanism Based on Link State

In the research of multi-channel, this paper adopts the channel coordination mechanism based on time slot interval and the channel access mechanism based on time division multiple access (TDMA) to
determine the basic architecture of the protocol. In the protocol infrastructure, a synchronization interval includes a control window and a data exchange window, and each window is further divided into time slots\cite{12}. The control window is used for broadcasting security messages and control messages, and the data exchange window is used for unicast or regional broadcasting of non-security information. The framework of VANET multi-channel MAC protocol is shown in Figure 5. The channel adaptive coordination mechanism based on traffic density is to dynamically adjust the control window interval and data exchange window interval according to traffic density information. On the basis of the proposed protocol framework, a distributed multi-channel scheduling algorithm is studied, which can allocate optimal resources to nodes from the two dimensions of frequency and time in a local area to improve channel utilization and throughput. On this basis, the performance of the algorithm is analyzed based on the whole network.

![Figure 5 Protocol Infrastructure](image)

5.2 Routing Algorithm Based on Relative Location
In the current vehicular network, the relative position between nodes can be obtained by link prediction, so as to select routes. In order to reduce the burden of data link layer and make the current routing algorithm independent of MAC, the method of providing location information by GPS equipment can be selected in the research. By predicting the movement of moving vehicle nodes and improving the existing clustering algorithm, the emergency message broadcasting mechanism is used to ensure that the emergency message is sent quickly and stably after a vehicle accident. On this basis, it is very important to design a clustering broadcast routing algorithm based on mobile prediction. At the same time, due to the high-speed movement of vehicle nodes in vehicle-mounted network, the network topology changes frequently. In order to improve the service quality of vehicle-mounted network and reduce the delay caused by frequent interruption of nodes during network transmission, it is necessary to predict the location, speed and acceleration information of nodes, estimate the connection holding time, and start the route discovery process before the route breaks. Guarantee the QoS of data transmission\cite{13}.

5.3 Group Handover Mechanism Based on Mobile Relay Technology
Group Handover (GHO) is the handover of multiple user terminals on a mobile vehicle to the next base station at the same time. In the handover process, resources need to be redistributed according to different service levels to ensure the QoS of services\cite{14}. For the problem of resource reservation in handover process, the technology of mobile user prediction can be used for preliminary estimation, so as to reduce the call drop rate and handover delay. The research contents of group handover based on relay technology include: design of group handover process based on mobile prediction, handover admission control strategy based on subchannel reallocation strategy, and research of speed adaptive handover algorithm, etc.

5.4 Two-level Scheduling Algorithm Based on Relay
After the introduction of relay technology in the vehicle network, relay nodes will be added in the broadband wireless access system. The base station and the user terminal will carry out signaling interaction through the relay station instead of direct communication between them. Therefore, in this system, the concept of hierarchical scheduling appears, which is mainly the resource scheduling of
base station and relay node. That is, a distributed scheduling mechanism is adopted. Because the relay station itself has strong processing ability, including part of the base station decision ability, it can help the base station to make the corresponding decision on resource allocation optimization for the user terminal through the relay node, thus reducing the burden on the base station and improving the throughput and data transmission speed of the system. The two-level resource scheduling algorithm is mainly based on the three-tier structure of "vehicle-MRS node-roadside base station", and carries out two-level dynamic bandwidth resource allocation (DBA) according to the change of network environment, providing spectrum resource utilization rate and providing different quality of service guarantees for different types of services.

6. Conclusion
In this paper, Markov chain is used to model the channel, accurately describe the change of the channel quality in the communication network, and scientifically analyze the state of the channel at every moment. On the basis of the traditional concurrent transmission method, the idea of time synchronization is put forward. When an agent has data to send, it monitors the channel state. If the channel is busy, switch to other idle channels for transmission, and send multiple data to an agent synchronously by time synchronization method. Finally, the effectiveness of the proposed method is verified by simulation experiments.

This paper also proposes a hybrid vehicle mobile network architecture based on WAVE-based vehicle self-organizing communication network and WiMAX-based vehicle broadband wireless access technology, and gives the protocol module model of the new vehicle mobile network. In the process of designing a new vehicle mobile network protocol framework, we have made theoretical research and analysis on the key technologies such as multi-channel coordination, scheduling and multicast routing mechanism in vehicle ad hoc communication, and group switching and multi-level resource scheduling and allocation mechanism in vehicle broadband wireless access.

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