Routing Optimization Algorithm for Internet of Vehicles Empowered by Symbiotic Radio and DAG

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Abstract Based on the development of mobile Internet of Things (IoT), communication networks and infrastructure, intelligent transportation systems are gradually becoming informatization and intelligence. The Internet of Vehicles (IoV), has problems such as fast node movement, frequent network topology changes, and poor link stability. This paper considers the driving characteristics of vehicle nodes in high-speed driving conditions, the factors of vehicle speed and relative vehicle distance, and the auxiliary routing transmission of road side units deployed around the road are comprehensively considered. Symbiotic radio equipment installed near the Road Side Unit (RSU) for anti-interference, and used to improve spectral efficiency and anti-interference. For delay-tolerant data, a blockchain Directed Acyclic Graph (DAG) structure for vehicle travel routes is proposed. The decision of the packet routing transmission vehicle is planned through the topological route of the DAG. The simulation experiment analysis demonstrated the optimized routing decision algorithm proposed in this paper can effectively improve the data packet delivery rate of routing transmission, and provide efficient and safer data transmission for the IoV network.

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1 Introduction

The Internet of Things aims to realize the information interaction and intelligent application of production and living tools in human society. Compared with traditional automatic control, the informatization method provided by the IoT can provide network support for the Internet of Everything (IoE) more accurately and efficiently [1, 2]. The rapid development of communication network technology has brought unprecedented driving force to the application of the Internet of Things, and the application of the IoT is not only satisfied with small devices or static devices [3, 4]. In the traffic scenario of vehicle driving, vehicles in the IoV realize the information exchange between vehicles through the on board unit (OBU) with communication and positioning capabilities [5]. Including road information, traffic environment, driving status, entertainment and other IoV applications emerge one after another. Establishing communication between vehicles for information exchange can not only improve the driving experience and efficiency, but also improve the safety of the traffic system, which is of great help in reducing congestion and accidents [6, 7].

Due to the limited communication range of vehicles, fast driving speed, and unstable network links, Vehicle Ad Hoc Networks (VANETs), as one of the ad hoc networks, is indispensable in the information exchange of the IoV [8]. Therefore, an efficient and stable routing protocol and routing algorithm is particularly important. Among the routing algorithms of the VANETs, routing algorithms based on geographic location have been widely studied and applied [9]. However, because its forwarding decision is made only by a simple distance factor, the transmission quality is low in environments such as high speed or sparse nodes. Efficient routing and forwarding algorithms are necessary guarantees for effective and reliable applications for network applications (such as autonomous driving, road accident information) and bandwidth demanding applications (such as multimedia, entertainment information), but also a big challenge.

Cognitive radio and environmental backscatter communication technology have been studied by many scholars as a technology to improve spectrum utilization and transmission efficiency. With the development of communication technology, spectrum resources become more valuable. At the same time, the problem of energy consumption still exists for a long time. Compared with traditional ambient backscatter communication technology, the backscatter device (BD) in symbiotic radio can share the radio spectrum and RF source of transmitting and receiving nodes, thus saving spectrum resources and energy consumption.

According to the forwarding strategy of the traditional geographical location based routing protocol, this paper analyzes the characteristics of vehicles in high speed driving environment and the characteristics of routing transmission. A routing optimization algorithm based on factors such as vehicle speed and relative distance is proposed for comprehensive decision making optimization, and a composite weighting formula is established to make the final decision to select the optimal next hop vehicle routing node. In the proposed model, the symbiotic radio technology is introduced. Design a BD device equipped with a symbiotic radio near the RSU of the system model. In the case of high node density, interference is easy to occur, and the RSU of the BD device equipped with the symbiotic radio nearby can be used to resist the interference and improve the transmission efficiency. For delay tolerant data, a DAG path planning model based on blockchain and vehicle driving routes is proposed. According to the DAG path, the data routing vehicle node is selected to improve the success rate of routing data packet transmission. Finally, the data transmission efficiency of the proposed routing optimization algorithm is verified by simulation experiments. The remainder of this paper is as follows: Sect. 2 describes current research and existing challenges. Section 3 introduces the system model and optimization ideas. Section 4 introduces the proposed routing optimization algorithm and DAG path decision algorithm. Section 5 conducts experimental simulation analysis. Section 6 demonstrates the conclusions of this paper and looks forward to future research directions.

2 Literature Review

Ambient backscatter communication uses passive technology to transmit data, which is susceptible to interference and affects transmission efficiency. SR is an integrated technology in which radio devices can benefit from each other, thereby improving data transmission performance. Researchers often combine research with technologies such as intelligent reflecting surface (IRS).

In [10], the authors used SR techniques with the aid of the IRS to improve communication physical layer security. Combining deep reinforcement learning (DRL) and IRS key generation scheme, the key generation rate (KGR) is effectively improved. Unmanned aerial vehicle (UAV) have always been a popular direction for communication assistance. Taking advantage of the mobility of UAVs, the authors in [11] proposed an SR using UAVs to assist IRS. Through the optimization of the UAV movement trajectory and IRS phase shift, the transmission efficiency and performance of the system are significantly improved. The authors in [12] applied SR technology to passive IoT, BD integrated on the main communication system, and formulated two beamforming optimization contents: weighted sum rate maximization (WSRM) problem and transmit power minimization (TPM) problem. The overall rate of the system is improved while reducing the computational complexity of beamforming. In order to cope with large scale and high throughput communication scenarios, the model proposed by the authors in [13] applies novel large intelligent surface/antennas (LISA) as an auxiliary purpose to the SR system. The active transmit beamformer and passive reflecting beamformer of BS and LISA are jointly optimized, and the effectiveness and superiority of the proposed algorithm are verified by experiments.

According to other parameters such as vehicle driving state, network bandwidth, etc., many researchers have proposed optimization and improvement methods for forwarding strategies based on geographic location routing protocols. The authors in [14] proposed a learning strategy for historical vehicle flow on routing optimization at bifurcations. The Q-learning algorithm is applied to monitor the traffic flow and establish a Q-table to select the optimal forwarding section. The proposed algorithm can effectively reduce the end to end delay and communication overhead. The prediction of the vehicle's driving trajectory can make routing and forwarding more accurate. The authors in [15] analyze the probability matrix of vehicle moving position and vehicle position correlation matrix, and propose a routing analysis algorithm based on vehicle position RAVP. Use the normalization method to analyze the distance and cache of the vehicle, and select the vehicle with the optimal forwarding capability to improve the delivery rate and reduce the network overhead.

The vehicle inevitably needs to be exposed to different scenarios during the driving process, so a single scenario consideration has low adaptability to multiple scenarios in the driving process. In order to allow vehicles to have higher routing transmission efficiency in different scenarios, the comprehensive routing optimization strategy proposed in this paper aims to enable vehicles to have higher transmission performance in different scenarios. The main contributions of this paper are as follows.

Symbiotic radio communication is introduced to utilize BD near RSU to improve spectral efficiency and anti-interference in node dense scenarios. Considering multiple indicators such as driving state, network state, etc., a normalized formula is established to select the optimal routing vehicle. In the sparse scenario, a DAG based vehicle route planning is proposed, and the optimal delay tolerant data transmission relay vehicle is selected according to the DAG topology, so as to improve the transmission success rate and reduce the delay.

3 System Model

All vehicles in the model are equipped with on board unit (OBU) capable of communication and GPS device with positioning function, which can obtain geographic location information in real time. The vehicle driving scene is divided into two cases: node sparse and node dense. According to the characteristics of different scenarios, two routing optimization system models are proposed. The dense scene system model is shown in Fig. 1.

There is a communication infrastructure RSU on the roadside, and a backscatter communication device BD is installed near the RSU. As a backscatter device for SR technology, BD is used to improve the spectral efficiency and anti-interference ability in dense node scenario. Among them, RSU, BD and the vehicle receiving the information together form a symbiotic radio system. At the same time, according to the indicators such as vehicle driving state and network bandwidth, a normalized formula is established to comprehensively evaluate the selection strategy of the

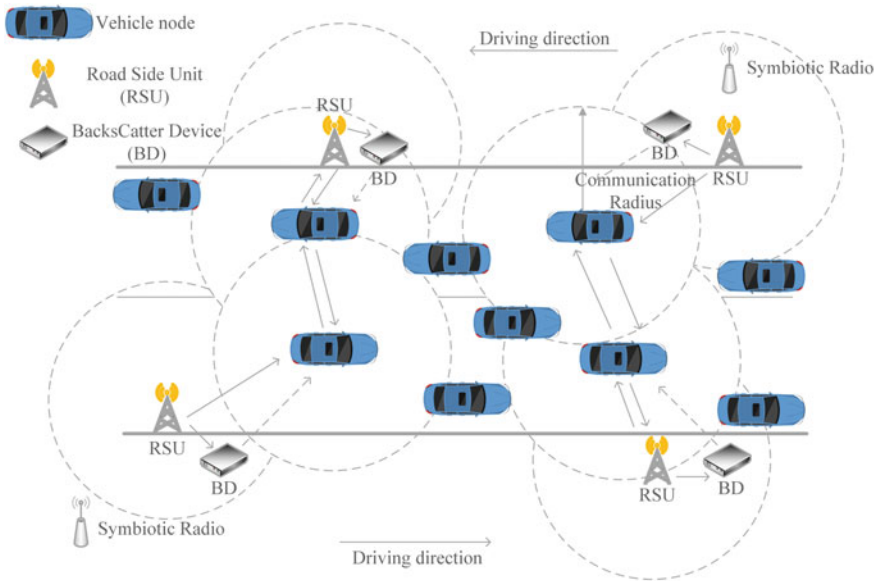

Fig. 1 Node dense scene model

optimal vehicle node for routing. The scene model with sparse nodes is shown in Fig. 2. When there are few vehicle nodes and instant routing transmission cannot be achieved, the transmitted delay tolerant data can be carried by the vehicle, and the data packet is forwarded to the next hop node when the path can be passed to the node near the destination node. All surrounding vehicles share the driving path, form a DAG topology diagram according to the path, and the sending vehicle selects the most appropriate next hop node according to the DAG topology diagram.

4 Algorithm Analysis

Considering the technical characteristics of IoV routing optimization and symbiotic radio, the proposed routing optimization algorithm is divided into three parts. They are routing decision algorithm based on driving state and network performance, symbiotic radio transmission performance improvement and DAG route sharing and planning, respectively.

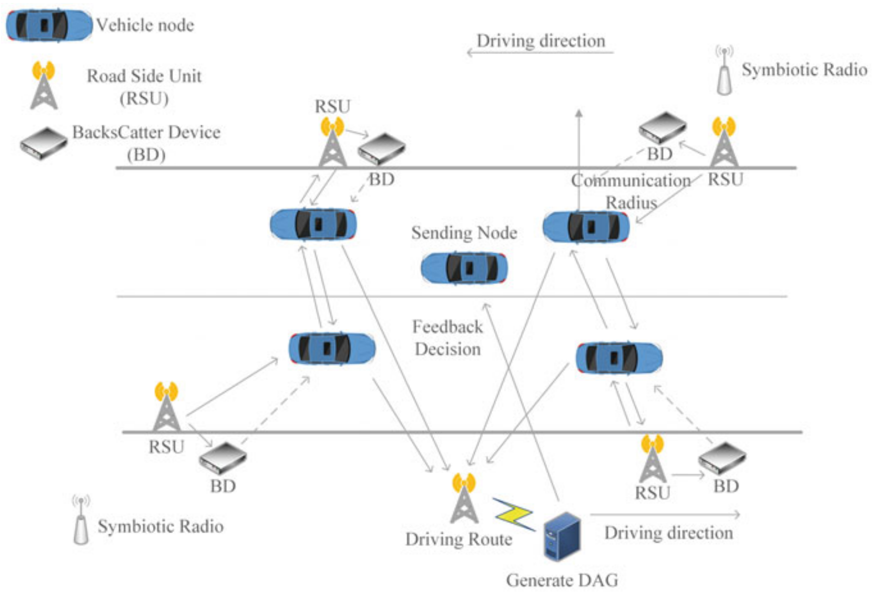

Fig. 2 Node sparse scene model

4.1 Routing Decision Algorithm

In the process of routing transmission, the available bandwidth rate of the node i can be expressed as:

$$\beta_i = \frac{B_{wa}}{B_{wi}}, \quad i = 1, 2, \ldots N \tag{1}$$

B_{wa} is the available bandwidth of the relay node, B_{wi} is the total bandwidth of the relay node.

The vehicle density can have a certain degree of influence on the routing transmission. The vehicle density parameter η is expressed as:

$$\eta = \frac{1}{n}\sum_{i=1}^{n} ki\left(\frac{\tau}{n}\right) \tag{2}$$

where k is the average density of neighbor nodes per unit time, τ is a constant coefficient, and n is the reciprocal of the total vehicle density.

According to the change of direction and speed, the coefficient value ψ used to evaluate the movement of the vehicle is expressed as:

$$\psi = \frac{|d_m| \cos\theta}{V_m} \tag{3}$$

The absolute value of d_m is the distance difference between the sender and the receiver, $\cos\theta$ is the angle between the direction of the sender's vehicle and the direction of the destination vehicle, and V_m is the speed difference between them.

According to the above vehicle driving parameters, a normalization formula is established to obtain the optimal relay vehicle node decision. The optimal next hop node O_n is:

$$O_n = \arg\max(\alpha_1\beta_i + \alpha_2\eta + \alpha_3\psi) \tag{4}$$

α_1, α_2 and α_3 is the weight value of each indicator parameter, and the addition result is equal to 1.

4.2 *Symbiotic Radio*

In the proposed routing optimization model, each RSU is equipped with a symbiotic radio scattering device BD near each RSU. As an integrated system, the symbiotic radio consists of three parts in this paper, the RSU, BD and the vehicle for data transmission. In a scenario with dense vehicle nodes, when the RSU communicates with the vehicle nodes, the RSU sends a signal to the vehicle and the BD, and the BD uses the received signal to improve the transmission spectrum efficiency and enhance the anti-interference ability. The routing decision optimization algorithm considering the parameters and the application optimization of the symbiotic radio are shown in Algorithm 1.

Algorithm 1 Routing Optimization

```
GET NODE INFORMATION(Periodic update)
MAINTAIN CANDIDATE SET
if d_m < Communication range then
   Next hop → Destinationnode
else
   Get value → β_i, η and ψ
   Calculate the value of O_n
   Select Max (O_n)
end if
if next hop node → Communication range then
   send data → BD and next node
else
   Reselect node
end if
```

4.3 DAG Route

In scenarios where vehicle nodes are sparse, transmission failure becomes a common situation. Therefore, some delay tolerant information can be carried by the vehicle and moved to the vicinity where it can be transmitted to the destination node before being forwarded. This will cause data transmission failure or excessive delay caused by factors such as driving route changes, which will seriously affect the transmission efficiency. Therefore, a DAG structured route planning scheme is proposed. Vehicles share and upload their respective driving route information, generate DAG by RSU, and select vehicles that can reach or are closest to the destination node according to the route of the DAG. The DAG will be stored in the RSU during the time period, which can provide route planning for other vehicle transmissions during the time period. After the time period, the DAG is reset and a new DAG route is created based on the route information uploaded by the vehicle. The route transmission of DAG route scheme is shown in Algorithm 2.

Algorithm 2 DAG Route

```
Begin
Get surrounding node information
for i = n − 1 do
    n = next hop → Destination
end for
if n = none then
    Get the number of node
    Upload route → RSU
    Establish DAG
    if Next hop or Destination → DAG route then
        Data packet → V_n
    else
        Data packet → Node closest to destination
    end if
end if
DAG storage period T
if Nowtime < T + 1 then
    Reset DAG
    Route upload
end if
```

5 Simulation and Results

This chapter uses simulation experiment to verify the proposed optimization algorithm. The simulation software is MATLAB, and the vehicle speed changes randomly in the simulation environment (5–30 m/s). The range is a rectangle of 1000 m * 200 m

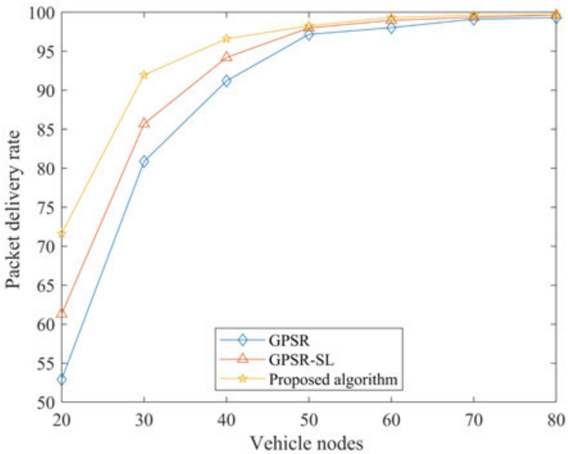

Fig. 3 Comparison of different number of nodes

and the direction of the vehicle is changed to random. The proposed algorithm is compared with Greedy Perimeter Stateless Routing (GSPR) routing algorithm and GPSR-SL [16] routing algorithm.

Figure 3 demonstrates the routing transmission performance in the scenario of different vehicle nodes. It can be clearly seen that the proposed routing optimization algorithm has a higher packet delivery rate than GSPR and GPSR-SL in the scenario of different vehicle nodes. When the vehicle nodes are sparse, that is, at 20 and 30, the success rate of packet delivery is significantly reduced. When the vehicle nodes are denser and reach more than 50, the delivery success rate is significantly improved, and with the increase of vehicle nodes, the improvement rate continues to decrease. At this time, the success rate of packet delivery is very tiny affected by the number of nodes. The proposed routing algorithm fully considers the vehicle's driving indicators and network parameters, and proposed a symbiotic radio that can improve spectral efficiency and anti-interference, that is, the application of BD near RSU. Therefore, the PDR is higher than GSPR and GPSR-SL.

Figure 4 demonstrates the PDR of vehicle nodes at different speeds. It can be seen that as the speed increases, the packet delivery rate continues to decrease. It can be easily seen that the rapid movement of the node will lead to unstable network topology and frequent link disconnection, thus seriously affecting the transmission efficiency. Therefore, it is particularly important to consider and optimize factors such as vehicle speed and direction in the routing process. Therefore, the proposed algorithm has higher PDR than GSPR and GPSR-SL. Moreover, the addition of symbiotic radio technology can also make transmission performance better.

Figure 5 demonstrates the system throughput under different vehicle nodes. The increase of vehicle nodes will increase the throughput first, because after the increase of vehicle nodes, the PDR is improved, which increases the throughput. However, when the number of vehicle nodes increases to a large number, the number of vehicle nodes will reduce the throughput. These vehicle nodes will improve the PDR very

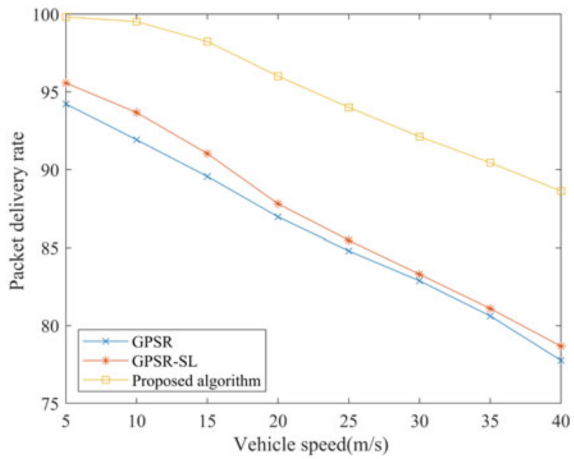

Fig. 4 Comparison of different speed

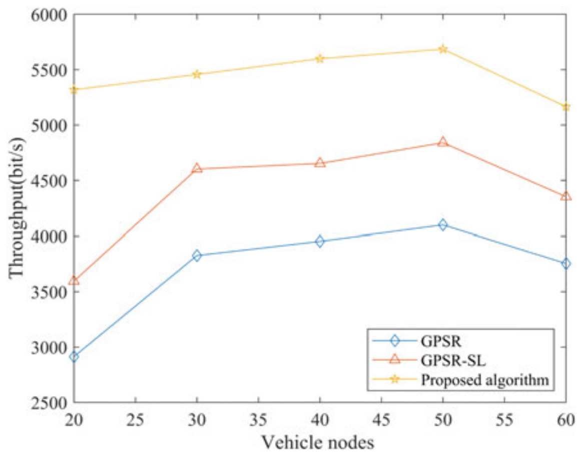

Fig. 5 Throughput of different number of nodes

little, but will cause more interference, and the update and maintenance of information tables will increase the system burden and affect the transmission performance.

6 Conclusion

According to the technical characteristics of the IoV and symbiotic radio, this paper proposes a routing optimization algorithm using symbiotic radio and DAG. Apply symbiotic radio and BD to improve transmission spectral efficiency and enhance anti-interference. The DAG route scheme can provide a better routing node selection strategy in the scenario of sparse nodes. On this basis, comprehensively evaluate the vehicle driving state and network parameters, and establish an optimal decision making formula. Simulation experiments show that the proposed routing optimization algorithm can provide higher transmission efficiency. In future research, consider combining DAG, blockchain, and incentive algorithm, and propose incentive algorithm for route sharing.

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