An Adaptive QoS-Aware Roadside Base Station Assisted Routing in Vehicular Networks

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摘要

智慧型傳輸系統(Intelligent Transportation Systems, ITS)所使用的資料傳輸技術主要分為兩種，車間通訊(inter-vehicle communication, IVC)與車道通訊(roadside to vehicle communication)。本論文提出了針對 QoS 服務的適性化道路基地台輔助繞徑機制。針對繞徑演算法，我們提出了強化通訊聯結的機制；而在道路基地台的資源配置部份，我們也提出基地台資源預測機制來有效的配置基地台資源。在基地台繞徑演算法與許可控制的核心模組部分我們則分別提出了分散式處理的粒子群最佳化演算法(particle swarm optimization, PSO)調整的模糊邏輯系統(fuzzy logic system)，相關的機制與架構透過模擬驗證了本論文所提方案之可行度。

關鍵詞：品質服務(Quality of Service)、車間通訊(inter-vehicle communication)、粒子群最佳化演算法(PSO)、模糊邏輯(fuzzy logic)、車用網路(vehicular network)。

Abstract

The transmission technology for intelligent transportation systems can typically classified into two categories, namely, road-to-vehicle communication (RVC) and inter-vehicle communication (IVC). This work proposes an adaptive QoS aware roadside base station assisted routing mechanisms to establish a routing path in IVC with assistance of roadside base station. A link failure prevention mechanism is employed to effectively construct alternative routing path required by the volatile network topology in vehicular ad hoc networks. Besides, a bandwidth consumption predictor is presented to avoid dropping data packets owing to inadequate bandwidth during handoffs. A PSO-tuned fuzzy logic system is proposed to compute the link break and congestion indicator in the route construction process. Simulation results demonstrate the effectiveness and feasibility of the proposed work.

Keywords: Quality of service (QoS), inter vehicle communication (IVC), particle swarm optimization (PSO), fuzzy logic.

1. Introduction

In recent year, the research on the intelligent transportation systems (ITSs) has been progressing intensively. ITS uses information communication technologies to connect “the person,” “the road,” and “the vehicle” as one system. The transmission technology for ITS can be typically classified into two categories, i.e., road-to-vehicle communications (RVC) and inter-vehicle communications (IVC). IVCs are achieved by using effective routing protocol that considers the specific characteristic of the road information. The most important requirement is the quality of service, especially the communication delay between end-to-end and the minimum consumption of network resources. Wireless mobile ad hoc networks (MANET) technologies promise delivery of network access area without the need of infrastructure. However, MANET technologies can not be directly applied to IVCs since the characteristic of vehicle movement is different from that in traditional ad hoc network. There have been several researches [1] addressed on the construction of ad hoc network among vehicles in the early stage of development of MANETs. Recently, the usage of MANETs as a base technology in IVCs has gained more popularity due to its potential applications. In addition, the dissemination of the network and road information can be more efficiently if base station allocated for RVCs can be arranged to participate in the determination of management policy or routing path construction in IVCs and RVCs.

2. Related works

The researches on IVCs can be roughly divided into three categories, unicast, flooding, and diffusion, in the literature. Traditional ad-hoc network routing protocols [2] or position based routing protocols [3] can be used to establish general unicast communication in a VANET. The ad hoc on-demand distance vector routing algorithm [4] is an example for this kind of IVC. Nevertheless, the overhead such as the latency and diminished network capacity caused by the service discovery mechanism and routing table maintenance makes this method infeasible for most safety critical applications.

The flooding and diffusion rely on the observation that the importance of sensed information about a particular location decreases with the distance to that location. Data is thus required to be disseminated in the vicinity of its origin. This is the case for most safety applications, but not for infotainment where all data comes from some remote site(s). Most IVC Protocols employ flooding to broadcast data, in which the performance drops quickly as the number of nodes increases because each node receives and broadcasts the message simultaneously and contentions and collisions, broadcast storms and high bandwidth consumption might occur.

In [6], Karp and *et. al* proposed a greedy routing algorithm, named Greedy Perimeter Stateless Routing (GPRS), in which it assumes nodes in the network can be aware of each other’s position, and the performance mainly relies on the physical distance. They select the node that is closest to the destination as the next hop on the routing path without considering the state of the nodes. Accordingly, the route becomes instable once there is a link broken event caused by mobility or congestion.

In [7], Korkmaz and *et. al.* proposed a cross layer protocol by using clustering transmission (CVIA). They create single-hop vehicle clusters and mitigate the hidden node problem by dividing road into segments and controlling the active time of each segment. However, the assumption of each vehicle on the road moves at a fixed speed without considering the impact of mobility causes this approach infeasible in the application of VANETs.

Unlike all of the solutions mentioned above, this work exploits roadside base station assisted routing mechanisms that adapt to the architecture of IVC/RVC and the specific characteristic of VANETs, and tackles the unresolved issues mentioned in the above brief discussions on the related work.

3. Roadside base station assisted routing mechanisms for VANETs

3.1 Routing path selection

In this work, the robust communications in the VANETs are established by constructing an effective routing path on which the vehicles can transmit or receive their data through IVC or RVC. The roadside base station assisted routing mechanism is described as following. The base station is employed to determine the routing paths for the vehicles on the road segment that the base station governs. When a vehicle enters the road segment and submits a data transmission request, the administrative base station attempts to arrange a most stable routing path to the destination for the data packets via IVC if the traffic in IVC is not congested. On the other hand, the administrative base station can grant the vehicle’s request in case there is enough freeable bandwidth to meeting the request’s minimum bandwidth requirement. To be more specific, we assume the data traffic transmitted in this work can be classified as either real-time or best-effort class, the freeable bandwidth for the request of real-time traffic can be expressed by,

$$Bw_f = Bw_{unused} + \sum_i \left(Bw_{i,cur} - Bw_{i,min}\right) - Bw_e, \qquad (1)$$

where Bw_{unused} is the unused bandwidth at the base station, $Bw_{i,curr}$ is the bandwidth currently allocated for the best-effort traffic with index *i*, $Bw_{i,curr}$ is the minimum bandwidth required for the best-effort traffic with index *i*, for real-time traffic and Bw_e is the bandwidth reserved for transmission of emergency events.

As for the best-effort traffic, the so-called freeable bandwidth is exactly the unallocated bandwidth at the base station, Bw_{unused}. Notably, code-division multiple-access (CDMA) is adopted in this work to ease the interference effect and increase the transmission efficiency as in [5]. Besides, the administrative base station will direct a route via the roadside base station that is stable to the destination, and all the roadside base stations will follow the same decision procedure as described before in case they receive the incoming requests from other base stations.

3.2 Link enhancement mechanism for IVC via RVC

In the VANETs, the fault-tolerant connectivity can be established by offering alternative routing paths whenever a possible link failure or congestion event occurs on the current routing path. We thus arrange each node in IVC to compute link break and congestion indicators to avoid possible link break and congestion events occurring at each node. Each vehicle will inform its administrative base station in case link break and congestion events are anticipated. The base station will then look up its routing table to construct the alternative route. Notably, the base station keeps monitoring the network status of each node on the road segment that it governs, and share the information with the neighboring roadside base stations.

3.2.1 Link failure avoidance based on link break and congestion indicators

In order to prevent link break caused by varied mobility or congestion events, we attempt to estimate each vehicle's speed in next time period by using particle swarm optimization (PSO)-tuned fuzzy logic systems. Notably, the PSO technique is used to adjust the two parameters, mean and variance, of each membership function in the fuzzy logic system.

The input-output mapping for the employed fuzzy logic systems can be expressed by,

$$V = \text{PSO\_FUZZY}(d, MS, S), \tag{2}$$

where d denotes the distance between two consecutive vehicles, MS represents the max speed limitation and S is the current speed of the vehicle.

Once the predicted speeds of the vehicle and its neighbors are obtained, we can easily determine whether the vehicle is within the communication range of its neighbors by computing the distances of the vehicle and its neighbors in next time period as follows,

$$p_{next} = v_{next} + p_{cur}, \tag{3}$$

where v_{next} denotes the speed of the vehicle in the next measuring period and p_{cur} is the current position of the vehicle.

Similar to Eq. (2), the congestion indicator can be derived by,

$$Cg = \text{PSO\_FUZZY}(qL, numP, numIn), \tag{4}$$

where qL denotes the queue length, $numP$ is the expected number of the packets traveling through the vehicles, $numIn$ is the expected number of the vehicles in the next time period, and the function PSO_FUZZY stands for the proposed PSO-tuned fuzzy logic model.

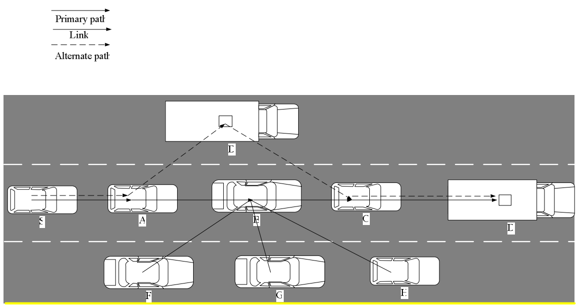

Fig. 1. Alternate path construction.

Now take Fig. 1 as an example, when there is a possible congestion or link break detected at node B, it sends a congestion/link break warning message to all its neighbors. As node A receives the message, it re-initiates route discovery process with congestion/link break indicator piggybacked in data packets to find an alternate path to destination D. Thus, new arrived data packets can then be delivered via a new path as shown in Fig. 1

3.2.2 Fuzzy logic system

The fuzzy logic techniques have been used to solve several resource assignment problems efficiently in ATM and wireless networks in the literature [8]. We thus employ fuzzy logic systems to determine the vehicle's speed in next time period and the congestion indicator.

Figure. 2 shows the architecture of the fuzzy speed prediction module. The basic functions of the components in the module are described as follows:

- **Fuzzifier**: The fuzzifier performs the fuzzification function that converts three inputs into suitable linguistic values which are needed in the inference engine.
- **Fuzzy rule base**: The fuzzy rule base is composed of a set of linguistic control rules and the attendant control goals.
- **Inference engine**: The inference engine simulates human decision-making based on the fuzzy control rules and the related input linguistic parameters.
- **Defuzzifier**: The defuzzifier acquires the aggregated linguistic values from the inferred fuzzy control action and generates a non-fuzzy control output, which represents the predicted speed.

Note that the architecture of fuzzy congestion detection module is quite similar to that of the fuzzy speed prediction module as described above.

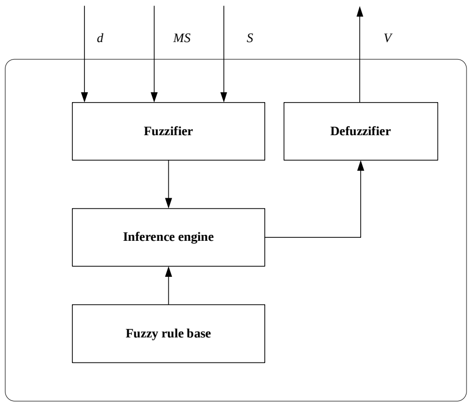

Fig. 2. The fuzzy speed prediction module.

3.2.3 Particle Swarm Optimization

In the PSO, every individual moves from a given point to a new one which is a weighted combination of the individual's best position ever found, and of the group's best position. The PSO algorithm itself is simple and involves adjusting a few parameters. With little modification, it can be applied to a wide range of applications. Because of this, PSO has received growing interest from researchers in various fields.

In this work, we allow each vehicle to execute its individual PSO algorithm. The PSO is used to adjust the two parameters, mean and variance, in the membership functions of the inputs for the fuzzy logic systems.

3.3 Bandwidth consumption predictor for roadside base station

In this work, the routing path for transmitting data packets is either through IVC or RVC. There should be a bandwidth management mechanism because the roadside base station has limited bandwidth. The estimated position of the moving vehicle in the next time period given by Eq. (3) can be used to count the number of vehicles that are located at the road segment that the roadside base station governs. The bandwidth consumed by the vehicles moving on each road segment can then be computed by,

$$Bw_{used} = \sum_i b_{i,incoming} + \sum_j b_{j,cur} - \sum_k b_{k,outgoing} , \quad (5)$$

where $b_{i,incoming}$, $b_{j,cur}$ and $b_{k,outgoing}$ represent the required bandwidth for the *i*th vehicle that moving into the target road segment, the *j*th vehicle that stays on the target road segment, and the *k*th outgoing vehicle in the next time period, respectively.

The roadside base station that is expected to run out of bandwidth during the next time period will inform its neighboring roadside base stations that it is unable to receive new routing requests for the time being due to scarce bandwidth.

4. Experiment results

We ran a series of simulations to evaluate the performance of the proposed work by using a network simulator written by C++. The compared schemes includes the roadside base station assisted routing mechanisms embedded with fuzzy link break and congestion detection modules (BAR-F), the proposed roadside base station assisted routing mechanisms embedded with PSO-tuned fuzzy link break and congestion detection modules (BAR-PF), and the representative ad hoc on-demand distance vector algorithm, i.e. AODV [4], and CVIA [7].

4.1 Simulation scenario

The simulation environment is a 10×10 square kilometer, and 50 vehicles are randomly distributed within the network. In order to simulate the road traffic, the traffic flow is simulated with microscopic traffic model [9]. The microscopic traffic model has been used for vehicle traffic simulation in the literature. The detail simulation parameters are listed in Table 1. Notably, CBR/UDP traffic is generated between randomly selected pairs of vehicles and the bandwidth for each channel is 2Mbps. The bandwidth of the base station is 54Mbps, there is one base station located in each road segment. There are two service classes, including real-time and best effort traffic. The CBR data packet size is 512 byte and packet rate is 4 packets per second. Each vehicle moves along the direction of the pathway, and the speed is randomly changed within a preset range that is related to the driver's age and the distance between the vehicle and the one in front of it. Once it reaches that position, it will change the speed and repeats the process.

4.2 Simulation results and analysis

We first investigated the impact of moving speed of the vehicles on the network performance. The performance metrics used in this work are packet delivery ratio, end-to-end delay and control overhead. The vehicle speed is varied from 0 m/s to 30 m/s. The simulation time ranges from 8:00 a.m. to 8:00 p.m., and the peak rush hours are set at 8:00 a.m. and 6:00 p.m. Notably, packet delivery ratio is the total amount of received data divided by the total amount of data transmitted during the simulation. Figures 3 and 4 illustrate the packet delivery ratio of the overall traffic and the real-time traffic for CVIA, BAR-PF, BAR, GPSR and AODV under different moving speeds, respectively. We can see that the proposed schemes, BAR-PF and BAR-F, which use the roadside base station assisted routing algorithm have better packet delivery ratio than other representative schemes, CVIA, GPSR and AODV, because the proposed schemes can effectively detect the link break and congestion events and timely activate the proposed roadside base station assisted routing algorithm to look for a more stable routes. Meanwhile, as illustrated in Figs. 3 and 4, the PSO algorithm can accommodate the factor of versatile network environment and adaptively tune the parameters of the membership functions in the fuzzy logic system to improve the packet delivery ratio.

Table 1. Simulation parameters.

Parameter type	**Parameter value**
Simulation time	3600 sec
Simulation terrain	10 km x 10 km
Number of vehicles	50
Length of the road segment	1000 m
Traffic simulation time	8:00 a.m.~8:00 p.m.
Traffic model	Microscopic traffic model
Mobility	0~30 m/s
Channel bandwidth	2M bps
Mac protocol	802.11
Transmission range for IVC	250 m
Transmission range for RVC	500 m
Bandwidth of base station	54M bps
Service class	real-time, best effort
CBR Real-time data sessions	25

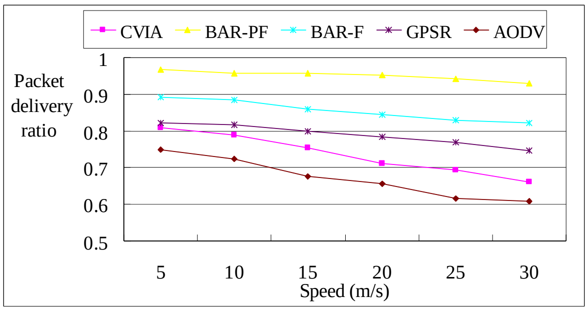

Fig. 3. The packet delivery ratio of CVIA, BAR-PF, BAR, GPSR and AODV under different moving speeds

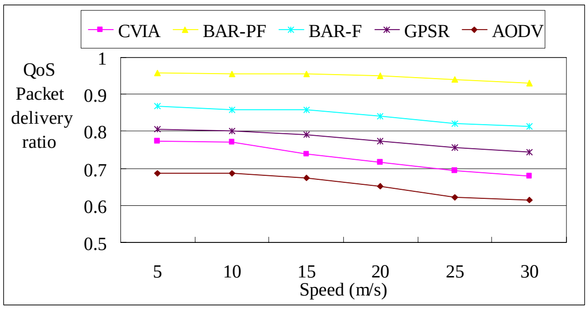

Fig. 4. The real-time traffic packet delivery ratio of CVIA, BAR-PF, BAR, GPSR and AODV under different moving speeds

Figure 5 represents the end-to-end delay of data packets for the five schemes under different moving speeds. Notably, the end-to-end delay in this work is measured for those data packets from mobile source vehicle to mobile destination vehicle. It can be observed that the routing schemes adopting roadside base station assisted routing algorithm have shorter end-to-end delay. We believe this is because the roadside base station can collect link status from mobile nodes and utilize it to choose the most stable routing path. As for CVIA, the formed routing groups turn into unstable state while the mobile nodes move fast. The routing groups thereby need to be reconstructed and result in high packet loss rate and end-to-end delay.

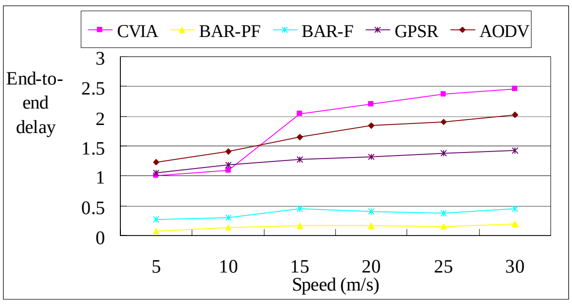

Fig. 5. The end-to-end delay of CVIA, BAR-PF, BAR, GPSR and AODV under different moving speeds

Figure 6 depicts the control overhead of the five schemes under different moving speeds. Since both BAR-PF and BAR-F schemes effectively transmit data packet through the most stable path, the control overhead is therefore largely reduced.

We next consider the impact of network density on the network performance. The moving speed of vehicles is fixed on 15 m/s. Figures 7 and 8 respectively show the packet delivery ratio of overall data traffic and real-time data traffic for the five schemes under different time periods. The proposed BAR-PF and BAR-F schemes still achieve higher packet delivery ratio since they can avoid transmitting data packets through congested routes with the assistance of alternate route construction mechanism.

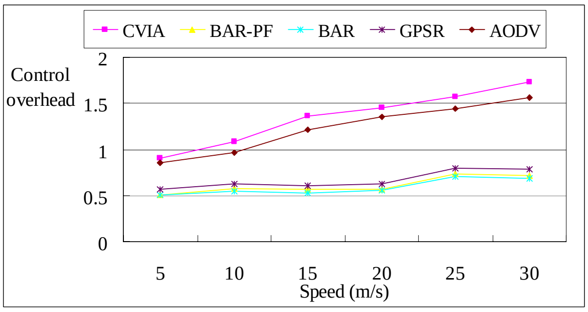

Fig. 6. The control overhead of CVIA, BAR-PF, BAR, GPSR and AODV under different moving speeds

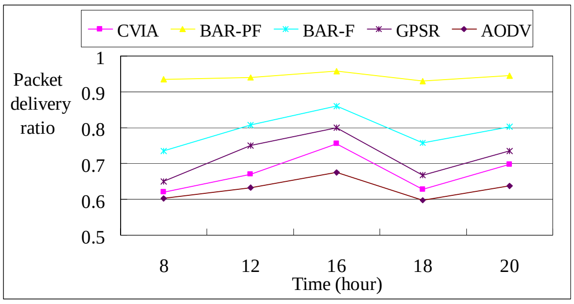

Fig. 7. The packet delivery ratio of CVIA, BAR-PF, BAR, GPSR and AODV under different time periods

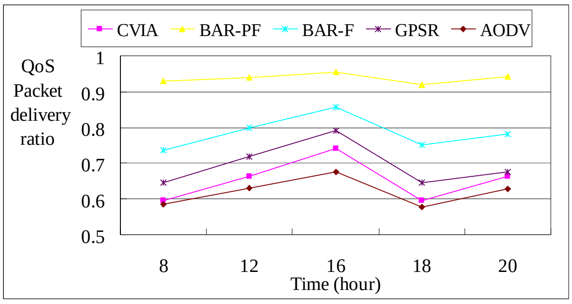

Fig. 8. The real-time data traffic packet delivery ratio of CVIA, BAR-PF, BAR, GPSR and AODV under different time periods

Figure 9 represents the end-to-end delay of data traffic for the five schemes under different time periods. Obviously, the proposed schemes can organize alternate routing paths before congestion occurs and therefore provide more reliable routing and better end-to-end delay. Figure 10 demonstrates the control overhead of the five schemes. Without considering the change of link status along the routing paths, CVIA and AODV schemes need to generate more control message to maintain their routing groups or routing paths when the network become crowded.

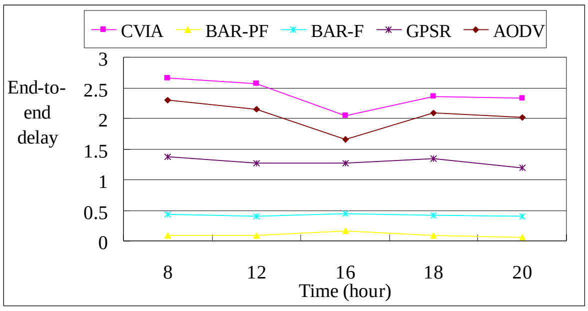

Fig. 9. The end-to-end delay of CVIA, BAR-PF, BAR, GPSR and AODV under different time periods

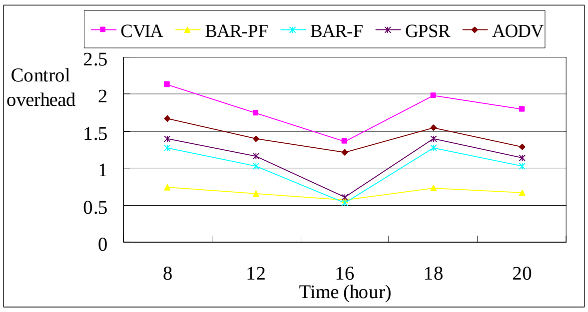

Fig. 10. The control overhead of CVIA, BAR-PF, BAR, GPSR and AODV under different time periods

5. Conclusion

In this paper, QoS-aware routing mechanisms for VANETs are proposed to establish an effective routing path in IVC with the assistance of roadside base stations. Alternate route construction and congestion avoidance mechanisms based on link status and congestion indicators are presented to prevent the link failure caused by frequent change of network topology and the occurrence of congestion. Notably, a PSO-tuned fuzzy logic system is employed as the core modules in the link enhancement mechanisms, and a bandwidth consumption predictor is embedded in each roadside base station to avoid dropping data packets owing to the inadequate bandwidth during handoffs. The simulation results showed that the proposed routing path construction and alternate route construction mechanisms can effectively prevent the link break caused by volatile vehicle movements and the change of network density. The performance metrics, including packet delivery ratio, control overhead, and end-to-end delay, are significantly better than those of the representative IVC routing schemes in the literature. Furthermore, the simulation results also support the effectiveness of using the PSO-tuned fuzzy logic system in the proposed work. In the future work, we will establish an autonomic policy based management system and integrate it with the algorithms proposed in this work to enhance the network resource management on safety applications and multimedia applications.

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