Chapter 84
DSRC Based Self-Adaptive Navigation System: Aiming Spread Out the Vehicles for Alleviating Traffic Congestion

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Abstract In the past decades, traffic problems has become a major research field of both academic and industrial community. In this paper, we propose a Self-Adaptive Navigation System (SeNS) to provide optimal tailored driving paths, reflecting real-time road traffic information. The current navigation systems are using server independently, and only use the static time stamp-based traffic information. For not consider the changing of traffic in near future, they tend to provide the path that sharing some roads. This kind of individual optimization could—create new bottlenecks on some roads, which was light traffic. Our proposed system consists of Traffic Control Center (TCC), Road Side Unit (RSU), mobile terminal (e.g. smartphone). TCC and RSU are for collecting road statistics, merging them and generating overall traffic information, in real-time. Based on this, mobile terminal can provide tailored optimal path, apply the algorithm of maximizing the traffic flow, for alleviating traffic congestion on target area of TCC. Therefore, based on the prompt exchange of road traffic conditions through the interaction among the mobile terminals, RSUs, and TCC, SeNS can provide drivers with a new type of self-adaptive navigation service, based on dynamic traffic conditions, such as temporal traffic jam and car accidents.

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84.1 Introduction

In modern society, vehicles are very common for daily transportation. The expansion of vehicle's usage and propagation is getting faster daily, hence, road networks are getting more complex and bigger. Therefore, navigation systems are highly required. The existing navigation systems' feature as follow.

First, existed navigation systems update their traffic information by constructing their own infrastructure [1] or reporting the road statistics report, made by drivers. The former one may be expensive to construct and maintain, but it can be more accurate. And the latter one is fully depend on their number of users and frequency of report. Second, both of mentioned collecting methods use mobile network. It can be expensive if raise up the frequency of update for fresh traffic information [2]. And also, it can be throw down the QoS of default service of mobile network (e.g. calling). Third, these existed systems use the independent system for each other. So, they provide the path that sharing some roads, depend on options (e.g. fastest, shortest, ECO driving [3]). This individual optimization can make new bottleneck on provided path.

These kind of systems are difficult to react to dynamic road traffic network instantly. Therefore, it is hard to aware the traffic situation, spread out the vehicles and use the road network effectively. Thus, these existed systems should provide more satisfaction to get their destination for driver. The satisfaction depends on how efficient we spread out the vehicles and how fast to get to their destination. In this paper, we propose Self-Adaptive Navigation System that has objectives as follows: (1) Providing traffic information to drivers in a fast and accurate way by constructing SeNS, adapts to dynamic traffic situations. (2) Architecting DSRC-based infrastructure in order to collect traffic information efficiently. (3) Providing a routing algorithm to compute a path with minimum travel time by using vehicles' travel paths.

84.2 Related Work

84.2.1 Infrastructure for Generate and Collect the Traffic Information

Recently, there are various infrastructures implemented in road network for providing navigation service. Such infrastructures can be roughly divided into private infrastructures and public infrastructures. In case of private infrastructures, they communicate with terminal by using their own server and mobile network. WAZE

[4], TOMTOM [5], TrOASIS [6], T Map [7] are the navigation system that use mobile network (TOMTOM connect with network via bluetooth tethering). Because of this, communicating traffic information between server and terminal, using quiet large amount of data, can be decline the QoS that default service of mobile network. And the case of public infrastructure, Traffic control center that managing traffic information, collect traffic information by communicating with loop detector, vehicle ID recognition unit, Road side Equipment (RSE, or Road side unit, RSU) [8, 9], CCTV. And these are connecting with optical network [10] and using another bandwidth. Therefore, even if traffic information's size is heavy, they can decrease the workload of mobile network [11].

84.2.2 Generate and Collect the Traffic Information

Basically, the navigation systems has GPS module for aware the information of current location and speed in terminal. Through this terminal, terminal can give the raw data to server. First of all, the information received from server is traffic information that provide which road has been jammed in visually to driver [12]. Next, the information transmit to server is collectable data from vehicle. Such as, requesting find new path, current location and current speed. Than the methods of collecting this kind of information is report the road status directly wrote by user and report the vehicle's status automatically. The former one should be non-periodic way, because this way is fully depend on the user. And the latter one should be periodically report to server. Additionally, the method that wrote by user directly, may have high probability of accident by using device in driving.

84.2.3 Traffic Information Providing Service

Through the navigation system, user can take two big services. First, user can take traffic information in terminal. This traffic information induces which road is congested and fluid to user. Second, user can take the trajectory from current location to destination. The calculation of path can be operate in server and terminal (TrOASIS does not support calculating path). Via this service, user can get the traffic information. Such as shortest, fastest path, CCTV stream, report from other users.

In this paper, we design the navigation system that aware and self-adapt the traffic information by using Road Side Unit, easy to deploy and collect information, and automatic report periodically for concentrate on driving [13]. Additionally, finding the optimal path will be implemented in terminal to reduce the workload of server. When re-routing, existed navigation systems handle the re-route request from user directly. So, it can hardly consider about user or designer's preference. Therefore, we propose the self-adaptive navigation system that reflect the intention through utility function, which include the experience of user or experts [14], when re-routing. And also, propose the system, which can provide optimal fastest path that effectively spread out the vehicles.

84.3 Self-Adaptive Navigation System

84.3.1 System Requirement

Table 84.1 is the comparison of existed navigation system mention in Sect. 84.2. Most right column shows the requirement of our system. It represents the limitation of workload in mobile network that most of existed navigation system used, the limitation of updating traffic information in social network based navigation system, like WAZE, the possibility of navigation system that based on wireless network, such as DSRC-based RSU, in growing ITS [15]. To overcome the limitation of vigation system, we have goals such as, present the merged traffic information made by modelling the road network, guarantee the fastest path avoid the congested road, aware the dynamic traffic information in real-time for auto-re-routing that reflect the intention of user or designers.

Therefore, we propose the system that use DSRC-based TCC-RSU-Vehicle architecture which is being built at the national and dynamically adapt the traffic information, keep changing. Our proposed system is more fast and accurate, generate the traffic information effectively, by using these, provide the tailored optimal path that fastest and spread out the vehicles.

84.3.2 Design

The components of proposed Self-Adaptive Navigation System has goals, functions and roles as follows. Figure 84.1 shows the interaction among the components in order to achieve goals.

- **Objective 1** Managing and Providing Overall Traffic Information

TCC (Traffic Control Center) has goal of generating overall traffic information of target area. To accomplish this goal, TCC has function of communication with all of RSU, deployed on target area of TCC, and transmission the traffic information, corresponding to request of vehicles. Traffic information, modelled at TCC, has a goal of including the road traffic network of target area. Hence, TCC has a role of merging the overall traffic information of target area and providing overall traffic information to vehicle.

- **Objective 2** Managing each Road Statistics

Table 84.1 Comparison of existed navigation systems

Navigation system Infrastructure		Waze Internet	TOMTOM Public infra	TrOASIS Internet	T map Private infra	Proposed method Public infra
Generating and collecting traffic information	Source	Report from client device	STI, device signal	Report from client device	Report from client device	Report from client device
	Collecting method	User's report	• STI • Anonymous phone signal	• User's report • Automatic gathering[b]	• User's report • STI	• Automatic gathering
	Update period	Non-periodic	2 min	Non-periodic	5 min	less than 1 min
Providing traffic information service	Service range	Traffic information, source-destination route	Traffic information, source-destination route	Traffic information only	Traffic information, source-destination route	Traffic information, source-destination route
	Information type	• Shortest/fastest path	• Shortest/fastest path	• CCTV • STI • user report	• Shortest/fastest path	• Shortest/fastest path/ prediction
Self-adaptiveness	Real-time service	Medium[a]	High	Medium[a]	Low	High
	Re-routing event handler	Manual	Automatic	Manual	Manual	Automatic

[a] If report from user frequently
[b] Drive direction and speed

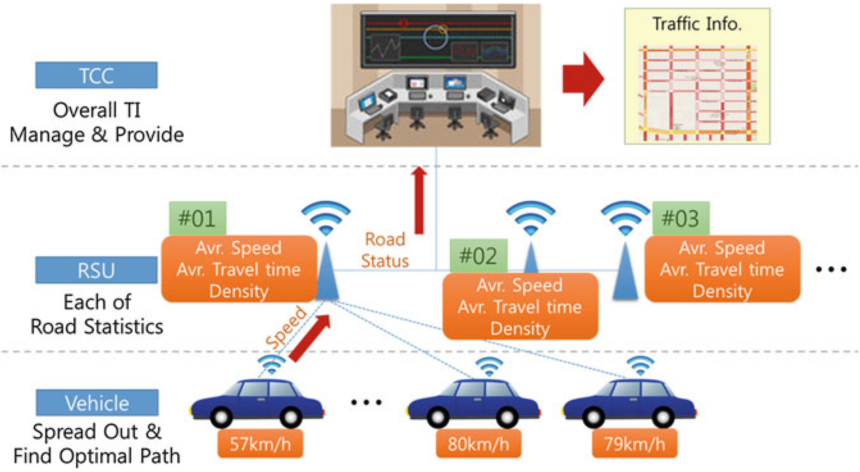

Fig. 84.1 Interactions among components

RSU (Road Side Unit) has a goal of generating road traffic statistics. To accomplish this goal, RSU directly communicates with vehicles via DSRC. And RSU deployed more than one unit in order to fully cover the road segment. Therefore, RSU has function of receiving speed data from vehicle and generating road traffic statistics based on received data and transmitting road traffic statistics to TCC. Hence, RSU has a role of collecting data of road segments and processing collected data and transmitting the processed data to TCC.

- **Objective 3** Spread Out the Vehicles and Find Optimal Path

Mobile Terminal installed on vehicle (smartphone or tablet) has a goal of delivering measured speed to near-by RSU and provide optimal path to user based on overall traffic information from TCC. To accomplish this goal, mobile terminal has 802.11 p module for DSRC. And mobile terminal has function of measuring speed using GPS module and providing optimized fastest path based on traffic information. Hence, mobile terminal has a role of sensing the vehicle's information and providing optimal path adapt on dynamic traffic information. As a guide, every vehicles has their own mobile terminal.

Therefore, SeNS are based on progress as follow: Certain RSU, deployed at near-by certain road segment, is continuously collecting unknown vehicle's speed. At this time, several vehicles are pass by this road segment, than vehicle's mobile terminal generate the speed data. And this speed data transform to packet and transmitted to RSU. After receive the speed data at RSU, than a RSU generate road traffic statistics (This RSU has a role of representing certain road segment and merging the traffic information, generated by another RSUs in same road segment). And transform the road traffic statistics to packet then transmit to TCC. TCC receives road traffic statistics from all of RSUs in target area, then TCC merges those statistics for overall traffic information. Finally, certain user request routing to their mobile terminal, the mobile terminal request the TI to corresponding TCC, and searching optimal fastest path based on the received TI. Additionally, when vehicle breakaway the path or congested the path, mobile terminal schedule the rerouting, same sequence of when we routing.

84.3.3 Routing Algorithm

In this section, describe about routing algorithm of SeNS. First of all, we modelling the TI at the TCC. Than searching optimal path based on model of TI at the vehicle.

84.3.3.1 Traffic Information Modelling

To architecting proposed SeNS, the collected traffic information modeling technique is necessary. So, we choose the modelling method of the Ford-Fulkerson Algorithm (FFA) that maximize the flow of network based on Min-Cut Max-Flow Theory [16]. As follow the FFA's modelling method, TI is modelled as directed graph at TCC. Intersection as node and road segment as edge. The edge, link between two nodes, has weight of capacity and flow. Capacity represent the maximum number of vehicles in a road segment at a time. Flow represent the number of vehicles in a road segment at a time. For example, certain road segment has full with vehicles and number of vehicle is 10. When same road segment, at another time, has 4 travelling vehicles, the capacity and flow will be 10 and 4. The node, representing an intersection, will occur more than one. And these nodes are assigned with number of approach roads. For instance, if there are four-way intersection, four nodes will generated. Because, four-way intersection has four approach roads.

84.3.3.2 Searching Optimal Path

When user request routing, mobile terminal request the TI from TCC and searches optimal path. Searching several path to destination, then calculate and compare their estimated travel time, as flow, each other. Finally the fastest one will selected. First of all, mobile terminal receive the TI then find the source node and destination node, input from user. Next, searches all of possible path on received TI model, using depth-based search algorithm. Finally, calculate those path's estimated travel time and select fastest one for provide to user.

84.3.3.3 Calculate Estimated Travel Time

Generally, estimated travel time is summation of average link delay of each road segment on certain path. But, this method cannot handle the traffic, which will dynamically change in future. Therefore, we can handle the dynamic traffic by applying prediction methods. In this paper, we use k-NN methods for calculate the estimated travel time based on stored TI. If the estimated travel time is greater than capacity, then estimated travel time will be assign to capacity. Through this, SeNS can searching optimized path, reflecting dynamically changed traffic.

$$Predicted\ flow = Average\left(flow(t)_i + \sum_{j=1}^{k} flow(t-j)_i\right) \qquad (84.1)$$
$$(t = current\ time\ stamp, i = ID\ of\ road\ segment)$$

84.3.4 Re-routing Algorithm

In the mobile terminal keep receiving traffic information, re-routing should be initiated by driver's necessary. Re-routing can be initiated when deviation from the path and decline of satisfaction of path. The former one operate by comparing between vehicle's current location and path information. And the latter one operate when the estimated travel time drop down the certain threshold. This means that estimated travel time goes longer. System designer can define the relationship between satisfaction and estimated travel time by using utility function (e.g. log, sigmoid), according to their intention [14]. For instance, long estimated travel time monitored and input to utility function, than it means low satisfaction of driving. Consequently, system will initiate the re-routing. At this time, mobile terminal will find the new optimal path from current location to destination as follow the Sect. 84.3.3.2.

84.4 Implementation and Evaluation

84.4.1 Simulator

Proposed SeNS is running on environment, Intel Core2Quad Q9550, RAM 4 GB, JAVA JRE 1.7. And this simulator is roughly divided on three part. First, constructing road traffic networks and managing running vehicles. Second, attaching the infrastructures on road traffic networks. Finally, routing the path for vehicle.

Basically, we assume that those road segments are implemented as single lane. And every vehicles are injected and routed to one of outer intersection to heading another one of outer intersection. It can be modified to change the parameter of injection in period and quantity. In the simulation we inject 14 vehicles (equal to number of injectable intersections), every 10 s. For making specific congestion, we generate the Gaussian distributed random variable and use for one of outer intersection to be more selected than other outer intersections. And we implement the speed of vehicles for the making a traffic information model, aspect of average speed, by considering the vehicle's time duration of transition in queue (e.g. road segment), ranged 0.7–1.0. Through this, we can achieve various average speeds on each road segments, average occupancy of roads and variance of occupancy in target area.

84.4.2 Scenario

Basically, following scenarios will be simulated under the same parameters except routing algorithm. First scenario is current time stamp-based routing without re-routing and second on is prediction-based routing with re-routing.

- Scenario 1—Current time stamp-based routing

The current time stamp-based scenario decides the estimated travel time of whole path by summation of average travel time of each road segments. Table 84.2 is the example of calculating whole estimated travel time, when a vehicle routing based on current time stamp. In edge 01–23 have 10 s of average travel time and in edge 23–34 have 7.5 s of average travel time, than estimated travel time of node 01–34 will be 17.5 s. We can get total estimated travel time by doing this sequence recursively.

- Scenario 2—Proposed routing

The prediction-based scenario decides the estimated travel time of whole path by summation of current and past average travel time of each road segments. Table 84.3 is the example of calculating total estimated travel time, when a vehicle routing based on prediction. In edge 01–23 have 10 s of average travel time and in edge 23–34 have three past average travel time. So, predicted average travel time will be 5.925 s, than estimated travel time of node 01–34 will be 15.925 s. We can get whole estimated travel time by doing this sequence recursively. After getting path, if there are some road that full occupancy, than initiate re-route sequence.

$$Occupancy = \frac{flow}{capacity} * 100\,(\%) \tag{84.2}$$

84.4.3 Evaluation

The simulation results of those two algorithm for 30 min is on Fig. 84.2. The variance, means how much spread out the vehicles, is calculated on occupancy of

Table 84.2 Example of calculating current time stamp-based travel time

Edge	01–23 (s)	23–34 (s)	34–25 (s)	25–18 (s)
Avr. Tt	10	7.5	6.24	7.7
Est. Tt	10	17.5	23.74	31.44

Table 84.3 Example of calculating prediction-based travel time

Edge	01–23 (s)	23–34 (s)	34–25 (s)	25–18 (s)
Avr. Tt	10	7.5	6.24	7.7
Avr. Tt-1	–	6.2	9	7
Avr. Tt-2	–	5	9	5
Avr. Tt-3	–	5	6	4
Est. Tt	10	15.925	23.485	29.41

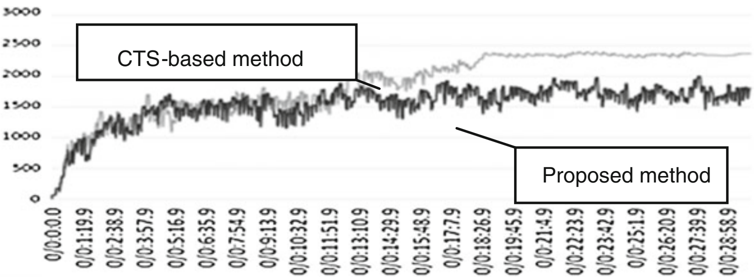

Fig. 84.2 Graph of variance for occupancy of roads in target area

roads. In case of variance, current time stamp-based routing has result of 1,875.482 in average, and our proposed method has result of 1,549.405 in average. This result show that our proposed method is more efficient in spreading out the vehicles about 17.39 %. And in case of average speed, current time stamp-based routing has result of 0.5040 in average, and our proposed method has result of 0.7691 in average. This result show that our proposed method is faster about 52.60 %. According to these results, we could prove the prediction-based routing and re-routing is a more effective way.

84.5 Conclusion

In this paper, we propose the self-adaptive navigation system (SeNS) in order to provide the optimal path to user by keep adapting the dynamic traffic information based on DSRC. This system constructs the traffic information of target area by collecting vehicular data (e.g. speed) via DSRC and generating road traffic statistics. Through this system, we made a baseline for researching about how the self-adaptive software can affect to ITS, and we adapt to current traffic information in real-time. As the comparison of simulation results, between current time stamp-based scenario and prediction-based scenario, we could prove our proposed system is better. Our prediction-based algorithm decrease about 17.39 % of variance of occupancy of target area and increase about 50.60 % of average travel speed. As future work, we will reflect realistic feature of ITS to simulator and apply various self-adaptive methods to this system for experiment and analysis.

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