

Vehicle-to-Vehicle Traffic Information System with Cooperative Route Guidance

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ABSTRACT

The possibility of ad hoc wireless communication between vehicles brings up innovative applications, which enhance the safety of driving or the quality of traveling. Passing traffic information such as travel times or warning messages about accidents or sloppy roads are only a few examples of the potentials created by equipping vehicles with appropriate communication infrastructure. The used networking topologies for travel information dissemination are typically centralized or distributed. However, as this paper shows, both systems present certain disadvantages. To overcome this, the paper presents a novel hybrid network architecture, which can take advantage from both worlds. A simulation environment designed to evaluate different ITS applications is also presented. By using this simulator we implemented and compared our architecture with the conventional solutions. Our solution presents better stability and performance for the simulated scenario.

KEYWORDS: Vehicle-to-Vehicle communication, Floating Car Data, cooperative routing, simulation

INTRODUCTION

Nowadays, an increasing number of commercial and private vehicles are equipped with Global Positioning System (GPS) devices. Many research projects have been implemented to use the vehicles themselves as probe-cars, to determine the traffic status and to provide traffic information. This concept is called *Floating Car Data* (FCD) supplying excellent basis data on actual traffic conditions. In the case of *centralized* FCD [1] a traffic information centre collects, maintains and supplies all traffic information by using a cellular mobile technology, e.g. GPRS. On the other hand, the *distributed* approach of FCD [2] does not involve any fixed infrastructure and assumes that vehicles share the traffic information among each other by using a local wireless technology, e.g. IEEE 802.11. In case of the centralized approach, the information centre has a global view of the road network, but there is a communication cost and some public investment is needed. On the other hand, the distributed approach has only the installation cost of the on-board unit without permanent communication costs. In this case the traffic information is shared among the equipped vehicles.

Several papers deal with traffic information systems, exploring both the centralized and distributed (ad hoc) network-based scenarios. The authors in [1][3] present solutions based on the centralized FCD. The limitations of this technology can also be derived from the presented results. Numerous papers are also dealing with the different aspects of ad hoc FCD scenarios. In [2] an adaptive broadcast algorithm is presented, which aims to reduce the number of messages circulating in the network. Collecting and disseminating travel information in [4] is based on IEEE 802.11 networks. The proposed solution is also compared with a centralized one.

Although these results look promising, there are several limitations of ad hoc FCDs, which are not explored in the literature. This paper aims to fill this gap and presents certain cases when these systems fail to deliver consistent results. A novel hybrid network architecture is proposed, which can take advantage from both kinds of networking infrastructures, centralized and ad hoc. A simulation environment designed to evaluate different ITS applications is also presented. By using this simulator we implemented and compared our architecture with the conventional solutions. Our solution presents better stability and performance for the simulated scenario.

The remaining of this paper is structured as follows. First, the system architecture is proposed that integrates the benefits of the centralized and distributed FCD technologies. Then we propose a Route Guidance Method that minimizes the overreaction by optimizing the routes of the vehicles and we evaluate the performance of the system by simulation.

COOPERATIVE ROUTE GUIDANCE

Both centralized and distributed FCD technologies are able to provide a route guidance system for the drivers. A number of surveys and trials show that a route guidance system decreases travel time since inefficiencies of human route choice are mostly eliminated. However, more and more simulations predict that these benefits will be lost once the ratio of equipped vehicles exceeds a certain threshold. This phenomenon can be explained by the fact that each driver's travel time is minimized independently and many drivers are guided from a congested to a favorable road causing congestion on other roads. This phenomenon is called “*overreaction*” that is solved for the centralized approach (e.g. in [3]); however, to our best knowledge, it is not solved for fleets using distributed ad-hoc protocols. Our aim is to minimize this drawback of the navigation systems by working out algorithms utilizing the advantage that they are connected in a network and carry out a joint traffic optimization.

BASIC SYSTEM ARCHITECTURE

The traffic information system consists of the following components: *On-board Unit* installed in the vehicles (see Figure 1) and *Central Unit* installed in the traffic information centre (see Figure 2).

The traffic information and the vehicle location information are collected in the On-board unit by a positioning device (e.g., GPS, GALILEO). This information is exchanged with other vehicles by a wireless communication system in an intelligent way. The IEEE 802.11 standard is used for this purpose. By this way, vehicles driving in the same or in the opposite direction provide road traffic information on the surrounding area. Based on the received information, each on-board unit makes a decision about the route.

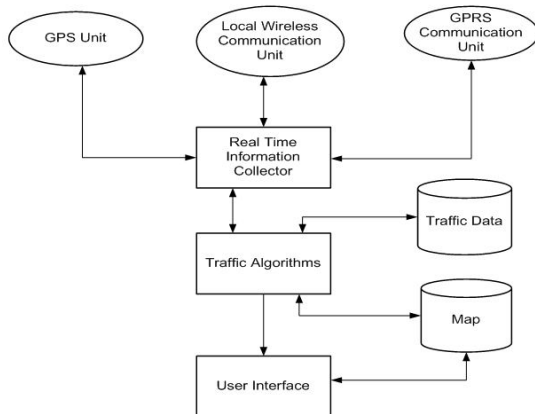


Figure 1 – On board Unit

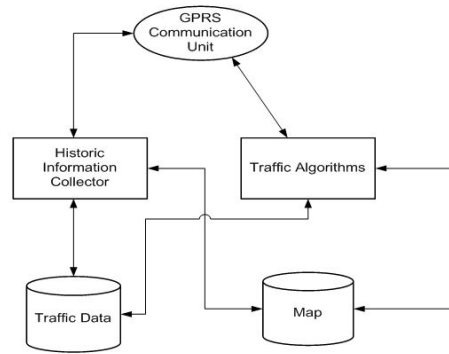


Figure 2 – Central Unit

The standard way of traffic information collection is the distributed one, which is carried out just based on the On-board unit. However, if this does not give enough information for any reason, the communication is set up with the center. If an extraordinary event happens (e.g., many traffic jam messages arrive), the information center is involved as well. In this case the on-board unit sends the collected actual data and the destination address to the center and asks for a new route. The center stores all historical traffic data and uses the actual data on traffic jams; calculates new routes to all the destinations of the incoming requests using a global path optimization method described later.

LOCATION BASED WIRELESS COMMUNICATION

The IEEE 802.11 family of protocols is designed for indoor applications. According to previous studies [4], its communication range is about 100 to 300 meters in outdoor scenarios. The authors show that the current range of this technology may require market penetration between 3% and 10% to obtain full benefits for traffic information.

Traffic information dissemination

It is important to choose correctly the time period when information exchange between vehicles is occurred. If the time period is too short then the messages overflow the communication network. Otherwise, if the time period between messages is too long then the information is obsolete. We propose the following method: each instrumented vehicle sends a status report about the road elements (1) at the time when it passed the road element (2) just in case the travel time exceeds a certain threshold, e.g., twice the free travel time.

Route Choice

Vehicles make route decision based on other reports of other vehicles. This raises the question how to aggregate the received travel times in order to avoid inconsistency. In our case, to each road element of the digital map an event list is assigned that stores the received events of the last hour. Just the significant events are stored: that belong to two or three potential routes to the destination. If the route to destination becomes jammed, potential routes are examined by calculating the average travel times on each road element. The routes can be recalculated at each decision point.

Global path optimization

As mentioned above, a global path optimization method has been developed for route guidance based on the common model of two types of networks. Telecommunication and transport networks show several similarities from the viewpoint of modeling: similar questions have arisen, which have been intensively researched in both disciplines [8]. In the world of telecommunication, mature, well-working methods have been developed that solve similar management problems, such as, to determine routes for the traffic and to handle temporarily breakdowns or congestion. Motivated by the analogy, methods used for telecommunication networks can be applied in traffic telematics for route guidance and congestion control of vehicles. However, several differences make the adaptation of these methods difficult, like the autonomy of drivers, finite travel time of vehicles, demand flow - travel time dependence, the queuing effect and the “selfish” behavior of drivers. Consequently, the global path optimization problem is solved by a method often used in telecommunication. We propose to use a method based on Simulated Allocation [7] that handles these features and solves the *cooperative route guidance*, also called *global path optimization problem*. The method routes each vehicle individually while considering the capacity of the road. Each route is chosen such that the total capacity of the road network is utilized.

RUBENS: THE SIMULATION ENVIRONMENT

The design and validation of the above described protocols are carried out by appropriate simulation tools. These simulators need to model road conditions, maps, sensors, actuators and wireless communication conditions. In 2005, several major car manufacturers began to develop their own simulation environment by melting two existing simulators together: BMW Research and Technology have combined CARISMA and NS-2 [5], which they use to simulate traffic jam warning messages, while Volkswagen AG have merged VISSIM and NS-2 to examine the effect of emergency warning messages [6]. Since there are more research areas to explore than addressed by the level of modelling in these simulation tools, we implemented a generic multi-purpose simulation environment, called Rural & UrBan e-Travelling Network Simulator (RUBeNS).

To find a suitable vehicular environment simulator, we have examined several tools (e.g. MITSIMLab, SUMO, etc.), and finally decided to use VISSIM [9]. VISSIM uses a microscopic, time step and behaviour based simulation model developed to analyze urban traffic and public transit operations. For the simulation of the telecommunications side, we have chosen NS-2. One of the biggest challenges in interconnecting these two simulation tools has been caused by the fact that VISSIM runs on MS Windows operating systems, while NS-2 prefers Linux. This implies that we have to think in terms of a distributed computing environment, where computer nodes are connected using network infrastructure and TCP/IP. Although the source code of VISSIM is not available, its functions can be accessed through a standard COM interface using C++. To interconnect the simulators, we have implemented a wrapper for VISSIM, which listens to network commands, and designed our own text-based communication protocol. In the implementation, we have used an open source cross-platform communications library with suitable TCP/IP socket implementations, called DataReel. Simulations are run in adjustable discrete time steps, as controlled by the NS-2 side.

The simulator is currently used for pile-up avoidance and route guidance scenarios, where realistic GPS modeling and special geographic routing based message passing are needed.

NUMERICAL RESULTS

We have carried out simulations on a sample network depicted on Figure 3. Let's assume that there are two demands in the network: the vehicles enter the network at *node 1* (*2*) and leave the network at *node 11* (*12*), respectively. We assume that in each simulation step of 1 second a vehicle enters the network with 0.25% probability on each entry point. The first group of vehicles has a route decision at *node 3*: they can take either *Route A* (with nodes 1-3-5-9-11) or *Route B* (with nodes 1-3-7-8-9-11). The second group of vehicles has a route decision at *node 4*: they can take either *Route C* (with nodes 2-4-7-8-10-12) or *Route D* (with nodes 2-4-6-10-12). The middle routes (B and C) are shorter (1100 meters) than the others (A and D) (2000 meters), consequently, each vehicle takes the middle route in the default case. As in many cities there is a bottleneck (e.g. a low capacity bridge) between nodes 7 and 8, while the by-pass routes A and D are less used. Every simulation was run for a duration of one hour.

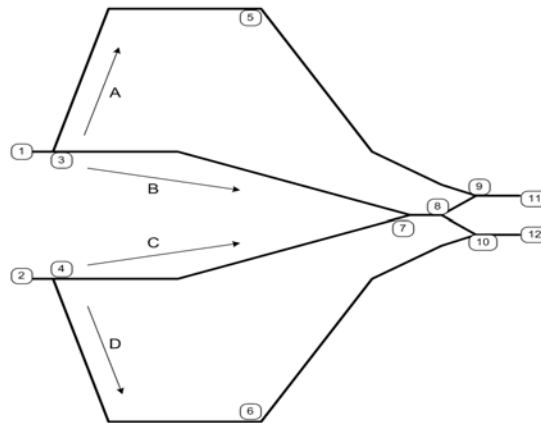


Figure 3 – The test road network

During the simulation, the following four cases were investigated: *traditional case* when there are no equipped vehicles in the network, *centralized Floating Car Data*, *ad-hoc route guidance* and *cooperative route guidance* cases.

Traditional traffic scenario

In this scenario vehicles are not equipped with intelligent communication capabilities; drivers are decision makers in the traffic network. Thus, every vehicle entered in the network will take the shortest path to the destination. The shortest routes are *Route B* and *Route C* (see Figure 3). As mentioned before, at the end of these routes, between *nodes 7* and *8* there is a bottleneck, which will cause traffic jam after a time.

In Figure 4 the travel time on routes B and C is represented in function of simulation time. Travel time is calculated by taking the average of vehicles' average speeds in function of the route length. The optimal travel times of the shorter (B and C) and longer (A and D) routes are represented by the dashed lines. This optimal time is calculated in function of the route length and the applied speed-limit (in our case 50kmph). The optimal travel time for the longer routes (A and D) is called the *decision limit*. Reaching this limit on the shorter routes, an intelligent decision maker would reroute the vehicles to the longer routes.

In the figure we can see that the travel time of each vehicle starts from the optimal value (vehicle enters and leaves with 50kmph). As the simulation progresses, the traffic jam at *node 7* appear, so the travel time starts to increase. The graph shows that the average travel time reaches its maximum after 20 minutes (approx. 1200 sec.) and it is kept this high until the simulation ends.

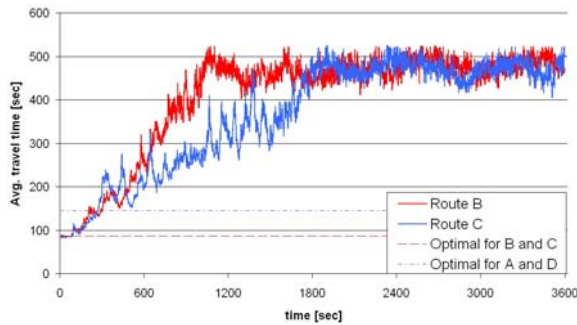


Figure 4 – Traditional traffic scenario

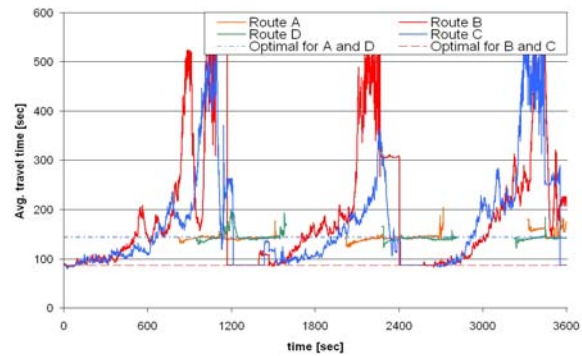


Figure 5 – Centralized Floating Car Data scenario

Centralized Floating Car Data scenario

In this case actual speed of each vehicle is transmitted to the center that stores the speed data and calculates the average travel time for the route sections. This database is queried by all vehicles at *nodes 3* and *4*. Nodes 3 and 4 are in this case decision points, where cars have to choose between two routes A and B or C and D, respectively. The cars choose the longer route (A or D) if the travel time on the shorter routes (B or C) is increased above the optimal value (*decision limit*). On the other hand, because of the finite wireless channel capacity and central processing delay, the *travel-time database* is updated after a time period (5 min in our case); thus, vehicles get a delayed view of the situation. In this case the route decision is also delayed. It can be observed on the figure that first time, when the average travel time for *Route B* and *C* reaches the *decision limit* is at approx 600 sec of the simulation time. The above mentioned overreaction effect causes an oscillation in the travel times with a time period of 20 minutes.

Ad-hoc route guidance scenario

Ad-hoc route guidance case is a fully distributed decision maker scenario. The actual speed of each vehicle is transmitted with the route information on which the vehicle travels. This information is carried even by opposite traveling cars or transmitted backwards by the cars traveling in the same direction. Cars get actual speed information and with the help of their digital map they calculate travel times on statistic basis. If the calculated travel time exceeds the *decision limit*, the cars decide independently and spontaneously to take the longer path. The spontaneous and independent decision making can conduct to the “*overreaction*” phenomenon in this case as well.

It can be seen on the graph that the *decision limit* is reached for the first time at approx. 300 sec. of simulation time. At this time all the cars from *Route B* and *Route C* are routed on *Route A* and *Route D*, which will cause traffic jam in *node 9* and *node 10*. One another observation is that the decision making is happening almost in the same time, as the travel time exceeds the optimal value for longer routes (there is no delay in the information stream).

We can see that even if the route information is fresh enough the rerouting will not reach its scope in most cases. This can be attributed to the fact, that vehicles make independent decisions and they will make congestion also on the alternative routes. Since there is no feedback from routes A and D, the vehicles cannot be aware of congestion and are often make bad decisions.

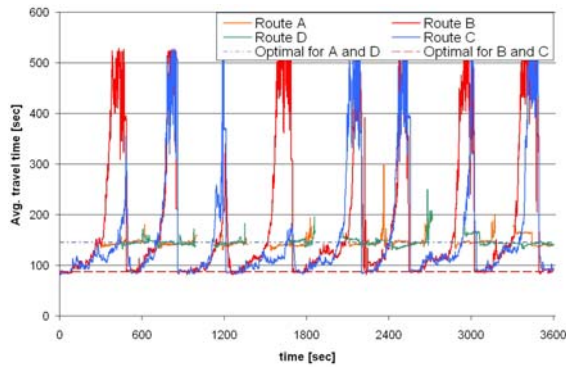


Figure 6 – Ad-hoc route guidance scenario

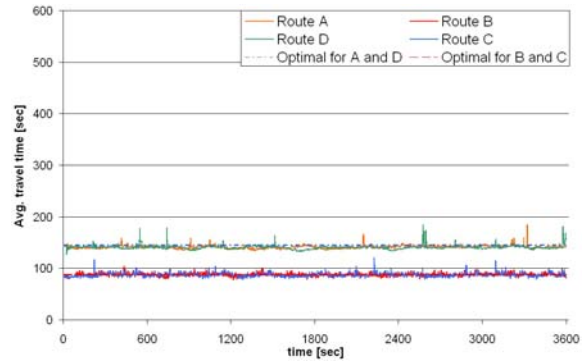


Figure 7 – Cooperative Route Guidance scenario

Cooperative route guidance scenario

To increase the performance of the decision making the Cooperative Route Guidance algorithm is used. In this scenario the cars are routed at the entry point such that the travel times are minimized by the Cooperative Route Guidance algorithm. They will be distributed on road A,B and C,D, respectively. Information spreading in this case is considered to be ad-hoc (car-to-car). The ad-hoc information spreading is good enough to be used (as presented in the previous subsection), but the decision maker has to be a centralized one, which can do a statistical analysis of all incoming data. Since the centralized network will help the decision making of vehicles, there will be no wrong decisions caused by incomplete information; thus, the overreaction can be avoided. The centralized decision system collects all data from routes A and B and does the statistical analysis with the help of Cooperative Route Guidance algorithm. As new vehicles enters the network and reaches the intersection equipped with decision points (node 3 and 4), asks which way to take. The base station, based on the Cooperative Route Guidance gives the best route for the vehicle. We can see in Figure 7 that if the traffic is optimally distributed in the network, traffic jams are not formed.

Table 1 – Average travel times

	Case 1.	Case 2.	Case 3.	Case 4.
Avg. tr. time on simulation run	386.5 sec	164.2 sec	156.8 sec	114.2 sec

The overall travel time can be seen for all four cases in Table 1. It can be seen that in the first case, when there are not any decision makers present in the network, the overall travel time is the highest. This is because the formed traffic jam in node 7 and 8 is present from formation (approx 300 sec.) during all simulation run. If Cooperative Route Guidance is considered, there is no traffic jam in the network, so the lowest possible travel time is reached. In-between these two values are placed the *ad-hoc* and *centralized* cases. If the latter case is considered, the decision is made based on delayed traffic information, so the average travel time is higher than in the spontaneous case (ad-hoc route guidance).

CONCLUSION

In this paper we have investigated the centralized and distributed FCD systems. We have found certain cases when these systems fail to deliver consistent results. To overcome this, a hybrid network architecture was proposed, which can take advantage from both kind of networking infrastructures (centralized and ad hoc). A simulation environment designed to evaluate ITS applications was also presented. The centralized, ad hoc and the proposed Cooperative Route Guidance system was compared with

the simulator. Our results show the benefits of the hybrid architecture, which lead to better travel times and less congested roads.

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