Route distribution control in road traffic networks to make on-board navigation systems become part of the traffic management

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Abstract

The paper will introduce the full chain for the centralized routing application developed within the eCoMove project for urban areas. The cooperative management of the transport infrastructure requires the provision of precise information and guidance on dedicated routes from a central knowledge base to a traveller's mobile device including navigation functionality. The traffic management is responsible for the main traffic network of the controlled area, where a traffic management control is needed to keep the traffic flowing. The onboard navigation system is responsible for the minor roads and the route to or from the controlled network, where a traffic management is not needed e.g. because of low traffic volumes. Within the major network the optimal route distribution is calculated by a neural network algorithm based on a objective function that optimises the CO_2 emissions. On request the vehicle is mapped to predefined origin and destination traffic zones. According to the route distribution matrix a route between these traffic zones is chosen. This route is sent out using the TPEG RMR (Road and Multimodal Routes) Protocol. The on-board navigation system completes the route provided by the traffic management by adding the routes within the traffic zones from its connection points to the final origin and destination.

Keywords:
ICT, ITS, eCoMove, 7th Frame program, CO_2 Emission, Traffic Management, Routing

Introduction

Algorithms that consider how to minimize travel times (or other objective functions) in a network by intelligent routing are plentiful [1]. Such algorithms are implemented within a navigation system and optimise the route of a single driver only. Navigation system recommendations contain the whole route from origin to destination.

Self-organizing, decentralized algorithms, e.g. [2], [3], [4], try to exchange data to improve network performance and prediction. They are theoretically easy to install, assuming that a certain penetration rate is reached, but fail to integrate requirements from a traffic management perspective and normally also do not arrive at a system but rather a user optimum [5]. In most cases they do not have access to detailed stationary sensor or traffic light strategies, but only to aggregated incidents like areas of congestion.

Today's central implementations try to optimize for a system optimum, but they are not yet used to transmit this information into a navigation system. Due to the access to detailed stationary sensor and traffic light data and also future traffic management measures, like traffic light program switches, tunnel systems etc., their optimisation potential is high. But until now only variable message signs have been used. These signs are only able to cover a few routes on the major network as they can only be placed at certain decision points. As the signs show the same information to all drivers, it is not possible to balance traffic with the same O/D across several routes. For a higher effect of these signs it is also only possible to provide quite general routing information and e.g. not a detailed route.

This paper describes a full chain for the centralized routing for complex major networks, which can take into account policy objectives from a traffic management perspective. We introduce the general concept, the algorithm used for optimization and the communication between centralized traffic management and the distributed navigation systems. We also report on a study for the northern Munich area using microscopic traffic flow simulation.

General Concept

The concept is based on the distribution of the routing task between traffic management facilities and vehicles' on-board navigation systems. The traffic management facility is responsible for the major traffic network of the area managed, where a traffic management control centre has been deemed necessary to keep the traffic flowing well. Working on this basis, the on-board navigation system is responsible for the minor roads and the route to or from the managed network, where traffic management is not performed e.g. because of low traffic volumes and no need for route management.

Following the principles of traffic planning, the controlled area is divided up into traffic zones. Against the planning of a demand model [6] the only used policy to create a traffic zone is its connection to the major network. Other policies, like the structure of the traffic zones, are not used.

Policy objectives from the traffic management can be included by defining the major network - e.g. by avoiding routing through residential zones – and through the configuration of traffic zones and their connection(s) to the major network.

For the definition of the traffic zones it is necessary to distinguish between traffic zones within the controlled area and outlying traffic zones. Traffic zones within the controlled area are bordered by the major traffic network. Each traffic zone has several connection points to the major network. They are placed at the intersections. Figure 1 shows an example of possible routes between an origin traffic zone (A) and a destination traffic zone (B). The figure includes the connection points to the major network (red arrows), the advised routes from the central routing system (green), the real starting and ending position of the vehicle (yellow circle) and the part that is completed by the on-board navigation system (yellow). The central routing only takes place between these traffic zones.

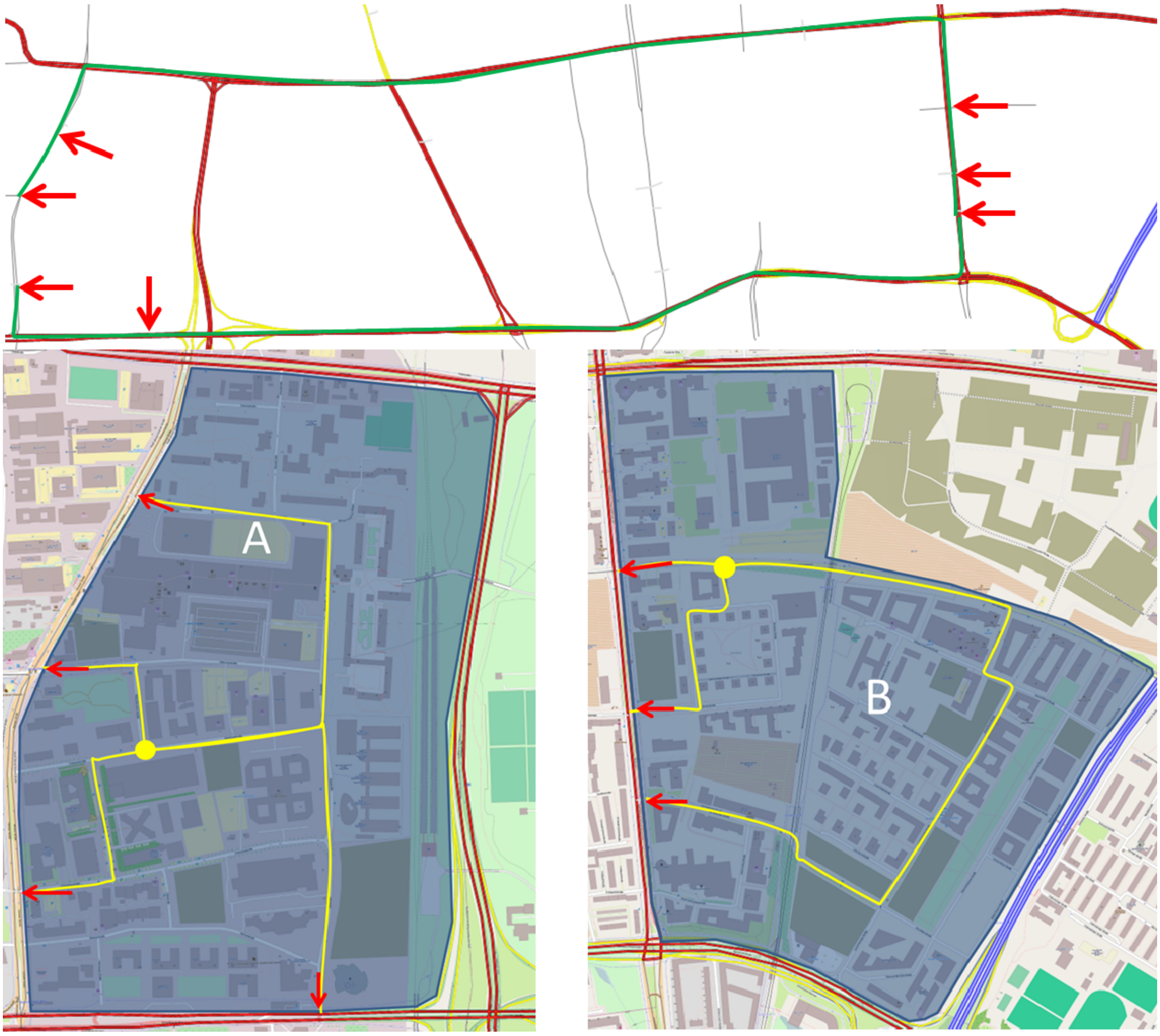

Figure 1: Example for routes between two traffic zones within the controlled area.

Every connection point of the origin traffic zone is connected to each connection point of the destination traffic zone by exactly one advised route from the central system which is optimal for the system performance. In the shown example all vehicles entering the controlled network from the two upper connection points are advised to take the northern route, whereas the vehicles entering the controlled network from the two lower connection points are advised to take the southern route. In this example there is only one route per O/D of the connection points. A distribution of the vehicles across several routes is also possible however. Depending on the exact starting and ending position within the traffic zones, the on-board system chooses the best route from the advised routes, which is chosen according to the objective function of the on-board navigation system. Due to the fact that starting and ending positions are distributed through the traffic zones, different routes will be taken through the controlled network.

Outlying traffic zones can, on the whole, be much bigger. Their size depends mainly on possible decision points in the network heading towards or coming from the controlled area. Figure 2 shows an example for possible routes between an outlying starting position (here Karlsruhe) and traffic zone A from the previous example.

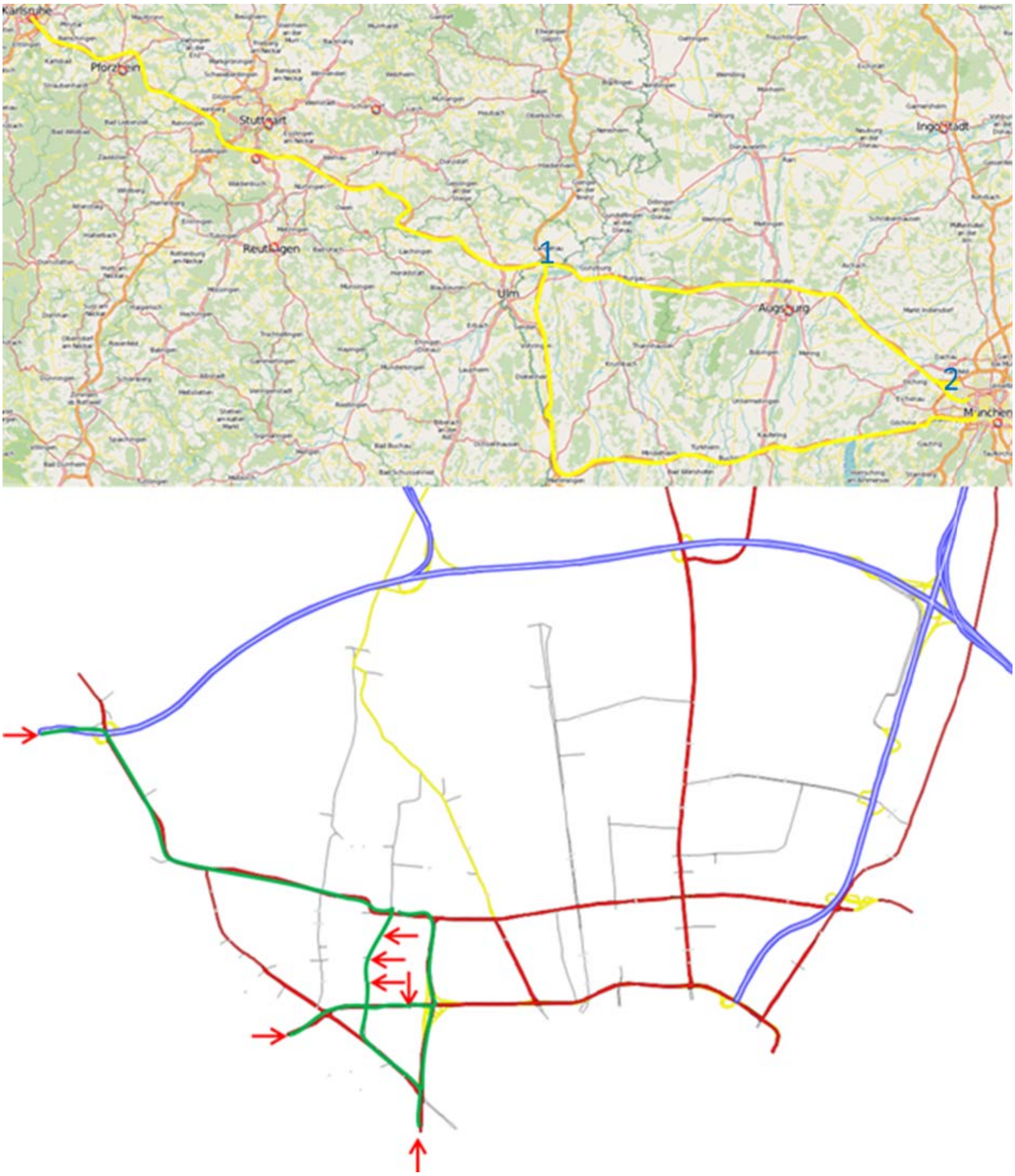

Figure 2: Example for routes between outlying starting points and traffic zones within the controlled area.

There are two ways of using the route advice service. Vehicles can (a) either subscribe to this service and receive updates on the route recommendation based on their current position and the current traffic along their route or (b) they actively request an update. Using the example shown in Figure 2, a vehicle requesting an advice for a route from Karlsruhe to the centre of Munich has initially three possible connection points to the Munich traffic management area. Upon passing the motorway junction near Ulm (1) the vehicle has to make a first route choice on its way to Munich. Now it either approaches Munich from the north which restricts the access points to the controlled area to one or from the east, allowing two options (2) for connecting to a route of the controlled area. The choice between approaching Munich either from the north or from the east is based on (a) current traffic information along the major routes (yellow) and (b) traffic information and prediction for the routes advised from the central system within the controlled area (green).

System Overview

The central system consists of several components which will be described in the following sections. Figure 3 shows the system overview.

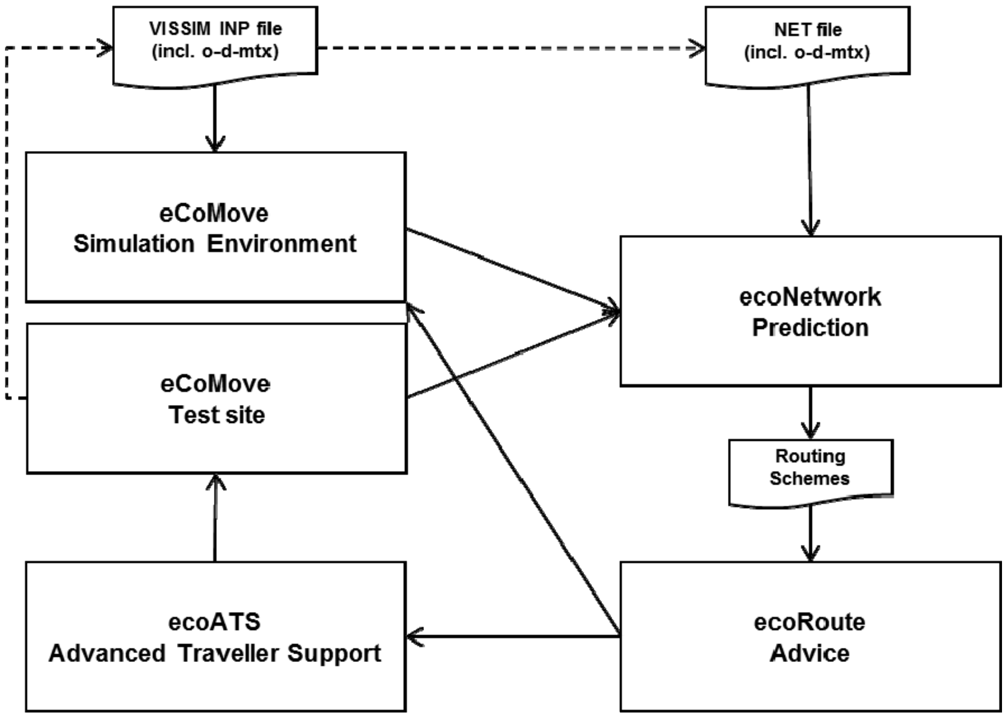

Figure 3: System Overview

The network model is derived from input data from the real test site including map and traffic light data. It is input for the simulation model as well as the ‘ecoNetwork Prediction’ model.

As the eCoMove simulation environment [7] allows the embedding of the eCoMove system with only a few changes the routing system can be connected to both the real test site and the simulation environment.

Desired Network State

As the service offered by the ‘ecoRoute Advice’ application is based on a database of current environmentally optimal routing schemes, the dynamic computation of the routing schemes on the basis of OD-matrices and dynamic TLC green time splitting rates is key.

The first step for the overall routing approach is the calculation of optimal routing schemes. This is performed by the ‘ecoNetwork Prediction’ component. It calculates the optimal route distribution within the major network (major urban roads and motorways) using a dynamic route choice and traffic assignment network model that works with a special objective function in order to optimize environmental benefit. This objective function expresses the correlation between traffic and fuel consumption and represents a strategy that reflects the system operator’s goal of minimizing the overall CO_2 emissions. The model results are time-dependent routing schemes for all origin-destination relationships in the network. The routes usually represent environmentally optimal driving though the network rather than minimal travel times. Figure 4 shows a visualisation of the desired network state.

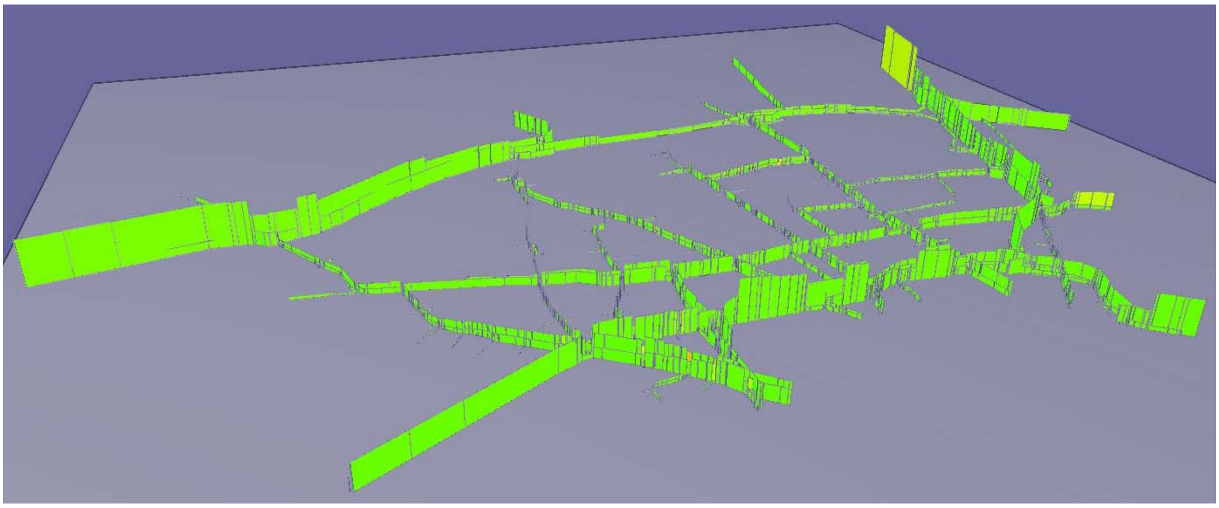
Figure 4: Visualisation traffic flows for an optimised desired network state

As the model's task is to estimate the environmentally optimal traffic states (and not the real ones), the only dynamic data it is provided with is the averaged green time splits of the TLC signal groups. From those green splits it periodically updates its current link capacity values. Detector data and vehicle-generated data are constituted only to the current, real situation and therefore are not considered in the context of environmentally optimal modelling for the future traffic situation.

The dynamic network model for integrated dynamic traffic assignment to road networks is based on an interpretation of the road network as a special nonlinear recurrent neural network that utilises a transposed linear recurrent error-propagation network in order to very effectively determine gradients of the given objective function [8]. The first nonlinear neural network represents the dynamics of the road network with certain free parameters (intersection splitting rates) that can be adjusted permanently by the second linear error-propagation network.

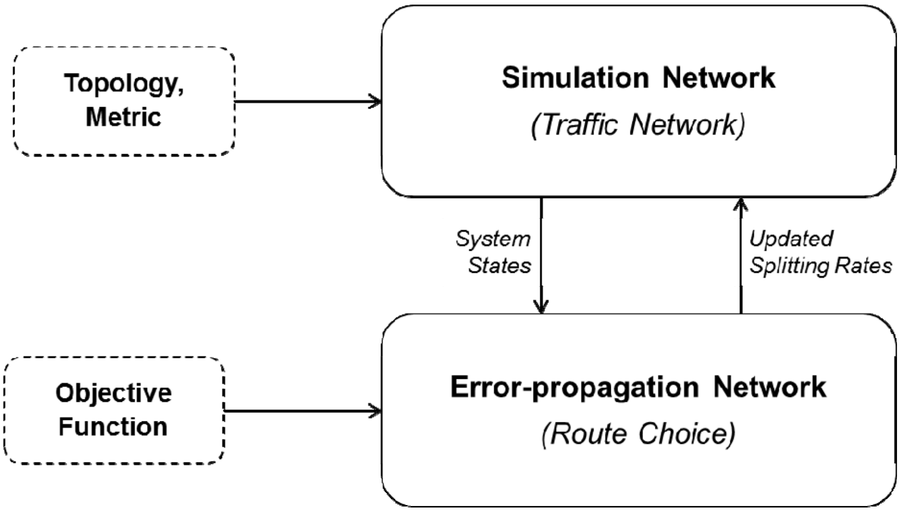

Figure 5: Two cooperating networks: The Simulation network to simulate the traffic dynamics and the error-propagation network as the controller of the first network

The note-worthy features of this dynamic network model approach are:

- The computation scheme is parallelised and can be distributed on many computation units (e.g. many processors or many processor cores).

- The simulation part of the model is capable of reproducing congestion phenomena like spill back effects.
- The error-propagation part of the model can work on almost any objective function (the only requirement on the function is that it be partially differentiable).
- It can separate any traffic subset into different layers in order to treat the traffic sub-flows differently from other ones.

The objective function uses values (i.e. gradients) that are provided by a macroscopic emission calculation that is based on a microscopic calculation [9]. The input values for the emission computation per network link are: (1) mean speed, (2) speed limit, (3) current queue length, (4) current traffic flow, (5) truck ratio and (6) road classification. The gradients are derived approximately from differences.

Route Advice

The second component, the so called ‘ecoRoute Advice’, is responsible for the distribution of the vehicles itself. All communication between on-board navigation systems and the central system are performed by the ‘ecoATS’ Service (Advanced Traveller Support), which is described below.

On request from the navigation system, the vehicle is mapped to predefined origin and destination traffic zones. Each traffic zone has at least one connection point to the major road network. According to the actual routing scheme data from the ‘ecoNetwork Prediction’, the ‘ecoRoute Advice’ chooses one route between each connection point from the origin traffic zone to the destination traffic zone.

If the traffic between two connection points is, according to the routing scheme from ‘ecoNetwork Prediction’, split up into several routes the one with the highest not yet served split is chosen. Therefore predicted split and desired split are compared. The difference between these splits is called the non-served split. When the on-board system navigation finally has chosen a route, this route is reserved and the non-served split for the next vehicle is adapted accordingly.

Advanced Traveller Support

The communication to the driver via the navigation system is realised by the 'ecoATS' (Advanced Traveller Support) Service. The service uses the general request mechanisms as defined in TPEG over HTTP [10]. The recommended routes are sent out using the TPEG RMR (Road and Multimodal Routes) protocol [11]. This protocol is currently under development within TISA (Traveller Information Service Association). For the transmission of route information a first draft of this future standard was investigated for the use within the eCoMove project.

Using the above mentioned ecoATS Service, the Peer-to-Peer communication scenarios are as follows:

- request of a route set fulfilling the driver’s requirements,
- route choice by the driver and submission of the choice to the ecoATS Service
- update route request (a) providing information about e.g. driver’s current position and (b) receiving updated route information including an update of the route

The ecoATS Service supports the same functionality for the provisioning of traffic event information using TPEG TEC (Traffic Event Compact) as well as for traffic state and prediction information using TPEG TFP (Traffic Flow Prediction).

On-board Navigation

The on-board navigation system completes the routes given by the traffic management by adding the routes within the area from its connection points to the final origin and destination. According to its used objective function of the on-board navigation system rates each route and chooses the optimal one. This route is then displayed to the driver and communicated via the ‘ecoATS Service’ to the ‘ecoRoute Advice’.

Validation Approach

The routing will be tested in the northern road network of Munich. Due to the low number of equipped vehicles within the ecoMove project, which do not allow to balancing the traffic demand within the network, the validation only takes place in simulation. For this reason two traffic models are built for the test site Munich.

The macroscopic traffic model for Munich was generated out of an existing macroscopic traffic model for Germany (PTV product: Validate Germany). It includes the general network with relevant traffic demand sinks and sources. New sinks and sources were generated at all network links at the border to the surrounding, original network. The demand matrices for the Munich network were generated based on the original demand matrices for Germany. Historical loop data gathered within a previous project (Wiki [12]) from the Bayerinfo service and the city of Munich, covering a period of six months, were used as input for the calibration of the new traffic demand model for Munich using VstromFuzzy [13] as a method to adjust traffic demand between sources and sinks.

Based on the macroscopic model a microscopic VISSIM model [14] was derived and improved through detailed modelling of traffic light controlled intersections including detectors, lanes, priority rules, signal heads and real signal plans. Figure 6 shows the network used within the simulation study.

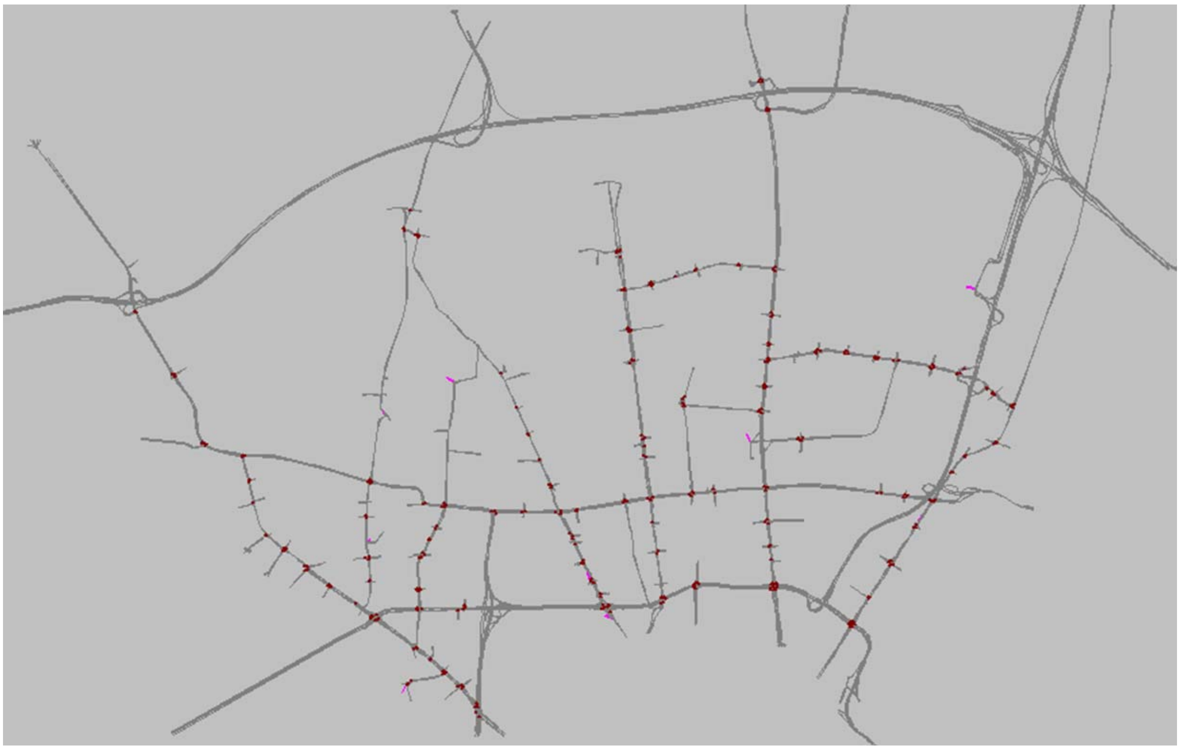

Figure 6: VISSIM model of the Munich test site

The network consists of 60 km of motorway, 100 km of urban major roads and 100 km of urban minor roads including 108 signal controlled intersections. The validation is performed for the hours of 6:00 to 12:00 of an average working day. The ratio of heavy duty vehicles for the whole network is about 10 per cent.

The validation is performed within the eCoMove simulation environment [7] through a socket connection by which dynamic TLC signal group data is provided. In response, 'ecoNetwork Prediction' writes the routing scheme data to text files that can then be used from the 'ecoRoute Advice' application to determine the optimal routes for individual vehicles. To validate the CO_2 emissions EnViVer 3.0 [15] is used.

Compared to a real implementation this has several limitations or simplifications:

- Vehicles do not have to be map matched to the traffic zones. Instead the VISSIM input link is used as a matching to the traffic zone.
- It is not possible for vehicles to change their connection point to the major network as the minor road network within the traffic zones is not part of the simulated network. For a real network this may lead to different saturations for some links of the major road network as vehicles may enter it from a neighbouring connection point.
- The 'ecoATS Service' is replaced by the VISSIM C2X interface which influences the vehicles' routes directly.

First Results

First simulation studies are carried out for the off-peak hour between 11:00 and 12:00 for a penetration rate of 100 per cent. The results are shown in Table 1.

	CO_2 total per hour	NO_x total per hour	Average number of stops per vehicle	Average travel time per vehicle	Total travelled distance per vehicle
Baseline	85830 kg	457 kg	1.87	403 s	6.29 km
With System	79380 kg	413 kg	3.69	426 s	5.87 km
Decrease	7.5%	9.6%	- 97.3%	- 5.7%	6.7%

Table 1: Results for the off-peak hour from 11:00 to 12:00 for a penetration rate of 100 per cent.

The results show that the system can lead to a reduction of 7.5 per cent of CO_2 emissions for an off-peak hour for the northern Munich network. It also can lead to a reduction of 9.6 per cent for NO_x emissions. Also the travelled distance per vehicle decreases by 6.7 per cent.

For the number of stops the standard queue parameters of VISSIM [14] are used, which is a hysteresis defining a stop starting at a speed of 5 km/h and ending when the vehicle reaches a speed of 10 km/h. Slighter changes in vehicle speeds are only recognized within the emission calculation. The number of stops increases highly with the system by 97.3 per cent and the average travel time per vehicles increases by 5.7 per cent. Therefore there is no positive correlation between either the number of stops nor the travel time and emissions. Hence, an optimisation on travel time or stops will not lead to an optimum for emissions and fuel consumption for the northern Munich network for the off-peak hour from 11:00 to 12:00.

Conclusion and Outlook

In this paper, we have presented a complete concept for point-to-point, environmentally-friendly routing anywhere within a road network in cooperation with a traffic-management authority. The system works by retrieving routes within the major road network from centralized traffic management and completing these using the on-board navigation system. Real data from the road network's traffic light control can be used to estimate the most environmentally optimally routes for a network optimum. Based on these, a route distribution process is carried out centrally that assigns drivers to the various routes. Communication to the driver is achieved using the on-board device, e.g. navigation system.

In order to quantify the benefit of the system, simulation trials were carried out. Here, emissions are assessed using the Enviver3 model based on microscopic vehicle data from the simulation. It is shown that a reduction of CO_2 emissions of up to 7.5 per cent for an off-peak demand is achievable for the Munich test site.

More studies will be carried out regarding peak hours, different penetration rates and the combination with other eCoMove applications on traffic light control and speed advisory. Due to the fact that within the peak hours serious traffic jams might be avoided an even higher reduction in CO_2 emissions is expected.

Also this paper does not contain a business model or a strategy for introducing the system to the real world, a European wide study [16] showed that drivers do not expect a big reduction of their own fuel consumption and even except a minor increase in travel time. However positive effects on stressless driving, general traffic flow and network wide environment-friendliness were expected by the drivers.

For simulation a 100 per cent acceptance of the recommended routes is assumed. In reality this will most probably not be the case, but already smaller acceptance rates (and with this also lower penetration rates) will lead to good results as not all vehicles have to be shifted to different routes.

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