Quantifying the Influence of Route Choice Optimization on Emissions and Fuel Consumption

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***Abstract*—Genetic algorithm-based route choice optimization techniques have recently demonstrated their potential to reduce the travel costs on the system level. In this context, the costs are reduced according to exactly one metric such as, e. g., the sum of all individual travel times. In the present study, we will investigate the tradeoff between the saved travel time and the additional costs in terms of higher emissions and a higher fuel consumption.**

I. Introduction

Intelligent transportation system technologies (ITS) [6] play a key role in the improvement of the efficiency of road networks in terms of their utilization. Typically used are in-vehicle systems that use either vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication [4] in consort with traffic information systems [9], [7], [8] to collaboratively optimize the route choices in the network. These intelligent solutions can help to balance the traffic across the network in order to avoid critical conditions such as traffic jams. But aside from showing that these approaches in fact do improve the road network efficiency, it can be worth to take a look at the environmental impacts they come with. In this paper, we focus on the evaluation and quantification of these impacts in terms of CO_2 (carbon dioxide) emissions as well as the fuel consumption. To this end, we consider the recently proposed concept of route choice optimization using distributed Genetic Algorithms [3].

II. Evaluation

Realistic vehicle movement plays a very important role in the evaluation of systems related to vehicular road traffic. For the evaluation in this paper, we therefore use a real world scenario from the city of Bologna [2] which represents an observed peak-hour traffic demand (8:00 am – 9:00 am). During this time period, a total of $11,000$ vehicles is inserted into the road network. A warm-up period of 15min is bypassed to allow traffic load in the road network to stabilize before the evaluation starts. Also the last 15min are not accounted for in this evaluation as the traffic load starts decreasing. The evaluation itself is performed in SUMO [1], a microscopic vehicular road traffic simulator.

We compare two sets of *route choices* in the given scenario. A set of route choices in essence describes which route *each* of the $11,000$ vehicles drives from his origin to his destination. On the one hand we have the *unoptimized* route choices: every driver chooses the shortest path (in terms of the free-flow travel time) from his origin to his destination. We compare this to *optimized* route choices on the other hand. These are optimized using the techniques described in our recent publication [3]. It aims at improving the costs for the system as a whole. In this context, the sum of the vehicles' travel times is used as the target function for a distributed on-line optimization process.

SUMO comes equipped with the ability to record emissions and fuel consumption according to the HBEFA v2.1 model [5]. In this context, the emissions are recorded in $\frac{\text{mg}}{\text{s}}$ and the fuel consumption in $\frac{\text{ml}}{\text{s}}$ in each timestep for each car. Additionally, the cars' total emission and fuel consumption is recorded after they have finished their journey. The two metrics are closely related, but not fully equivalent, because different classes of vehicles use different types of fuel, which in turn correspond to different amounts of CO_2 per litre of fuel [5].

It can be observed that the route choice optimization increases the total emissions of CO_2 from $2605.43\,\text{kg}$ to $3000.96\,\text{kg}$ ($+15.18$ %) and the total fuel consumption from $1038.74\,\text{l}$ to $1196.36\,\text{l}$ ($+15.17$ %), while the total driven distance increases from $13\,075.66\,\text{km}$ to $15\,977.07\,\text{km}$ ($+22.18$ %). However, due to the optimization, a different set of vehicles will reach their destination during the simulated time frame. More precisely, 8556 vehicles arrive at their destination before the route choice optimization is applied. Using the optimized route choices this number grows to 9369. Therefore, the absolute fuel consumption or CO_2 emission do not constitute suitable metrics: they do not refer to the resources spent for achieving the same goal or delivering the same amount of service.

We therefore compare the additional expenses of the optimization in terms of higher CO_2 emissions and a higher fuel consumption per kilometer of the *unoptimized* route. That is, in a sense, we use the unoptimized (i. e., shortest path) route length as a measure for the "amount" of transportation service delivered to the driver of the respective car. Let r_c be the route of car c as it was planned in the unoptimized scenario and l_{r_c} the length of this route. Let $\text{CO}_2(r_c)$ and $\text{FUEL}(r_c)$ denote the CO_2 emission and the fuel consumption along that route, respectively. Then, given the CO_2 emission $\text{CO}_2(\widehat{r_c})$ and the fuel consumption $\text{FUEL}(\widehat{r_c})$ in the optimized scenario, we normalize these values to the length of the unoptimized route l_{r_c}. Furthermore, we are interested the in the ratios $\frac{\text{FUEL}(\widehat{r_c})}{\text{FUEL}(r_c)}$ and $\frac{\text{CO}_2(\widehat{r_c})}{\text{CO}_2(r_c)}$ for all cars that finish their journey in both the unoptimized and the optimized case. These ratios show by

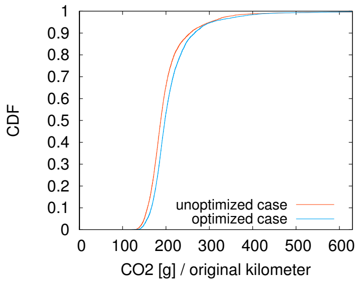

Fig. 1. Comparison of CO_2 emissions.

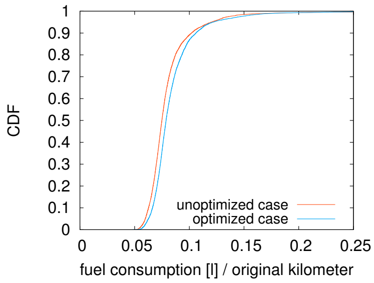

Fig. 2. Comparison of the fuel consumption.

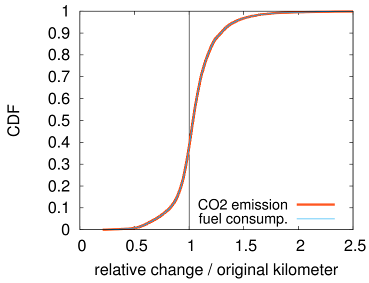

Fig. 3. Relative change after optimization.

which factor the CO_2 emission and the fuel consumption of a vehicle driving from the same origin to the same destination have changed.

Figure 1 shows the cumulative distribution function (CDF) of the CO_2 emissions per kilometer before and after the optimization of the route choices, as discussed before in both cases in relation to the length of the unoptimized, shortest-path route. It can be seen that the values do not change much: only a small subset of vehicles experience noticeably higher emissions and a higher fuel consumption. Also, only a small number of vehicles can lower these values to a non-negligible extent. The same pattern can be observed when looking at the comparison of the absolute fuel consumption in Figure 2.

While the CDFs of the absolute values show that the distribution of emissions and fuel consumption do not change much, it does not show what that means from the drivers' point of view. Figure 3 shows the CDF of the relative changes in the absolute CO_2 emissions and fuel consumption per original kilometer after the optimization has been applied. Here, it can be seen that, around $40\,\%$ of all vehicles can reduce their CO_2 emission and fuel consumption noticeably while the other $60\,\%$ experience increased values. This indicates that disadvantages (in terms of a non-optimal emission / fuel consumption) are reallocated among the cars: we still have cars that cause much pollution, its just that these are different cars after the optimization of the route choices. In a next step, we take a look at the same values, but now accumulated over all routes. It can be seen that the total emissions of CO_2 have increased from $199.25\,\mathrm{g}$ to $207.33\,\mathrm{g}$ and the fuel consumption has increased from $79.44\,\mathrm{ml}$ to $82.65\,\mathrm{ml}$ per kilometer. This corresponds to a $4.05\,\%$ increase of CO_2 emission and an increase of $4.04\,\%$ in the fuel consumption for the entire system. The observed increase in emissions and fuel consumption after applying our proposed route choice optimization methodology is relatively small given the fact that the costs for the system as a whole (in terms of the total travel time) can be reduced by over 20 % [3].

III. Conclusion

In this abstract, we focused on the quantification of the impact on both the CO_2 (carbon dioxide) emissions as well as the fuel consumption which is caused by the route choice optimization using the on-line route optimization techniques described in [3]. In this context we evaluated the increase in emissions and fuel consumptions for the new (optimized) route choices per kilometer of the route as it was driven in the scenario with unoptimized route choices. It could be shown that the system as a whole experiences an $4.05\,\%$ increase of CO_2 emission and an increase of $4.06\,\%$ in the fuel consumption per original kilometer. At the same time, the cost (in terms of the total travel time) for the entire system was reduced by over $20\,\%$. While from the ecological point of view the route choice optimization leads to poorer results, the environmental overhead is reasonably low compared to the benefit that can be achieved by the drivers in terms of a lower travel time.

References

[1] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz. SUMO – simulation of urban mobility: An overview. In *SIMUL '11: Proceedings of the Third International Conference on Advances in System Simulation*, Oct. 2011.

[2] L. Bieker, D. Krajzewicz, A. Morra, C. Michelacci, and F. Cartolano. Traffic simulation for all: a real world traffic scenario from the city of Bologna. In *SUMO '14: Proceedings of the Conference on Modeling Mobility with Open Data*. May 2014.

[3] D. Cagara, B. Scheuermann, and A. L. Bazzan. Traffic optimization on islands. In *VNC '15: Proceedings of the IEEE Vehicular Networking Conference 2015*, Dec. 2015.

[4] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil. Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions. *Communications Surveys & Tutorials, IEEE*, 13(4), 2011.

[5] M. Keller and P. de Haan. Dokumentation hbefa 2.1. *Bern/Essen/Graz/Heidelberg, INFRAS*, 2004.

[6] P. Papadimitratos, A. La Fortelle, K. Evenssen, R. Brignolo, and S. Cosenza. Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation. *Communications Magazine, IEEE*, 47(11), 2009.

[7] J. Rybicki, B. Scheuermann, W. Kiess, C. Lochert, P. Fallahi, and M. Mauve. Challenge: Peers on wheels – a road to new traffic information systems. In *MobiCom '07: Proceedings of the 13th Annual ACM International Conference on Mobile Computing and Networking*, pages 215–221, Sept. 2007.

[8] J. Rybicki, B. Scheuermann, M. Koegel, and M. Mauve. Peertis: A peer-to-peer traffic information system. In *VANET '09: Proceedings of the 6th ACM International Workshop on VehiculAr Inter-NETworking*, pages 23–32, Sept. 2009.

[9] L. Wischoff, A. Ebner, H. Rohling, M. Lott, and R. Halfmann. Sotis-a self-organizing traffic information system. In *VTC '03-Spring: Proceedings of the 57th IEEE Vehicular Technology Conference*, pages 2442–2446, Apr. 2003.