A Hybrid Vehicular Re-routing Strategy with Dynamic Time Constraints for Road Traffic Congestion Avoidance

Shen Wang [1], Soufiene Djahel [2] and Jennifer McManis[1]
[1] Lero, RINCE, School of Electronic Engineering, Dublin City University, Ireland
shen.wang4@mail.dcu.ie, mcmanisj@eeng.dcu.ie
[2] Lero, School of Computer Science and Informatics, University College Dublin, Ireland
soufiene.djahel@ucd.ie

Abstract

Nowadays, the rapid rise of the number of vehicles on the roads has led to several challenging problems for road authorities, such as traffic congestion, increasing number of accidents and air pollution. According to recent statistics, road traffic jam leads to a huge economic loss due to the increasing delay on the roads and the extra fuel consumption. Intelligent Transportation System (ITS) provides a promising framework to alleviate the congestion on the roads. However, a lot of work needs to be done to improve its efficiency, such as in the area of vehicles re-routing strategies. The main focus of this paper is on designing novel vehicles re-routing strategy to reduce the traffic congestion in urban areas. The proposed strategy is a hybrid approach which takes full advantage of both exact and heuristic algorithms and meets the requirements of dynamic time constraints of real road traffic scenarios. The next step of our work is to evaluate the performance of our strategy and compare it with the existing algorithms based on several metrics and under a benchmark of road topologies and traffic scenarios.

Keywords: ITS, Vehicles Re-routing, Shortest Path, Heuristic Algorithms.

1 Introduction

With the trend to worldwide urbanization, an increasing number of vehicles are swarming into limited capacity road networks. This leads to two challenging problems: traffic congestion and excessive fuel consumption. According to the new released report [1] from Texas Transportation Institute, the economic loss of traffic congestion in the United States in 2011 is $121 billion in terms of extra waiting time and fuel consumption. For the average commuter in rush hour, 38 hours extra travelling time and 19 gallons fuel are wasted in 2011. The corresponding numbers in 1982 are only 16 hours and 8 gallons respectively. Therefore, scientists and researchers have recently proposed the so called Intelligent Transportation Systems (ITS) [2], which have been already successfully deployed in many regions in United States, Japan and Europe to ease the traffic management task. ITS monitoring equipment such as CCTV cameras, radars, sensors and induction loops are able to collect real time traffic data such as number of vehicles, their average speed etc. These data feeds are used to assess the traffic conditions and then adapt the traffic lights cycles to avoid traffic congestion and reduce the vehicles delay on the roads.

Smart routing of vehicles is one of the key services offered by ITS for achieving optimal load balance of the traffic on the roads. Some of the existing commercial routing products, such as Google Maps and Nokia Ovi, can either only plan the route before the drivers start their journey or cannot quickly provide an alternate route in case of incidents. Thus they cannot react to sudden changes in route conditions during the journey. Therefore, real-time, or near real-time re-routing strategies which can help the vehicles to react to any update in traffic conditions, including incidents, are highly required. In order to achieve this goal, upon advertisement of a real-time event, such as vehicle crash, stalled vehicle on the road, congested road segment etc, the re-routing algorithms should find an alternative optimal/near-optimal route before the vehicle reaches the next junction; otherwise it will probably be difficult to avoid the congestion.

In this paper, we propose a new vehicles re-routing strategy that combines the strength of both exact and heuristic algorithms with respect to the dynamic time constraints. These time constraints refer to the remaining time for a vehicle to reach the next junction, which represents the available time threshold to find the best alternative route to avoid the announced congested roads ahead.

2 Related works

The vehicular routing problem is a variant of the classical shortest path problem, with links represent road segments and vertices refer to road junctions. The links are weighted according to several parameters such as travel distance and travel time. For ITS systems, the available time to provide a re-routing solution must be limited due to road network constraints. In what follows, we classify the existing solutions into two categories; exact and heuristic algorithms and briefly discuss their key principles, strengths and weaknesses.

2.1 Exact Algorithms

Exact algorithms provide the best route according to the specified criteria and link weights. Nevertheless, there are no guarantees on their response time. Dijkstra Algorithm (DA) [3] is the most representative algorithm in this category. It searches the shortest route from one node to all other nodes in the road network. Moreover, it guarantees the termination property. Its time complexity is O(V^2), where V is the number of vertices, or junctions in the real road networks. DA's time complexity can be reduced to O(E+V*log V) if Fibonacci heap sort is used, in which E refers to the number of edges or roads in a real map. However, due to the large size of real road networks, it cannot ensure short response time.

2.2 Heuristic Algorithms (HA)

In 2004, Bogdan Tatomir et al. proposed a routing solution [4] based on dynamic traffic data to tackle road traffic congestion problem using Ant Based Control (ABC). Ants can always find the shortest route for food source due to their particular method of information exchange. The authors use backward-forward ants mechanism to update the routing tables of agents distributed on each junction. Three years later, Hitoshi Kanoh [5] applied the virus genetic algorithm (GA) to dynamic route planning. According to the principle of species evolution, the algorithm can find the optimal route, and then improve it iteratively. Just one year later, an improved version [6] of this approach has been proposed by the same author to balance the travel distance, travel time and easiness of driving with a better quality of initial infected virus generated by DA. Horst Wedde et al. [7] introduced a new system called Bee Jam Avoidance (BJA) inspired by the form of bee foraging communication. This distributed, multi-layered and adaptive congestion avoidance system can reduce the average travel time but cannot deal with other criteria. As described above, several approaches have been proposed for smart routing of vehicles, but none of them is able to react efficiently and within short time threshold to the potential change in road conditions during the vehicle journey. This is because they use a fixed computational time threshold which is less-efficient and unrealistic. Additionally, no performance comparison among them is conducted and most of them have been evaluated against DA only.

3 Our proposal

To overcome the drawbacks of the aforementioned solutions, we propose a hybrid vehicle route planning strategy based on proactive real-time event report mechanism. As shown in Figure 1, at the initialisation stage of our strategy, the road network map is loaded along with real time data and the corresponding prediction information (e.g. estimated average speed of vehicles in a certain road segment, estimated traffic congestion level after X minutes, etc). Simultaneously, the driver should input the desired destination, the vehicle features (e.g. type, height, size, emission of engine etc.) and route planning metrics (travel time, easiness of driving or fuel consumption level) to the system. Then, the driver gets the best route to destination using DA before the journey starts. While the vehicle is running on the road, if it receives real-time event report, the map with real-time data should be updated. Notice that for the whole hybrid re-routing system, the report mechanism works as an interruption in computer architecture; it can push the event information to the related vehicles with highest priority pro-actively, rather than letting the vehicles check the related status periodically. We assume that the vehicle will use the initial route plan until its destination is reached, if there is no real-time event received during the entire trip. If an event is received, according to the comparison between the computation time of DA (T_{DA}) and current due time (i.e. estimated travel time from current position to next intersection) T_d, the algorithm uses DA or HA to provide the new optimal route. In this case, HA can be implemented by one of the following algorithms: Particle Swarm Optimisation (PSO), Simulated Annealing (SA) or Tabu Search (TS), as they have never been proposed in this research field. The idea behind this design is to make full use of the dynamic due time. If T_d is long enough, we do not need HA which can only provide near-optimal solution instead of the optimal (best) one. Finally, the algorithm ends up with a sign of destination road segment reached. It is worth noting that during the vehicle journey, if a re-routing is required then our algorithm will choose the scope of a map from a rectangle whose diagonal is from current position to the destination.

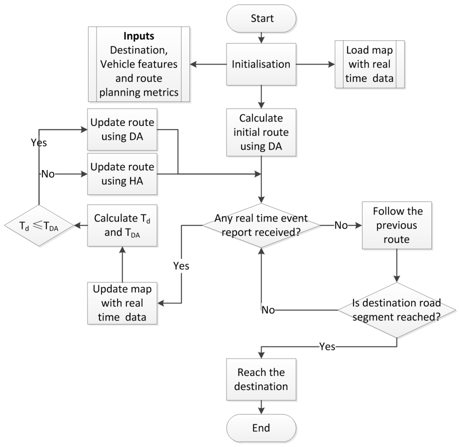

Figure 1: Flowchart of our Hybrid Re-routing Strategy

To validate the effectiveness of our strategy, we will compare it with the aforementioned HA solutions and DA. To this end, we use the following metrics to evaluate their performance: travel time, fuel consumption, easiness of driving, computation time and scalability. The travel time is crucial as the short travel time means high work productivity and more satisfaction of the city's citizens, everyone in this society can thus benefit from this improvement. Lower fuel consumption reduces the economy cost for a driver as well as the air pollution. It should be measured as the average litres of the consumed fuel per kilometre. The factor easiness of driving is judged from drivers perspective. It is also an important matter due to two reasons: first if the drivers do not get comfortable driving experience from a system, they will choose another product; second, if they drive in their easiest way the risk of their involvement in accidents will decrease significantly. We can score the difficulty of the planned route in terms of number of turns, traffic lights, and the width of lanes in each road etc. As the re-routing solution has to be provided to the vehicles before they reach the next intersection, hence the computation time is important as well. Finally, we will take the scalability into account as the algorithm efficiency would be totally different when it is applied to various map layouts (average length of road segments, average number of roads and junctions etc.) or different traffic loads (i.e. density of vehicles). To implement the re-routing strategies, we will use the most widely used open-source microscopic transportation simulator named SUMO [8]. To do so, each algorithm will be implemented, and then dynamically called, using TRACI, whenever an event happens during the vehicle journey. Various testing maps would be also extracted from OpenStreetMap (OSM) to test the scalability metric. For the traffic flow generation, we use Trafficmodeler tool [9]. This tool generates real statistic data of traffic conditions provided by Dublin City Council. Finally, a benchmark of over 10 testing group scenarios will be carried out.

References

[1] S. David, B. Eisele, and T. Lomax, 2012 Urban Mobility Report, Texas Transportation Institute, Texas A & M University, 2012.

[2] K. Chen and J.C. Miles, ITS Handbook 2000 Recommendations from the World Road Association (PIARC), Artech House, 1999.

[3] E. W. Dijkstra. A Note on Two Problems in Connection with Graphs. Num. Mathematik, 1:269-271, 1959.

[4] B. Tatomir, S. Fitrianie, M. Paltanea, and L. Rothkrantz, Dynamic routing in traffic networks and manets using ant based algorithms, in Proceedings of the 7th International Conference on Artificial Evolution, Lille, France, October 2005.

[5] H. Kanoh, Dynamic route planning for car navigation systems using virus genetic algorithms, International Journal of Knowledge-based and Intelligent Engineering Systems, vol. 11, pp. 65-78, Jan. 2007.

[6] H. Kanoh and K. Hara, Hybrid genetic algorithm for dynamic multiobjective route planning with predicted trafic in a real-world road network, in Proceedings of GECCO 08,New York, NY, USA, July 2008.

[7] S. Senge and H. Wedde, Bee inspired online vehicle routing in large traffic systems, in ADAPTIVE 2010, The Second International Conference on Adaptive and Self-Adaptive Systems and Applications, 2010.

[8] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, SUMO - Simulation of Urban MObility - an Overview, in SIMUL 2011, The Third International Conference on Advances in System Simulation,(Barcelona, Spain), 2011.

[9] L. Papaleondiou and M. Dikaiakos, Trafficmodeler: A graphical tool for programming microscopic traffic simulators through high-level abstractions, in Vehicular Technology Conference VTC2009-Spring, Barcelona, Spain, 26-29 April, 2009.