AN INTEGRATED ARCHITECTURE FOR INFOMOBILITY SERVICES
Advantages of Genetic Algorithms in Real-time Route Planning

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Abstract: In the field of Intelligent Transportation Systems, a key role is played by efficient route planning services. Such systems have been evolving rapidly, but they still have some restricting drawbacks, such as the lack of a full support of real-time traffic monitoring and the consequent real-time update of the best route suggested. In this paper, an architecture is proposed for the management of dynamic path planning and limitations of traditional search algorithms in these kinds of applications discussed. A variant of the proposed approach is consequently presented, based on the joint use of virus-evolutionary genetic algorithms for real-time route planning and traffic forecasting.

1 INTRODUCTION

The latest study on global urbanization conducted by the Population Division of the Department of Economic and Social Affairs of the United Nations was released in 2007 and predicts that, in 2050, nearly 70% of the global population will be living in larger cities (UN, 2008).

This immense aggregation of people will surely pose great challenges to the sustainability of modern lifestyle, and the problem of an efficient management of mobility stands out as one of the most relevant ones. As a matter of fact, densely populated cities imply the concentration (from the country) and distribution (within the city) of massive amounts of people and resources (EU, 2010).

In addition to the vast economic importance and consequences of such situation, urban and sub-urban mobility is a serious challenge also due to the circulation of large amounts of people and goods in a relatively small area. This poses hazards to life and health, especially for children, the elderly, and unfamiliar visitors, as well as to the environment.
Urban mobility, in fact, accounts for some 30% of energy consumption and 70% of transport pollution in Europe, and this problem is magnified by the increasing population concentration in large cities.

In such a scenario, the efficient management of traffic is a challenge that governments, industries and researchers are forced to face worldwide. Private travellers, commercial road users, and the public sector are continually searching for new and faster travel routes and methods.

In this context, one of the most important applications is the support of real-time, meant as the constant monitoring of traffic and road conditions, and the consequent possible update of the routes previously suggested. As a matter of fact, the best path in a given situation can vary when traffic conditions vary and updates should be notified to the user in real-time.

Nevertheless, up to now, no simple and marketable product has been proposed for monitoring traffic and providing real-time information to road users.

Roads efficiency can be substantially improved by the deployment of Intelligent Transportation Systems (ITS), which exploit Information and Communications Technologies (ICT) in order to provide traffic safety and efficiency.

ICT can be considered as the foundation for carrying out *smart navigation*, meant as the paradigm where mobile entities (vehicles and pedestrians) move wisely through a given environment, exploiting reliable and timely information about traffic conditions.

New solutions are gaining interest: several projects and consortia (ERTICO, 2010; Car2Car, 2010) and relevant standardization bodies are working on the development of new standards, so as to define common ITS communication architectures to let vehicles, roadside units, and wireless infrastructures communi-

cate.

However, only the knowledge and appropriate processing of actual traffic conditions, as well as their forecasting, can make the difference in route planning applications. The problem, thus, is (at least) twofold: on the one hand, an efficient integrated architecture must be designed for the management of traffic and vehicular mobility; on the other hand, such architecture must rely on appropriate route planning algorithms.

As for the architecture, in this continuously evolving scenario, the Italian PEGASUS project (PEGA-SUS, 2010) represents one of the first initiatives proposing an infrastructure really able to attain smart navigation in the short-medium term, on the basis of actual traffic conditions.

The need of an efficient support for real time, though, focuses the attention on the second aspect mentioned above, i.e. the use of algorithms capable of adapting to the changing environment.

In fact, even though efficient solutions and traditional algorithms are still being applied in most commercial systems, the ever growing dimension of the problem suggests one should reconsider such solutions in the broader context of intelligent infrastructures and environments.

As a matter of fact, not only could such systems benefit from the use of ad-hoc architectures of Ambient Intelligence, but, in particular, they could be greatly enhanced by the use of advanced algorithms from Artificial Intelligence. Recent studies indicate that the use of genetic algorithms seems promising (Cook et al., 2009b; Cook et al., 2009a; ElHillali et al., 2007; Ni, 2007; Zheng et al., 2004; Santos et al., 2010).

In Section 2, the PEGASUS scenario and main strategies are presented. Section 3 describes the system architecture. In Section 4, some drawbacks of the proposed approach and currently adopted routing algorithms are detailed and a variant of the core architecture is sketched. Such variant is based on virus-evolutionary genetic algorithms.

2 SMART NAVIGATION SCENARIO AND STRATEGIES

In Fig.1 the smart navigation scenario considered is shown: vehicles are equipped with on-board units (OBUs), which periodically transmit their speed and position (known through the GPS integrated on board) to a Control Center. Such data are transferred through the General Packet Radio Service (GPRS) network.
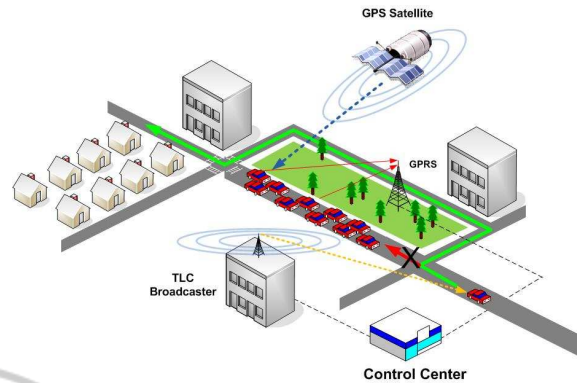

Figure 1: Smart navigation scenario.

The fleet equipped with OBUs is addressed as *floating car data (FCD)*.

In March 2010, the Italian FCD to which the PEGA-SUS project refers, reached over 1.000.000 equipped vehicles (OctoTelematics, 2010); this number is to increase quickly (note that the number of public and private vehicles in Italy was 34 million in 2003 (ecoage, 2003), hence the FCD is a not negligible percentage of the overall private vehicles number).

All such data, once processed, can be exploited for the real-time dynamic navigation of vehicles or forwarded to public or private institutions for traffic management.

The best route has to be calculated and re-evaluated as soon as possible through a convenient strategy; the three approaches currently investigated are the following:

1. **Centralized Strategy:** evaluation of the best route at the Control Center;

2. **Distributed Strategy:** on-board evaluation of the best route;

3. **Hybrid** evaluation of the best route.

All the above mentioned strategies are based on the knowledge of roads conditions on the basis of the FCD information.

As far as the first strategy is concerned, all the data collected from vehicles are analysed by the Control Center. A user interested in a given trip asks the Control Center, which calculates the best route on the basis of current traffic conditions and transmits it to the user's on-board navigator.

In this case, the navigator is a "dummy" entity, simply receiving the path.

As for the distributed strategy, the Control Center periodically transmits the up-to-date road conditions to all the users.

In this case, thus, the best route calculation is demanded to the on-board navigator, which becomes a

complex and intelligent device.

The hybrid strategy represents a compromise between the aforementioned solutions. When a user asks for a route, the Control Center returns updated traffic conditions so that the on-board navigator can evaluate the optimum path.

3 THE PROPOSED ARCHITECTURE

In order to implement the above strategies, it is necessary to design and develop a modular and flexible architecture. The proposed one (Fig.2) contains a Control Center core which manages and processes all the data collected by the FCD, so as to provide a variety of infomobility services.

The communication between vehicles (both FCD and users) and the Control Center is carried out by two layers: (1) a two-way telecommunication **access network** and (2) a **user-system interface**, the latter performing operations of format adaptation and content scalability.
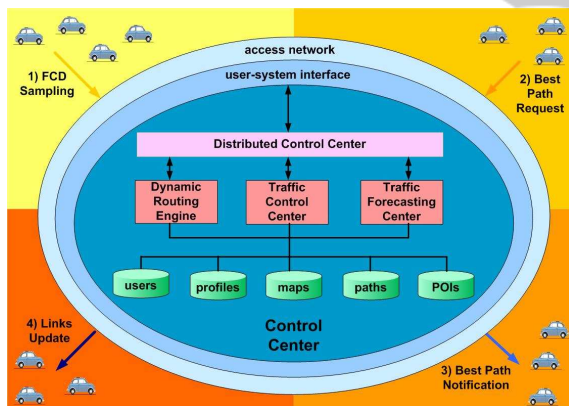

Figure 2: Main Architecture.

The components of the Control Center are detailed separately in the following:

- **Distributed Control Center (DCC):** it is the controller of the whole architecture; when receiving information (FCD speed and position samples, best path request, etc.), the DCC forwards it to the modules in charge of its processing. In the opposite way, the DCC makes the outgoing data (traffic updates, best path response, etc.) available to the user-system interface and the telecommunication access network.

- **Dynamic Routing Engine (DRE):** it is the routing engine, and is the module that will be re-

disigned taking genetic algorithms into consideration.

In the current implementation, the DRE determines the best route applying a Dijkstra-like algorithm to three kinds of information: (1) *static*, i.e. the travel time of each road segment in the absence of traffic; (2) *dynamic*, based on actual travel time data measured by the FCD; (3) *forecast*, i.e. travel time based on traffic forecasts.

All the static, dynamic and forecast information are stored in specific databases. The DRE can also handle Points Of Interest (POIs) along the route, finding the optimal path that allows to reach a set of POIs; this, for instance, can be very useful for touristic purposes.

- **Traffic Control Center (TCC):** it is the module which processes position and speed samples from vehicles and evaluates the real-time traffic conditions, in particular, the actual travel time needed to go through a particular road. The TCC also performs arithmetic, weighted and temporal average operations in order to estimate the real traffic conditions of all the segments of the road map.

- **Traffic Forecasting Centre (TFC):** it is the module that analyzes current and historical traffic information and their trend, forecasting the traffic evolution over time.

Also this module will be involved in the architecture revision based on genetic algorithms.

All the components described so far make use of databases storing all the information required for the processing phases: *users, profiles, maps, paths, POIs*.

The overall architecture in Fig.2 can be ideally divided into four quadrants, as indicated by the different colours, in order to highlight the four different kinds of interaction processes developed.

1. **The FCD Sampling.** Vehicles belonging to the FCD fleet are equipped with an OBU, so they send their position and speed to the Control Center through the telecommunication access network.

2. **Best Path Request.** On-board navigation devices, rather than planning routes using their own static local cartography, could require a real-time shortest path calculation to the Control Center. In this kind of interaction, only required for centralized or hybrid strategies, the on-board navigator sends a message to the Control Center, setting the current position and the required destination, beyond eventual POIs along the path. Such request is processed in Control Center, forwarded by the DCC to the DRE, in charge of calculating the best route.

3. **Best Path Notification.** This type of interaction is only required for the on-board strategy. The Control Center returns a route based on real-time traffic data, taking into account traffic jams, car crashes and actual travel times measured by the FCD. The response given by the DRE is based on both the data stored in the static Maps database and all the real-time updates stored in its dynamic portion, properly integrated by the traffic forecasts coming from the TFC. The route is returned to the on-board navigator through a message listing all the road intersections or milestones needed to reach the destination.

4. **Links Update.** This type of interaction is only meant for the on-board and hybrid strategies. Using the telecommunication network, it is possible to send information about updates of the travel times in an asynchronous way. Each on-board navigator is thus able to update the road segments conditions, achieving thus a sort of "distributed navigation intelligence".

By means of this real-time updated information, transmitted periodically through the telecommunication network, each on-board navigator can thus apply a routing algorithm which takes into account the actual traffic conditions, so as to avoid problematic situations.

4 AN EVOLUTION OF THE PROPOSED ARCHITECTURE BASED ON GENETIC ALGORITHMS

As described in previous sections, the best path in a given situation can vary when traffic conditions vary and updates should be notified to the user in real-time (Bonnifait et al., 2007; Chen et al., 2007; Jula et al., 2008; Najjar and Bonnifait, 2007).

If such a feature were enhanced through the use of appropriate algorithms from Artificial Intelligence, it would naturally become an integrant part of advanced navigators in intelligent environments (Cook et al., 2009b; Cook et al., 2009a; ElHillali et al., 2007; Ni, 2007; Zheng et al., 2004; Santos et al., 2010). For instance, the methodologies described so far could greatly benefit from the use of genetic algorithms instead of traditional search methods. In particular, on the basis of recent studies on dynamic environments, a variant of the proposed architecture is here discussed where virus-evolutionary genetic algorithms replace traditional methods in the Dynamic Routing Engine and in the Traffic Forecasting Centre.

In order to better explain this viewpoint, some considerations must be made.

4.1 Exact Routing Algorithms

The solution discussed hereto and all similar ones arise from classic problems of shortest path finding in the static case and try to extend them to real-time route planning, taking into consideration traffic analysis, forecasting and path updating.

In particular, the algorithm used so far in the Pegasus system is a classic variant of Dijkstra. In this kind of approach, a map is represented by a graph whose nodes are intersections of roads and whose arcs represent segment of routes. If no traffic conditions are considered, arcs are weighted by means of lengths between nodes. In the dynamic case considered, in order to represent traffic conditions, length is substituted by time-varying, actual travel times.

On the basis of data collected about road conditions, arcs are periodically assigned updated weights and routes may change consequently.

In context of static environments, shortest path problems are generally solved in this way, by means of exact algorithms such as Dijkstra. Many variants and different approaches were proposed in order to guarantee better performances, such as A^* and many others, and further variants were also proposed in order to face the real-time case, such as RTA^* and PHA^* (In-Cheol, 2006; Felner et al., 2004; Korf, 1990). The variants mentioned above make use of heuristic functions and, step by step, determine a suitable next move until a suboptimal solution is found.

Still, one of the main drawbacks of such approaches is that, even though adapted to the real-time case, these algorithms consider only one solution at a time and do not deal with the entire route until the end. In consequence, route evaluation is slow; furthermore, proposing the same alternative to many clients can give raise to new congestions.

4.2 The Genetic-based Approach

These considerations indicate that the parallel analysis of many solutions could improve the overall performance of the system. In particular, (Kanoh, 2007; Kumar et al., 2009; Yuecong et al., 2007) suggested that genetic algorithms could be applied to dynamic route planning.

With respect to traditional search algorithms, the genetic approach considers many and entire solutions at a time, so it acquires knowledge and improves the set of candidate solutions during the search process. The

efficiency of global search improves the limits of traditional algorithms.

Yet, genetic algorithms applied to dynamic route planning present a limit: although directed by the fitness function, the stress is on random search rather than directional, as it should be in order to solve local traffic problems.

4.3 The Virus-enhanced Variant

An alternative which optimizes the genetic approach and seems to overcome the above limits was proposed in (Kanoh, 2007) and enhances genetic algorithms through viral mutations. The basic idea is that, whereas in the static case *diversity* in the population is a key factor to reach convergence, in dynamic environments *evolvability* is also needed, meant as the ability of members to change to meet the new requirements of the dynamic environment. This feature can be guaranteed using viral mutations. As a matter of fact, whereas typical genetic algorithms may not be able to solve large-scale problems within a practical amount of time, viruses give a direction to the search, improving thus search rate, quality of solutions and speeding the whole process up.

In a general virus-enhanced genetic algorithm (VEGA), two kinds of population are considered: the traditional host population of candidate solutions and a virus population (more properly, a substring set). First, viruses infect the host population (horizontal propagation), then viruses are transmitted to offspring (vertical inheritance).

In more detail, a VEGA includes genetic operators and virus infection operators, namely *reverse transcription* and *transduction*. When reverse transcription is applied, a virus transcribes its content on the string of a host individual; in case of transduction, a virus transduces a substring from the host individual.

The virus-infection operators defined in this way are added to the usual selection, crossover and mutation ones.

To some extent, viruses can be regarded as local changes that can be used to enhance modifications in specific parts of the whole solution space. A part of a road is considered as a virus and a population of viruses is generated in addition to a population of routes. Crossover and infection together determine the near-optimal combination of viruses. When traffic congestion varies, a better route is determined in real-time using viruses and other routes in the population.

The results in (Kanoh, 2007), which simulates 28.000 cars in Northern Tokio, is that genetic algorithms improve the performance of exact algorithms
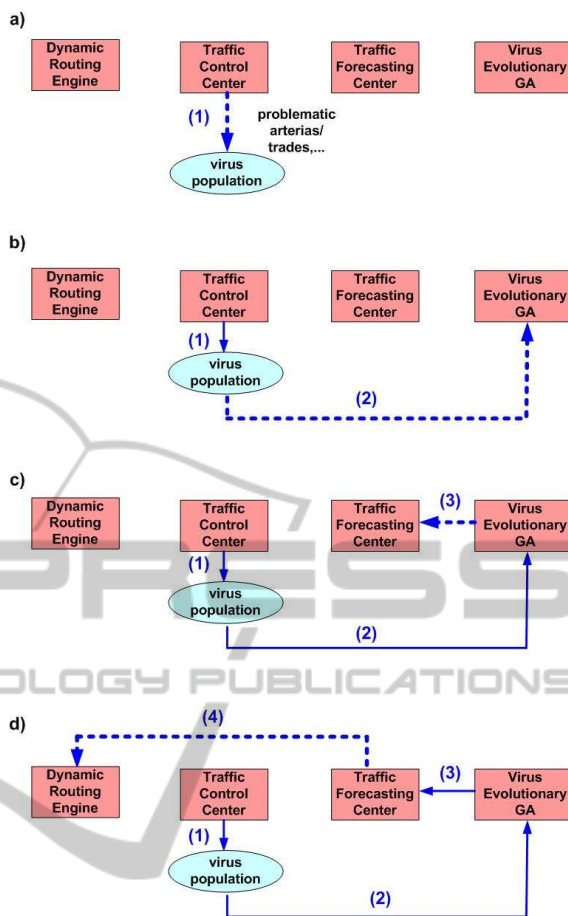

Figure 3: Virus-based variant of the Routing Engine and Forecasting Center.

in both the static and dynamic case and, if further mutations are applied, based on viral infections, the dynamic case can be solved even more quickly.

In dynamic route planning environments, forecasting models are the premise for developing urban Intelligent Transportation Systems. In (Yuecong et al., 2007), a proposal can be found which applies genetic algorithms to traditional forecasting models.

Our proposal is that virus-enhanced genetic algorithms could be applied to the PEGASUS system in order to improve its overall performance and, in more detail, to use viruses to drive the search of better solutions directly where traffic jams and problematic situations are detected.

Fig. 3 shows how the core of the proposed architecture can be modified. First, on the basis of data traffic analysis made by the Traffic Control Center, suitable viral populations could be defined representing the most problematic trades (Fig. 3a). This population could be used to define the viral population of a Virus Evolutionary Genetic Algorithm (Fig. 3b), so

as to direct genetic operations in such areas. This algorithm could be directly applied to feed the Traffic Forecasting Center (Fig. 3c). The traffic flow determined in this way could be directly used by the Dynamic Routing Engine (Fig. 3d).

5 CONCLUSIONS

In this paper an architecture was described for the constant monitoring of road conditions and the consequent real-time update of routes affected by problematic traffic conditions.

The system relies on a Dijkstra-like algorithm and, since this approach is not suitable to handle dynamic large-scale problems, a first bibliographic research was carried out in order to compare different solutions to the search of optimal routes in the real-time case. Some authors indicate that good performances can be achieved using virus-evolutionary genetic algorithms, and a variant of the proposed architecture was consequently sketched.
Future work will be devoted to the refinement of the considered approach and to suitable simulations.

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