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Amulti-Agent Architecture for a Co-Modal Transport System

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Abstract: *Improving the co-modal transport and introducing systems for traveler information is becoming more and more urgent in our society in order to guarantee a high level of mobility in the long term. The goal of this research is to develop a distributed co-modal transport system that takes into account all possible means of transport including carpooling, vehicles on service and public transport and satisfies traveler's queries, constraints and preferences. The main contribution of this work is to propose an innovative multi-agent approach to solve problems in wide co-modal transport networks. First, we propose a multi-agent architecture to model the system. Then we use a method to construct a co-modal transport network representation by categorizing the transport services and using transfer links and a distributed algorithm in order to resolve the shortest paths problem. We test our model and algorithms based on a case study in Lille, France. The experiments results on theoretical graphs as well as on real transport networks are very promising.*

Keywords: *Co-modal transport, Co-modal Transfer Point, Distributed Shortest paths, Multi-agent Systems, Optimization.*

I. INTRODUCTION

Nowadays, the daily mobility of passenger has become a very important problem in our society. Also, the spatial dispersion of habitat and activities contribute to a considerable growth of the use of cars and traffic. Private vehicle remains the most popular and the preferred mean of transport thanks to its flexibility, efficiency, speed and comfort. In fact, statistics show that in 2008, the private car is the dominant mean of transport by 60% of urban travel while the others means like walking, public transport, bicycle and motorcycle represent recursively 27%, 9%, 2% and 2% [1], [2]. Traffic congestion acts directly on the economy, causes an increase of pollution, and reduces citizens' comfort. According to the "Agency for the environment of the European union", transport represents 23,8% of the total greenhouse gases emissions and 27.9% of total CO2 emissions [3].

Different policy options exist in order to deal with thetransport problem such as the resort to other solutions that complete the classic public transport like transport on demand, vehicle-sharing services (carpooling, car sharing) and cycling (free use bicycles for example).These solutions are complementary and respond to each specific need. In fact, combining the different private and public transport means might be more effective.

The idea of combining different transport modes is supported by the European commission of transport since 2006. The new notion of co-modality was introducedin the transport policy as the optimum combination of modes of transport chain [4]. With this approach, we don't seek anymore to oppose transport modes one to another but rather to find an optimum solution exploiting the domains of relevance of the various transport modes and their combinations.

The co-modal approach, in the same way as its predecessor, the "multimodal" approach, consists on developing infrastructures and taking measures and actions that will ensure optimum combination of individual transport modes i.e. enabling them to be combined effectively in terms of economic efficiency (i.e. providing the most cost effective combination), environmental efficiency (the least polluting combination), service efficiency (level of service provided), financial efficiency (best use of society's resources), etc[5]. It refers to the "use of different modes on their own or in combination".

In the research community, many projects were devoted to transport systems that recommend travelers a combination of transport means door to door journeys [6], [7], [8], [9].

Knowing that our target is to satisfy transport user demands, respecting user's preferences, we propose in this paper a distributed vehicle-sharing services system. This system combines all possible means of transport including private cars, vehicles on service and public transport, which remains a remarkable solution for the environment and the streets obstruction. The adopted method combines the optimization methods and the multi-agent system. It is a distributedco-modal approach based on a multi-agent system. The resolution of the co-modal transport problem is divided into two parts. First, a co-modal approach is applied to a transfer graph in order to compute the shortest paths in terms of time andthen an evolutionary optimization approach in terms of total cost, time and gas emission volume is adopted, taking into account passenger constraints and preferences. In this paper, only the first part of optimization is considered.

So, some related works and researches will be introduced in section 2 following by the problem description in section 3. Section 4 describes the multi-agent system organization for the co-modal system. In our multi-agent system, the notion of roles is applied and especially for one special agent. The different roles of this agent are described in section 5. Then, the distributed co-modal graphs are described in section 6 with some definitions of co-modal graphs and a special distributed graph: the transfer graph. We present then in the next section our approach and our algorithms in order to resolve the transfer graph and applied by the "Super Agent". We end the paper with a simulation example and a conclusion and some prospects in respectively section 8 and 9.

II. RELATED WORKS

Recently, the transport sector is under pressure across the world. Overloaded roads lead to both economical and ecological problems. This engendered the rise of Intelligent Transportation Systems (ITS). An ITS is a transportation system that aims to alleviate and minimize the transport congestion problems using different information and communication technologies (geo-localization, GPS, mobile technologies…)[10]. As an integral important part of intelligent transport system, Advanced Travelers Information Systems (ATIS) provides travelers all the pre-trip and real-time information through a dynamic transportation network. An ATIS must have the ability to model not only mono-model itineraries but also co-modal ones including both private and public transport services. Multimodal and co-modal transport models and optimization algorithms attract many researchers' interests. In France, [11] and [12] proposed systems that optimize in real time user itineraries in term of cost and travelling time for the multimodal common transport and [13] enriched the system by adding co-modal transport in case of perturbation. [14] proposed a transfer graph approach for multimodal transport problems. An hybrid approach using the Dijkstra's algorithm and Ant colony optimization was applied. In other works, [15] proposed a parallel algorithm for solving the Time Dependent Multimodal Transport Problem (TDMTP) in very large transport networks. [16] proposed a public transportation domain ontology that considers different concepts related to the best and more relevant planning for the passenger.In the United States, different multimodal trip planner for mobile devices were developed [17], [18],[19]. Also, a distributed solution integrating different trip planning systems into a distributed system was presented by [20]. In Germany, many researchers were interested by extending networks from single mode to multimodal like [21] and [22]. Mentzcompany [23] developed a personal travel companion. This system focuses on personalized multimodal journey planning, mobile multimodal trip management and smart-phone-based pedestrian orientation and guidance in complex public transport transfer buildings. We can cite another application, the RUHRPILOT. It is a multimodal trip planner for the "Rhur" area in Germany. Public transport schedules from 15 cities are combined with each other to cover the whole geographical area and also a dynamic car routing is offered [24]. [25] proposed a switch point approach to model multimodal transport networks. In the Netherlands, [26], developed a personal intelligent travel assistant for public transport. [27] proposed a multimodal transport network model for advanced traveler information systems that simultaneously consider private and public transport modes. A co-modal travel planner, combining both private and public modes of transport was introduced in Stockholm, Sweden [28]. In other countries, Zografos [29] described an algorithm for itinerary planning based on dynamic programming. Su [30] developed a multimodal trip planning system for intercity transportation in Taiwan.Also, in India a multimodal transport system for Hyderabad city was proposed by [31].

All the researches described above deal with traveler information systems in multimodal networks. We can remark that there is a small difference between the different descriptions of multimodal networks. For some researches, multimodal transport concerns the different modes of public transport (bus, subway, train…). Others consider that multimodal transprt includes both of private (car, bike…) and public transport. The term of co-modality is not commonly used since it is a new notion. Based on all these researches, we propose a distributed co-modal transport system that satisfies the traveler's demands and plans their trips in real time. It respects the new notion of co-modality and combines all possible means and services of transport including private cars thanks to the carpooling service, vehicles on service (carsharing, bikes) and public transport. We model co-modal transport networks and categorize networks into different services.

III. PROBLEM DESCRIPTION

The main concern of our system is to combine all the existing transport services in order to satisfy the users by providing optimized co-modal itineraries and respecting their priorities criteria.

As shown in Fig.1, a transport user can use a medium of communication (e.g. laptop, PDA, smartphone) in order to express his demand and provide a departure and arrival points and the correspondent earlier and later schedules. In a short time interval, many transport users can formulate simultaneously a set of requests. So the system should find feasible decompositions in terms of independent sub-itineraries called Routes recognizing similarities. For a given Route, we can have several possibilities with different vehicles which are available to ensure this Route through the same time window. All these identified Routes constitute our co-modal graph and we have to recognize the different possibilities of RoutesCombinations to compose each itinerary demand. The problem is how to choose the most effective RouteCombination to a given user, taking into account his constraints and preferences in terms of total cost, total travelling time and total greenhouse gas volume for example.

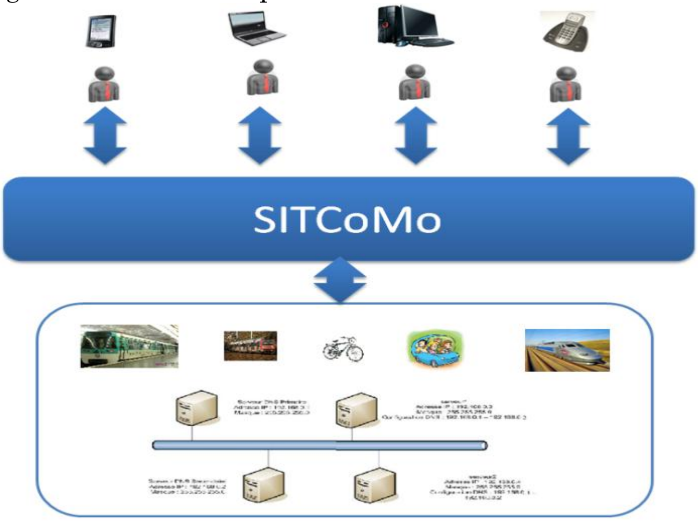


Figure 1 Global system description

At a time t, our problem is defined by:

- N requests formulated through a short interval of timeΔ_ε~milliseconds. $I_t$is the set of these requests. In fact, the system catches simultaneously all travellers queries expressed through Δ_ε.
- $I_k(d_k, a_k, W_k) \in I_t$ is an itinerary request formulated by a user k at a time t from a departure point $d_k$to an arrival point a_k through a time window $W_k = [td_k, ta_k]$; td_k and ta_k correspond respectively to the earliest (minimum departure time from d_k) and the latest (maximum arrival time to a_k) possible schedules with $t \le td_k < ta_k$;

- $R_g(d_g, a_g, W_g)$is a *Route* identified to respondto a part of the total itinerary requests $I_k \in I_t$.

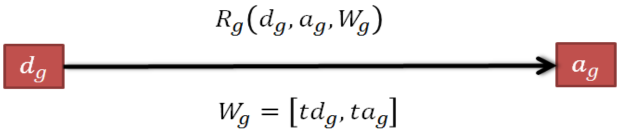


Figure 2 Route $\boldsymbol{R_g(d_g, a_g, W_g)}$

A junction or a succession of different routes$R_g(d_g, a_g, W_g)$ composes a possible solution for one request. $RC_{k,p}$is a possible *RouteCombination* identified to respond to the request $I_k(d_k, a_k, W_k) \in I_t$.

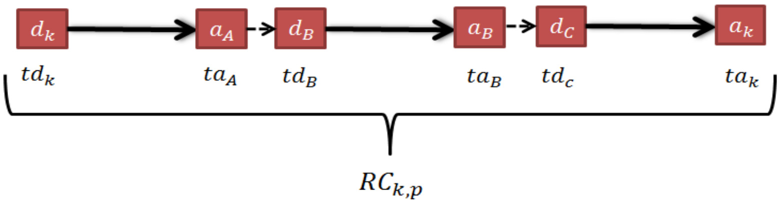


Figure 3 Route combination $\boldsymbol{RC_{k,p}}$

- For one *Route*$R_g(d_g, a_g, W_g)$, we need a mean of transport available to move from the departure point d_g to the arrival point a_g through a time window $W_g = [tg_d, tg_a]$ with tg_d and tg_a correspond respectively to the possible earliest departure time to leave d_g and the possible latest arrival time to attend a_g.
- $R_t$is the set of all identified *Routes* to response to I_t.
- $(RC)_k = \{RC_{k,p}, p \in [1..P]\}$is the set of all possible Routecombinations identified to answer to the request $I_k(d_k, a_k, W_k) \in I_t$. P is the total number of these RouteCombinations.
- Let CR be the total number of the optimization criteria. We focus on three criteria ($CR = 3$): Total Cost, Total Travel time and Gas emission. When a user k formulates his itinerary request I_k, he has also to mention his priorities criteria.
- A*Route*$R_g(d_g, a_g, W_g)$ can be ensured by more than one vehicle. We note $V_h^{R_g}$ the vehicle V_h that ensures the*Route*$R_g(d_g, a_g, W_g)$ at the time t with $1 \leq h \leq H$, H is the total number of the vehicles $V_h^{R_g}$ available for the *Route*$R_{g,t}$. Each vehicle$V_h^{R_g}$ $(1 \leq h \leq H)$ is characterized by a value for each criterion Cr_i (dynamic character obtained by $V_h^{R_g}.Cr_i$).
- A vehicle $V_h^{R_g}$ $(1 \leq h \leq H)$has a departure time and a single value per criterion. We distinguish in this paper three types of vehicles : private vehicles used for the carpooling services, free use vehicles (e.g. Free use bicycles “VLIB”, free use cars “AUTOLIB”) and the multimodal transport vehicles (Bus, Metro…)

According to the problem described above, we pass from the multimodal network to the co-modal network. In fact, our system is a co-modal system that combines different means of transport services like the public transport service, carpooling and free use vehicle services. In order to resolve the co-modal transport problem, we choose to combine optimization algorithms with the multi-agent systems and apply a distributed co-modal approach based on multi-agent system and distributed co-modal graphs.

IV. Multi-Agent SYSTEM ARCHITECTURE For A Distributed Co-Modal Transport System

The agent computing paradigm is one of the powerful technologies for the development of distributed complex systems [32]. The agent technology has found a growing success in different areas thanks to the inherent distribution which allows for a natural decomposition of the system into multiple agents. These agents interact with each other to achieve a desired global goal [33]. Since transport systems are usually geographically distributed in dynamic changes environments, the transport domain is well suited for an agent-based approach [34]. Each agent is composed of states, different types of knowledge (environmental, social and personal), messages, behavior rules and a perception function. Thanks to the behavior rule, the agent can modify its state according to current states, knowledge and received messages in order to reach the collective goal [35].A set of rules and behaviors can define a role. An agent can though have different roles. From a role to another, the agent changes its capabilities and behaviors [36].

According to the problem described above, we propose a multi-agent system based on the coordination of several kinds of software. The architecture of the proposed multi-agent system is described below (Fig.4).

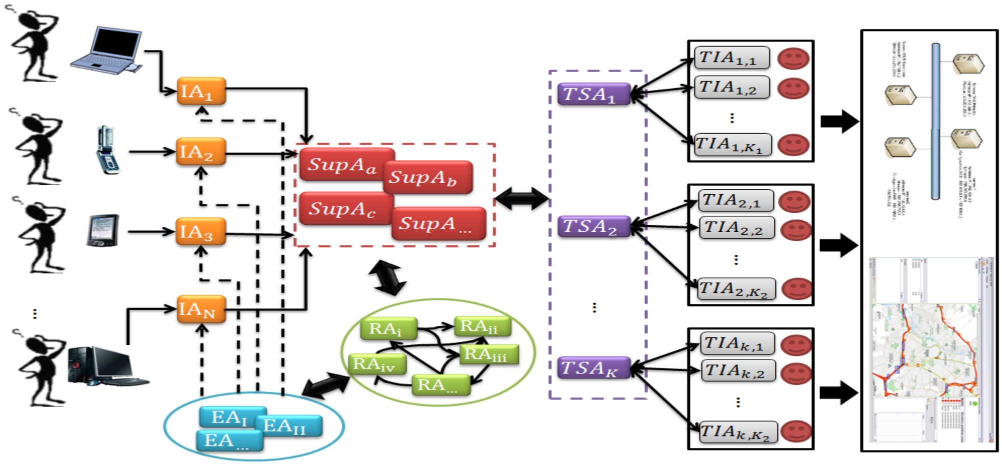


Figure 4 Multi-Agent system architecture

In our system, we consider K transport services and K_i transport operators associated to the transport service$i$ ($i \in [1..K]$. We associate an agent to each transport service and an agent to each transport operator. A *transport Service Agent* ($TSA_i, 1 \leq i \leq K$) is responsible for a set of Transport Information Agent ($TIA_{i,j}$, $1 \leq j \leq K_i$). Each $TIA_{i,j}$ is able to respond to an itinerary request $(x, y, W_{x,y})$ by a shortest path $RC^{*i,j}_{x,y}$ that allows to go from x to y on a transport network of the operator j associated to the service i.

For a global request $I_k(d_k, a_k, W_k) \in I_t$, an *Interface Agent* (*IA*) interacts with a system user allowing him to formulate his request choosing his preferences and constraints and displays at the end the correspondent results. When an *IA* handles a user request, it sends it to a *SuperAgent* (*SupA*). It is an agent with different important roles. Firstly, this agent asks the *TSAs* for a search domain and all the transport operators that will be involved in the itinerary research. We assume that the *SupA*has a global view of all the *TSAs* that define the environment. The *SupA* cooperates then with the set of *TIAs* identified by the *TSAs* and starts by constructing a co-modal graph. The *SupA* decomposes this complex graph into a special graph called "Transfer graph" and a co-modal approach is applied. After a first computing of the shortest paths in terms of time, the *SupA* generates all possible RouteCombinations from simultaneous itinerary requests thanks to the *Route Agents* (*RA*). All the roles and the tasks executed by the *SupA* are detailed in the next sections.

The *RA* represents a generated chromosome scheme called VeSAR for an identified useful $RouteR_g(d_g, a_g, W_g)$in order to assign concerned users to possible vehicles.As soon as each *RA* assigns persons to vehicles, updating the number of passengers in carpooling vehicles and the number of available vehicles of free use vehicle service, it computes all values criteria of each vehicle for each assignment. A multi-agent coalition [37], [38] is then created regrouping all *RAs* corresponding to a possibl0e Routecombination for a given itinerary. Therefore, we have as many coalitions as combinations knowing that an *RA* can belong to many different coalitions according to combinations overlapping. Coalitions appear and disappear dynamically according to requests receptions and responses.

The chromosome scheme generation and the assignment were explained in previous works [39], [40]. Then, the generated data is transferred to an *Evaluator Agent* (*EA*) who decides of the best Combinations thanks to its interaction with the autonomous *RAs*. The EA computes the best Combination Route for each itinerary demand and sends it to the correspondent *IA*.

V. DIFFERENT ROLES OF THE SUPER AGENT

We focus in this paper on the distributed co-modal approach applied by the *SupA*. As explained in the previous section, we consider that each agent can have one or more different roles. In fact, the *Sup A* have three roles.

The goal of the first role is to define the domain search. The *SupA* executes two tasks. The first task is to locate all the departure and arrival points of all the requests and identify though the correspondent TSAs. The second task is to send the requests to the identified TSAs. Thanks to the Domain Search Selection Algorithm (DSSA) [41], all the TSAs will provide to the *SupA*the list of TIAs that are interested to respond to the requests. Then, the *SupA* begins its second roleof the identification of the different Routes and the determination of the first shortest paths. For the first goal, it sends the requests to the identified TIAs. It receives then all the possible *Routes* that could be solutions or part of the solutions to the requests.The second goal of the second role is to determine the preliminary optimizedRoutes that will construct later the solutions to the requests. The *SupA* constructs a co-modal graph with the different Routes. This graph may be very complex and hard to resolve. So we adopt a new approach based on a special form of graph that we called transfer graph. The *SupA* executes then a Distributed Shortest Path Algorithm (DSRA) in order to solve the transfer graph and to compute the shortest paths in terms of travel time. This approach is explained in the next sections. Until this step, no person is affected to any Route or vehicle. Also, we want to provide to the users a set of optimized itineraries in terms of three criteria: the travel time, the gas emission and the travel cost. In order to complete the approach, the *SupA* have to switch to its third roleand generate the RAs. In fact, after the application of the DSRA, each Routeis represented by a RA which is a special chromosome VeSAR.The chromosome VeSAR is a matrix where rows correspond to Persons (transport users) and columns correspond to different identified vehicles $V_h^{R_g}$ where$1 \leq h \leq H$which are available to transport these persons through the same time window W_g to serve the route $R_g\left(d_g, a_g, W_g\right)$.

Each element of the matrix is an assignment of the person P_{cp} to the vehicle V_{ch} as follows:

$$CH[p,h]=\begin{cases} \mathbf{1} : \text{if } P_p \text{ is assigned to } V_h \\ \mathbf{*} : \text{if } P_p \text{ can be assigned to } V_h \\ \mathbf{x} : \text{if } P_p \text{ can not be assigned to } V_h \end{cases}$$

A person cannot be assigned more than one time to a several vehicles and cannot be assigned to a vehicle if his preferences or constraints exile this assignment. For example, when a person can't drive an AUTOLIB, we take into account this constraint in the assignment process: the assignment of this person to this AUTOLIB is x (i.e.non-assignment). For example, we have three simultaneous itineraries requests at t=9:15 whose correspondent possible RoutesCombinations are generated. We suppose here that the route R_2(x, y, W_2) belongs to at least a possible RouteCombinationof three users with W_2=[9h30,10h45]. For this identified Route (sub-itinerary), we have a VeSAR instance where rows correspond to all users concerned by this Route through the same time window and columns to all transport vehicles available to go from departure point to arrival point of this route also through this same time window with:

User 1 (P_6) : does not like carpooling,
User 2 (P_3): does not like public transport,
User 3 (P_{25}): can't drive a Vlib.

The life cycle of a VeSAR starts with (pre-assignment):

R(x, y, [9h30,10h45])	$V_{13}(2,3)$	Vlib(12)	$V_4(1,4)$	Bus_9	Autolib(8)
P_6	x	*	X	*	*
P_3	*	*	*	x	*
P_{25}	*	x	*	*	*

A possible assignment can be:

R(x, y, [9h30,10h45])	V_{13}(0,3)	Vlib(12)	V_4(1,4)	Bus_9	Autolib(8)
P_6	x	*	x	1	*
P_3	1	*	*	x	*
P_{25}	1	x	*	*	*

While, the system continue to identify the best Route Combination thanks to the application of genetic operators and the RAs coalition, the *SupA* keeps in mind all these Routes. It will be help full for the coalition of RAs to consult the *SupA* and its knowledge since it can optimize the number of messages and negotiation between the different RAs. In this paper, we don't explain in detail the RAs coalition and the Negotiation protocol but we focus on the distributed co-modal approach used in order to compute the shortest paths in the co-modal graph. So the second role of the *SupA* is detailed in the next sections.

VI. DISTRIBUTED CO-MODAL GRAPHS

Co-modal Graph

Let $G(N, E, M)$ denotes a co-modal graph or co-modal network, where $N = \{n_1, \dots, n_J\}$ is a set of vertices and J is the total number of vertices, $E = \{e_1, \dots, e_L\}$ is a set of edges, L is the total number of edges and $M = \{m_1, \dots, m_K\}$ is a set of transport services (e.g. Public transport, Carsharing or Carpooling), K is the total number of transport services . An edge $e_l \in E$ with $l \in \{1..L\}$can be identified by $(n_p, n_q)_{m_r}$, where $n_p, n_q \in N$ and $m_r \in M$ with $p, q \in \{1 \dots J\}$ and $r \in \{1..K\}$. The e_l expresses that it is possible to go from vertex n_p to n_q by using transport service m_r. A value $D_{e_l} = D(n_p, n_q)_{m_r}$ is associated to each edge e_l, indicating the weight and the cost of including the edge in the solution.

Definition 1: A graph $G(N, E, M)$ is said to be comodal if there is at least two transport services $m_i,\ m_j \in M$ where $(n_p, n_q)_{m_i}, (n_{p'}, n_{q'})_{m_j} \in E, m_i \neq m_j$ with $i, j \in \{1..K\}$ and $n_p, n_{p'}, n_q, n_{q'} \in N, p, p', q, q' \in \{1..J\}$. It is possible to have $n_q = n_{p'}$ and also $n_p = n_{p'}$ and $n_q = n_{q'}$ with $, p, p', q, q' \in \{1..J\}$. If there is only one transport service in the graph, the graph is said to be uni-service.
Given a co-modal graph $G(N, E, M)$, a path or a routecombination$RC_{n_1, n_l} = (n_1 \rightarrow n_l)$ is a sequence of edges between a pair of vertices n_1 and n_l with $((n_1, n_2)_{m_i}, \dots ,\ (n_{l-1}, n_l)_{m_k}$ where $\forall\, l \in \{1, \dots, J\},\ n_j \in N$, $\left(n_j, n_{j+1}\right)_{m_i} \in E, m_i \in M$ and $i \in \{1..K\}$.
So, a path $RC_{n_1, n_l} = (e_1, e_2, \dots , e_l)$ is said to be comodal if $\exists\, e_p, e_q \in E,\ e_p = (n_p, n_{p'})_{m_i},\ e_q = (n_q, n_{q'})_{m_j},\ m_i \neq m_j\ ,\ i \neq j$ and $i, j \in \{1..L\}$. If there is only one service involved in the routecombination, the routecombinationis said to be uni-service.

Definition 2: Given a routecombination$RC_{n_i, n_j} = (n_i \rightarrow n_j)$ or an edge $\left(n_i, n_j\right)_{m_k}, i, j \in \{1..L\}$and $\in \{1..K\}$, a time window is defined as a time interval $[t_{n_i}, t_{n_j}]$ where t_{n_i} denotes the departure time from vertex n_i and t_{n_j} the arrival time at n_j .

Definition 3: Since each edge represent a route assured by a transport service, the cost of edges is considered to be time-dependent. $\forall\, e_i \in E$we can have $D_{e_i}\left(t_j\right) \neq D_{e_i}(t_k)$. Our graph $G(N, E, M)$ becomes a dynamic comodal graph.

Transfer Graph

The authors of [Ayed et al. 2010] proposed a new approach based on transfer graph in order to solve a time-dependent multimodal transport problems while a transfer graph is composed of a set of uni-modal graphs. In our case, we adopt this approach with a transfer graph described by a set of uni-service networks and a set of arcs connecting them. It is defined by $G_T(C, TR)$ where $C = \{C_1, C_2, \dots, C_k\}$ is the set of uni-service networks called components and TR is the set of virtual edges which interconnect them. Each component $C_i = (N_i, E_i, M_i, PTC_i)$ is such that $\forall i, j \in \{1, \dots, K\},\ M_i \neq M_j$. Besides, $N = \cup_{i \in \{1,\dots,K\}} N_i,\ E = \cup_{i \in \{1,\dots,K\}} E_i,\ M = \cup_{i \in \{1,\dots,K\}} M_i$ and

$TR = \{(n_i, n_j)\ such\ as\ n_i \in C_i,\ n_j \in C_j, n_i = n_j\}$ where (n_i, n_j) represents a transfer from service transport m_i to another service transport m_j $(m_i, m_j \in M)$ at the *co-modal transfer point*n_i (or n_j). $n_i \in PTC_i,\ n_j \in PTC_j,\ i, j \in \{1..K\}$ are called *Co-modal Transfer Point* and symbolized the same location. So, we have$PTC_i = \{n_i \in C_j \setminus \exists n_j \in C_j\ with\ n_i = n_j,\ i, j \in \{1, \dots, K\}\}$.

Figure 5 illustrates an example of a transfer graph $G_T(C, TR)$ where $C = \{C_1, C_2, C_3\}$, C_1, C_2 and C_3 are three components connected by four transfers. Each component $C_i = (N_i, E_i, M_i, PTC_i)$ represents just one transport service. C_1represents the multimodal public transport service, C_2 represents the carpooling service and finally C_3 corresponds to the free use vehicles. The vertices a, c, b and d are *co-modal transfer points*. $a, c, b \in PTC_1$; $a, c, d \in PTC_2$and $b, d \in PTC_3$. $TR = \{(a, a), (b, b), (c, c), (d, d)\}$ Each component contains edge belonging to only one transport service. In this example, we can go from d_k to d_a using only the public transport $RC_{d_k, a_k} = (d_k, c)_{C_1}, (c, b)_{C_1}, (b, a_k)_{C_1}$. Another possibility is the Routecombination$RC_{d_k, a_k} = (d_k, d)_{C_2}, (d, e)_{C_3}, (e, a_k)_{C_3}$.

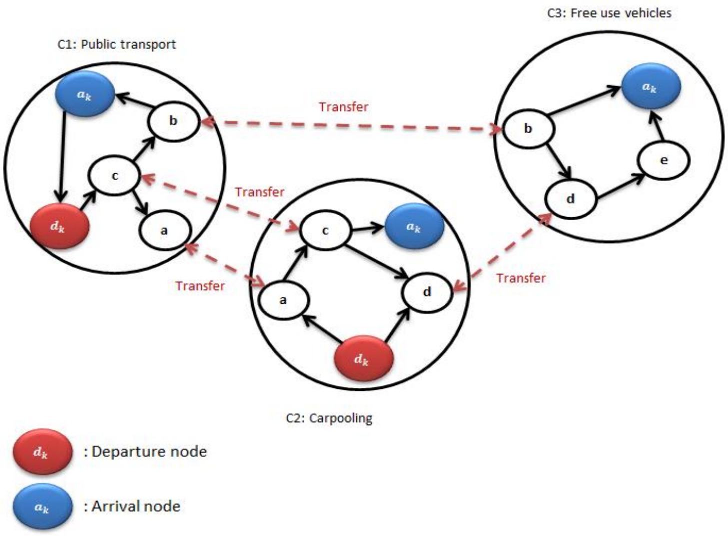


Figure 5 Example of transfer graph

The transfer graph represents and adapts to the distributed nature of real word transport information providers since it separates and keeps all transport modes in different uni-modal or uni-service networks.

So, each uni-modal network is independent and can be easily changed or updated without requiring any further recalculation [42], [43].

In this graph, we distinct two path's types: inter-components and intra-components. An inter-component path is considered as any path which connects two vertices x, $y \in N$, where at least two edges belong to two distinct components. However, an intra-component path with C_i is a path which connects two vertices x, $y \in N_i$ whose edges belong to only one component C_i. It is possible to have several routecombinations$RC^i_{x,y}$ which connect x and y in the componentC_i.

An intra-component can be one of the following categories:

- $RC^{*i}_{d_k, a_k}$is the shortest path which starts at source vertex d_k and ends at target vertex a_k within C_i.
- $RC^{*i}_{d_k, PTC_i}$is the set of shortest paths which start at source vertex d_k and end at a *Co-modal Transfer Point*PTC_i within C_i.
- $RC^{*i}_{PTC_i, PTC_j}$is the set of shortest paths which start at any Co-modal Transfer Point PTC_i and end at PTC_j within C_i.
- $RC^{*i}_{PTC_i, a_k}$is the set of shortest paths which start at any *Co-modal Transfer point* $PTC_i$and ends at target vertex a_k within $C_i \in C$.

The transfer graph $G_T = (C, TR)$ has to be solved by computing the different intra-component paths: $RC^{*i}_{d_k, a_k}, RC^{*i}_{d_k, PTC_i}, RC^{*i}_{PTC_i, PTC_j}, RC^{*i}_{PTC_i, a_k}$ for all components $C_i \in C$.

VII. SOLVING THE TRANSFER GRAPH

The *SupA* has to compute$RC^{*i}_{d_k,a_k}$, $RC^{*i}_{d_k,PTC_i}$, $RC^{*i}_{PTC_i,PTC_j}$, $RC^{*i}_{PTC_i,a_k}$for all the component $C_i \in C$ knowing that each C_i is represented by a $TSA_i, 1 \leq i \leq K$.

Each transport service $C_i$can be provided thanks to different operators. Each transport operator's information system (TOIS) is composed of a local database (DB) describing the different means of available transport that it manage (Metro, Bus, Tramway, with stations, timetables, carsharing available with stations and cars for carpooling…) and of an Itinerary Calculating Algorithm (ICA) which uses these local data to search optimal itineraries for users requests. To integrate the co-modal information from the different heterogeneous Transport Operator's Information Systems (TOIS), we proceed to applications integration. This integration tries to take advantage of the current multi-modal or mono-modal information systems and make the TOIS cooperate to calculate multi-modal route. For this reason, each service or each component $C_i = (N_i, E_i, M_i, PTC_i)$ is composed of different classes $C_{i,j}$ with $1 \leq j \leq K_i$, K_i is the total number of operators related to the component C_i.

Definition 4: A class in a distributed system refers to an autonomous subsystem. A class possesses its independent resources [44].

Each class $C_{i,j}$ is represented by a graph $G_{i,j}(N_{i,j}, E_{i,j})$ with $N_{i,j}$ and $E_{i,j}$ are respectively the set of vertices and edges related to the operator j of the service C_i. A vertex $n_{i,j}$ can be even a public transport's station, carsharing station or a departure or arrival point for a carpooling service. Also, an edge $e_{i,j}$ represents a *Route* using a transport mode managed by the operator $C_{i,j}$ with $1 \leq j \leq K_i$.

The graph $C_i = (N_i, E_i, M_i, PTC_i)$ is a supergraph that allows more than one edge between a pair of vertices. For example, if x and y are intersections of class $C_{i,l}$ and $C_{i,j}$ (i.e., $x \in N_{i,l}$, $x \in N_{i,j}$, $y \in N_{i,l}, y \in N_{i,j}$), $(x,y)_{i,l} \in E_{i,l}$and $(x,y)_{i,j} \in E_{i,j}$ with $1 \leq l, j \leq K_i$, then there are two edges $(x,y)_{i,l}$ and $(x,y)_{i,j}$ between vertices x and y in $C_i = (N_i, E_i, M_i, PTC_i)$ and each edge has a label $D((x,y)_{i,l})$ and $D((x,y)_{i,j})$, respectively.

Since the component represented by $C_i = (N_i, E_i, M_i, PTC_i)$ is a distributed system in which local classes maintain their own data and there is not an aggregate central database, $C_i = (N_i, E_i, M_i, PTC_i)$ is actually a virtual graph and not stored with the central computing server. The distributed shortest path problem is defined as a problem for the central computing server to find the shortest inter-class route between any two vertices in $C_i = (N_i, E_i, M_i, PTC_i)$ based on some local information provided by individual classes.

In the case of one operator, a shortest path can be resolved using the following non-distributed Dijkstra's Algorithm or another shortest path algorithm.

We consider a system represented by a graph $G(N,E)$ with vertex set N and edge set E. The graph may contain cycles. Also, the graph is assumed to be simple meaning that there is no edge from a vertex to itself (no loops) and between any two vertices there is at most one edge. There is a label, $D(n_1, n_2)$ for an edge (n_1, n_2) representing the length of the edge. Dijkstra's algorithm identifies the shortest route between two nodes, A (source) and B (destination), as follows.

The non-distributed Dijkstra Algorithm
Step 1: Let vertex set $R = \{A\}$; let $N = N \setminus \{A\}$.
Step 2: Iteratively **do until** node $B \in R$:
Identify a smallest label $D(j,k)$ such that
$j \in R$ and $k \in N$
Step 3 : Let $R = R \cup \{k\}$, $N = N \setminus \{k\}$

This algorithm is used to find the shortest intra-class route within a class that is a non-distributed subsystem. But for the central computing server of a distributed system, Dijkstra's algorithm does not guarantee the optimal result since the central computing server does not have complete data. So the adopted approach used by Wang and Kaempke [Wang et al 2004] will organize the local information about the intersections into a non-distributed graph. So the shortest route identified by Dijkstra's algorithm in this graph forms a trace of the shortest route in the original distributed system.

The approach begins by constructing a graph of intersections and the shortest route on it can be calculated by Dijkstra's algorithm and can be easily extended to the original distributed system $C_i = (N_i, E_i, M_i, PTC_i)$.

Let $RC^{*i,j}_{m,n}$ be the shortest route linking m to n in class $C_{i,j}$. Also, let $I(m,n) = \{j \setminus m,n \in C_{i,j}\}$ denote an index set of classes containing both vertices $n$and m. The following procedure formally defines the complete intersection graph G_{cint}.

Definition 5: Let G_{cint} denotes the intersection graph. A vertex $n \in G_{cint}$ if and only if n is an intersection vertex in (N_i, E_i, M_i, PTC_i). There is an edge between vertices m and n in G_{cint} if and only if n and m are clannish.

Each edge (n,m) has two labels, $RC^{*i}_{m,n}$and $rec(m,n)$, so that:

$RC^{*i}_{m,n} = min_{j \in I(m,n)}\left(RC^{*i,j}_{m,n}\right)andrec\,(m,n) = j$ if $RC^{*i}_{m,n} = RC^{*i,j}_{m,n}$ for some $j \in I(m,n)$.

Label $RC^{*i}_{m,n}$ on edge (m,n) in G_{cint} represents the shortest distance between vertices m and n by using the resource of only one class. $RC^{*i}_{m,n}$is the length of the shortest intra-class route between m and n. Label $rec\,(m,n)$ indicates the class associated with $RC^{*i}_{m,n}$.

To compute the shortest route between d_k anda_k in the time window W_k, we need to extend the complete intersection graph by including d_k anda_k in the graph. This graph is called the virtual extended intersection graph, denoted as $G_{veint}\,(d_k, a_k, W_k)$.

Definition 6: Let the virtual extended intersection graph $G_{veint}\,(d_k, a_k, W_k)$ contains all vertices of G_{cint} plus the departure and arrival vertices d_k anda_k (if they are not in G_{cint})

$G_{veint}\,(d_k, a_k, W_k)$contains all the edges of G_{cint} and the following: an edge between d_k and each of its clannish vertices and an edge between a_k and each of its clannish vertices.

The distributed Shortest Route Algorithm using all the definitions described below, is described as following.

Distributed Shortest Route Algorithm (DSRA)
Step 1: Construct the complete intersection graph G_{cint}
Step 2: Construct the extended virtual complete intersection graph $G_{veint}\,(d_k, a_k, W_k)$.
Step 3: Compute the shortest route$RC^*_{d_k,a_k} = (d_k = n_0, n_1, \dots, n_n = a_k)$ using a Shortest Route Algorithm (SRA).
Step 4: For each pair of vertices on the shortest route$RC^*_{d_k,a_k} = (d_k = n_0, n_1, \dots, n_n = a_k)$call relative class to the edge (n_k, n_{k+1}) to fill in the details of the intra-class route associated.

We consider that:

$\varphi_{d_k j}\,(td_k)$denotes the earliest arrival time to the vertex j leaving from the depart vertex d_k at the time td_k.

$pred_{td_k}(j)$defines the predecessor vertex j at td_k.

The algorithm that computes the shortest route$RC^*_{d_k,a_k}$ is described as following:

Shortest Route Algorithm (SRA)
1. Initialization $\varphi_{d_k d_k}(td_k) = td_k$ $\varphi_{d_k l}(td_k) = \infty, \quad pred_{td_k}(l) = \infty\; et rec(l) = \infty \quad , \quad \forall l \in N_i - \{d_k\}$ $pred_{td_k}(d_k) = d_k$ and$N_{current} = \{d_k\}$
2. Node Selection Let the node l with $min_{j \in N_{current}}\,(\varphi_{d_k j}\,(td_k))$
3. Exploration of possible successors $\forall\, j \in N^+(l) do$

$If((\varphi_{d_k j}(td_k) > \varphi_{ij}(\varphi_{d_k l}(td_k))) \; and (\varphi_{d_k j}(td_k) < ta_k))$ Then

$\varphi_{d_k j}(td_k) = \varphi_{lj}(\varphi_{d_k l}(td_k))$

$pred_{td_k}(j) = l$

rec (j) = Class Index

If $j \notin N_{current}$ then $N_{current} = \{j\} \cup N_{current}$

4. If $N_{current} = \emptyset$ then end of the algorithm else go to the step 2.

After the computing of each shortest paths we obtain a Shortest Path Transfer graph defined as following:

Definition 7: Given a transfer graph$G_T(t) = (C, TR)$, we define a Shortest Path Transfer graph as $G_F = (N_f, E_f)$, where $N_f = \cup_{C_i \in C} PTC_i \cup \{d_k, a_k\}$ and $E_f = \cup RC^{*i}_{d_k, a_k} \cup RC^{*i}_{d_k, PTC_i} \cup RC^{*i}_{PTC_i, PTC_j} \cup RC^{*i}_{PTC_i, a_k}, \forall C_i \in C$

VIII. SIMULATIONS

Our application is the result of a significant and sustained work by our research team in the French High School EcoleCentrale (LAGIS – EC-Lille) to implement a distributed co-modal transport system. In order to explain in detail and evaluate the solution proposed in this paper and validate the distributed co-modal approach for the vehicle sharing services system we applied the methodology proposed on two examples for transport requests.

We are developing our system, with JADE platform (Java Agent Development platform). JADE is a middleware which permits a flexible implementation of multi-agents systems; it offers an efficient transport of ACL (Agent Communication Language) messages for agents communication which complies with FIPA specifications.

We chose a part from the transport network in the region of Lille (Fig.6) and we collected data from the different existing transport services.

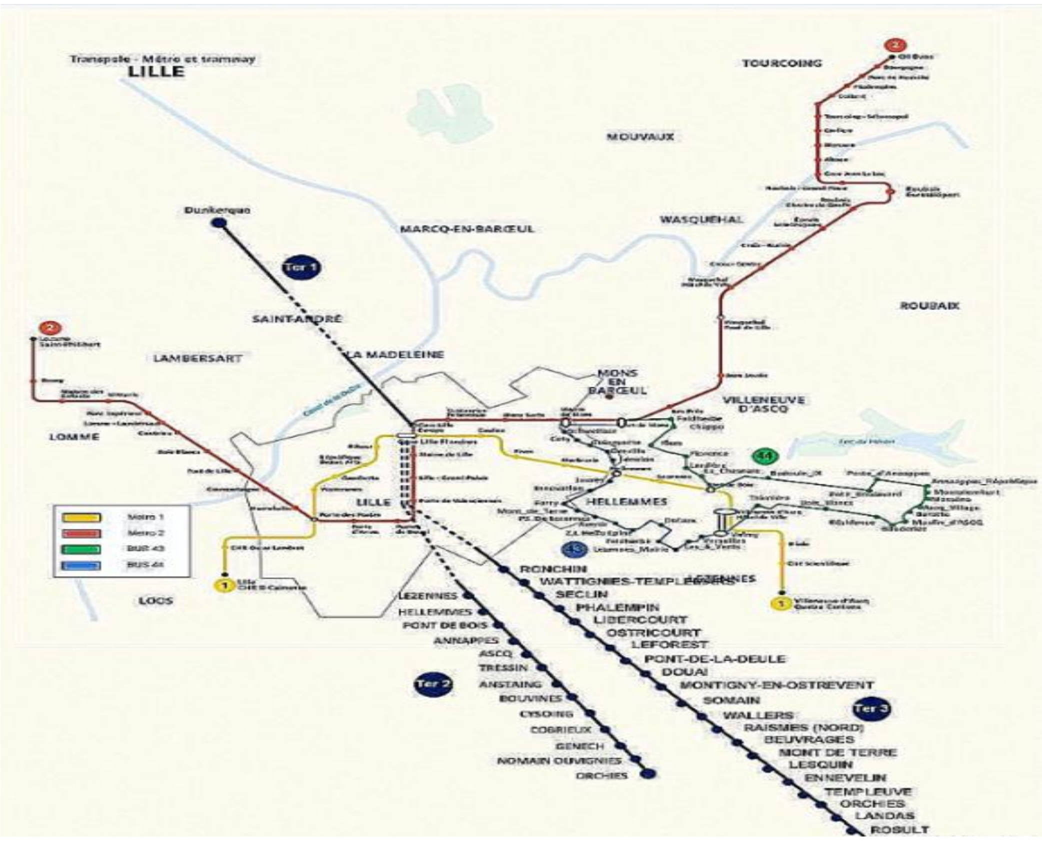


Figure 6 Transport network for simulations

The data include three transport services which are public transport, carpooling and vehicles on service. For the public transport service, we collected data from three operators: Transpole, SNCF and BCDLigne. The carpooling service is assured by one operator. We also have one operator Vlille for bikes' service and Lilas for carsharing service.

In order to illustrate our approach, we propose two examples of simulation. For the first example, we consider just one request in order to explain the co-modal approach:
We consider one request I_1 at t= 7:45 am going from Dunkerque to Lezennes in the window time [8, 9:15]. The user has no preference in terms of transport modes.

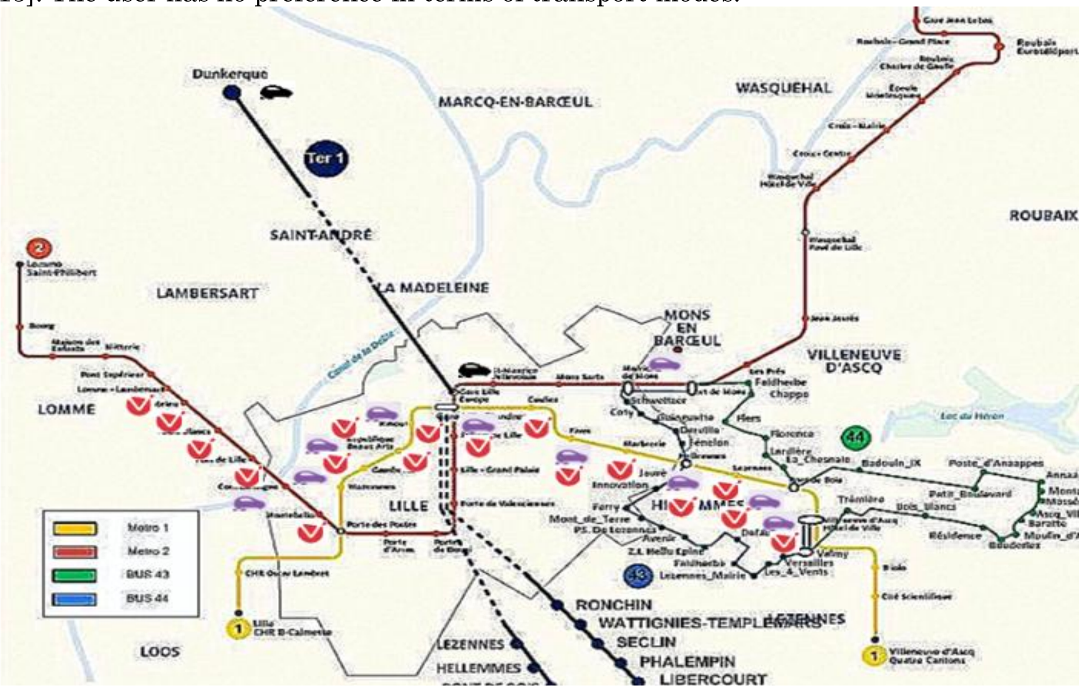


Figure 7 Transport network fot the first example

For the second example,we consider six itinerary requests at t=7 am:

- I_1(Dunkerque,Villeneuve d'Ascq Hotel de Ville,[7:30,9h30]). Transport service preferences: Public transport and carpooling. Criteria priority: Cost, time, Greenhouse gases emission;
- I_2(CHRB Calmette,Orchies,[7:20,10:30]). Transport service preferences: Public Transport and carsharing. Criteria priority: Time, Greenhouse gases emission, cost
- I_3(Dunkerque,CHDron,[7:30,9:30]) : Transport service preferences: Public transport and carpooling. Criteria priority: Cost, time, Greenhouse gases emission;
- I_4(Cormontaigne, Ascq_Village,[8:45,10]) : Transport service preferences: All the proposed services. Criteria priority: time, cost, greenhouse gases emission;
- I_5(Boulogne Ville, Port de Douai,[6,9:15]) : Transport service preferences: Public transport. Criteria priority: time, cost, greenhouse gases emission;
- I_6(Lezennes, C.H.R Oscar Lambret,[7,9]) : Transport service preferences: Public transport, carpooling. Criteria priority: greenhouse gases emission, time, cost;

Identification of the TIAs

The IAs receive these itinerary requests and send it to the *SupA*. This agent locates all the departure and arrival points and asks all the TSAs for a domain search. In our case, we consider that we have three TSAs: TSA_1 for the Public transport service, TSA_2 for the carpooling service and TSA_3 for the free vehicle services (free use vehicles). Each TSA sends to the SupAthe list of TIAs identified for each request. In fact, each TSA executes a Domain Search Selection Algorithm (DSSA) in order ti identify the operators that could response to the request. The Fig. 8 and 9 show the results sent by the TSAs to the SupA for the two examples. The operators that will intervene in order to respond to the user's requests are:
Example 1:

- $TIA_{1,1}$: Transpole
- $TIA_{1,2}$: SNCF
- $TIA_{2,2}$: VLille
- $TIA_{3,1}$: Carpooling

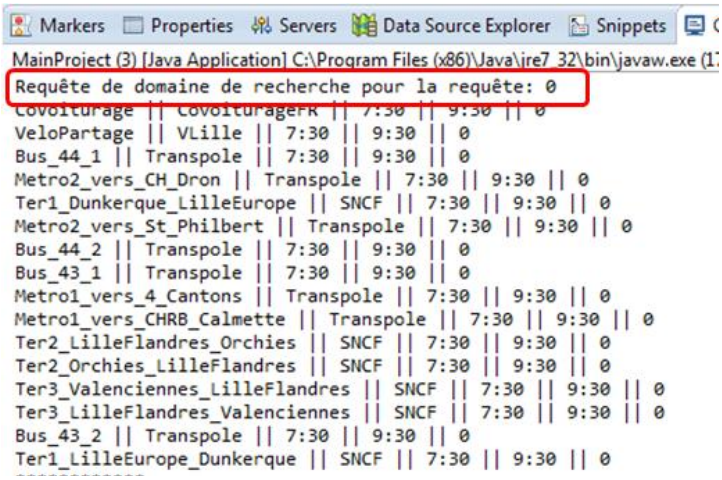


Figure 8 Identification of the TIAs for the first example

Example 2:

- $TIA_{1,1}$: Transpole
- $TIA_{1,2}$: SNCF
- $TIA_{1,3}$: Ligne BCD
- $TIA_{2,1}$: Lilas
- $TIA_{2,2}$: VLille
- $TIA_{3,1}$: Carpooling

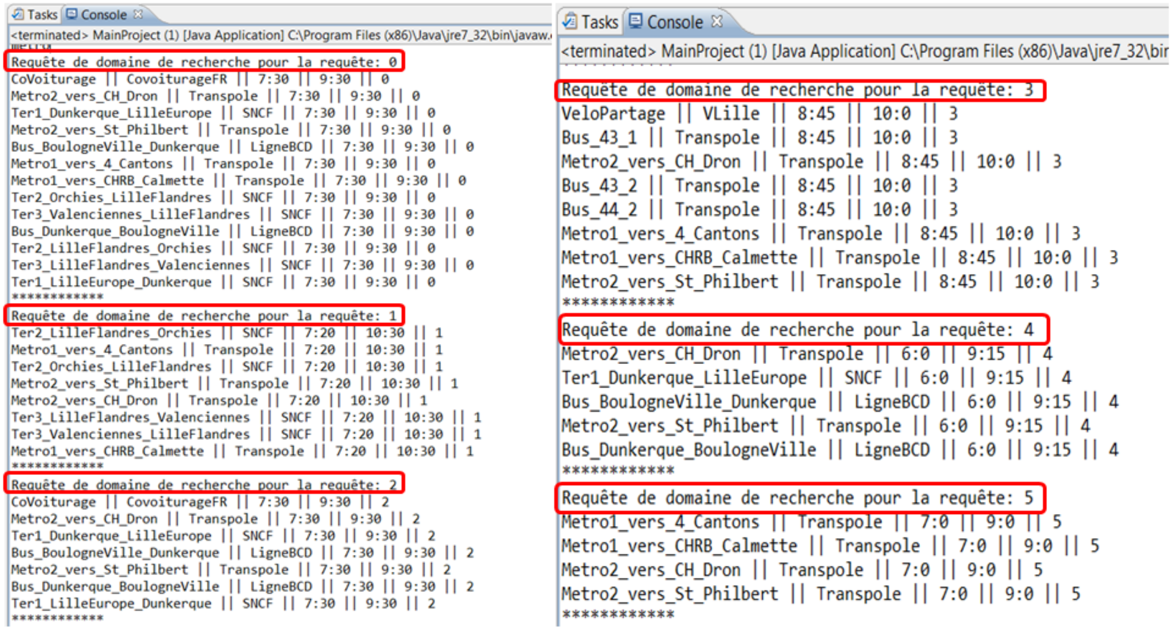


Figure 9 Identification of the TIAs for the second example

Computation of shortest paths in the Transfer Graph

After the identification of transport operators list, the SupA sends all the requests to the correspondent agents (TIAs) and wait for the set of routes that could be part of the final itineraries. Once the SupA received all the routes from all the TIAs, it constructs the Transfer Graph and executes the DSRA algorithm in order to find the shortest paths.

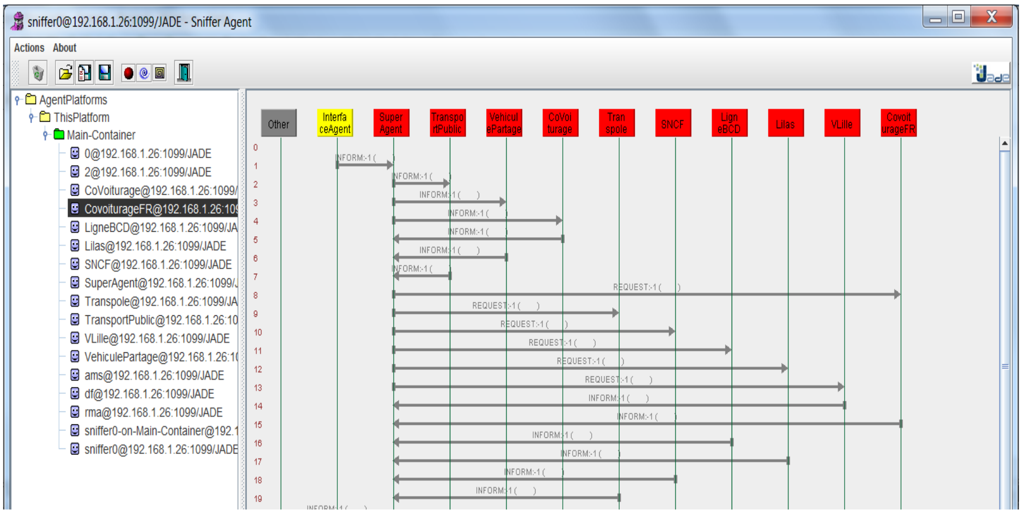


Figure 10 Communication between the different agents $\boldsymbol{supA}$, $\boldsymbol{TSAs}$ et $\boldsymbol{TIAs}$

For example 1, the transfer graph obtained is represented in the Fig.11:

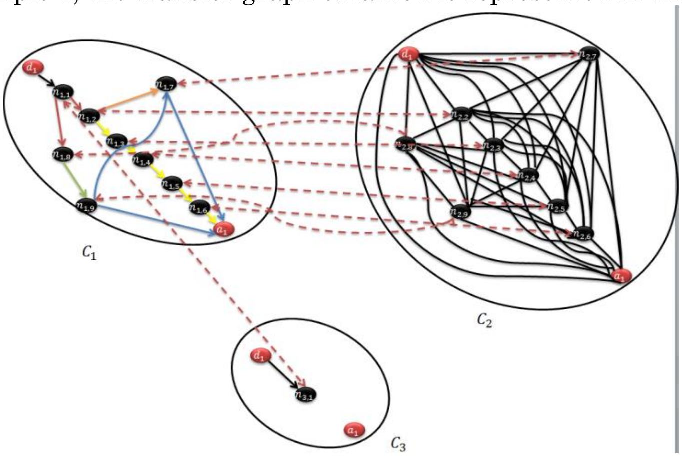


Figure 11 Transfer graph for example 1

The transfer graph is composed of three components C_1, C_2 et C_3 related respectively to the public transport, free use vehicles and the carpooling services. In this transfer graph , we obtained nine Co-modal Transfer Points (PTCs) :

Table 1Liste of PTCs

$n_{1,1} = n_{3,1}$	Gare Lille Europe
$n_{1,2} = n_{2,2}$	Gare Lille Flandres
$n_{1,3} = n_{2,3}$	Caulier
$n_{1,4} = n_{2,4}$	Fives
$n_{1,5} = n_{2,5}$	Marbrerie
$n_{1,6} = n_{2,6}$	Hellemmes
$n_{1,7} = n_{2,7}$	Mont de Terre
$n_{1,8} = n_{2,8}$	Fort de Mons
$n_{1,9} = n_{2,9}$	Faidherbe

The DSRA is applied in this transfer graph in order to compute all the shortest paths. The computation of the shortest path between d_1 and a_1 is described in Fig.12 and Fig.13.

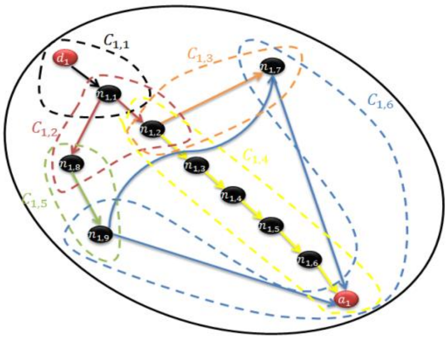


Figure 12 Classes of component $\boldsymbol{C_1}$

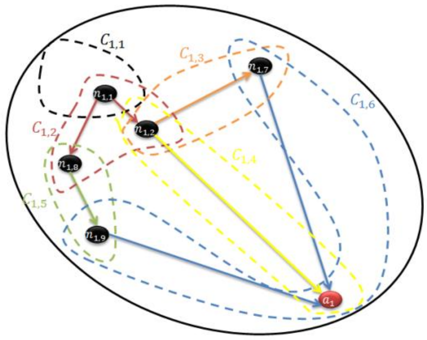


Figure 13 Intersection graph

The application of the DSRA begins by constructing the intersection graph which is composed of 6 classes. The shortest path obtained is: $(d_1 \rightarrow n_{1,1} \rightarrow n_{1,2} \rightarrow a_1)$.

The second example is more complex and it is difficult to represent the corresponding graphs. In fact, when constructing the Transfer Graph and after the computation of the shortest paths in each component, we obtained the following results:

Table 2: Results obtained with the Transfer graph

Component	C_1	C_2	C_3
Number of nodes	125	60	13
Number of Co-modal Transfer Points (PTC)	14	12	3
Number of edges	248	3540	2

Table 3Results obtained with the SPTG

Component	C_1	C_2	C_3
Number of nodes	30	21	13
Number of Co-modal Transfer Points (PTC)	14	12	3
Number of edges	88	66	2

In these tables, we distinguished the number of nodes, co-modal transport points and edges in both of the Transfer Graph and the SPTG. All these parameters are compared in Fig.14 :

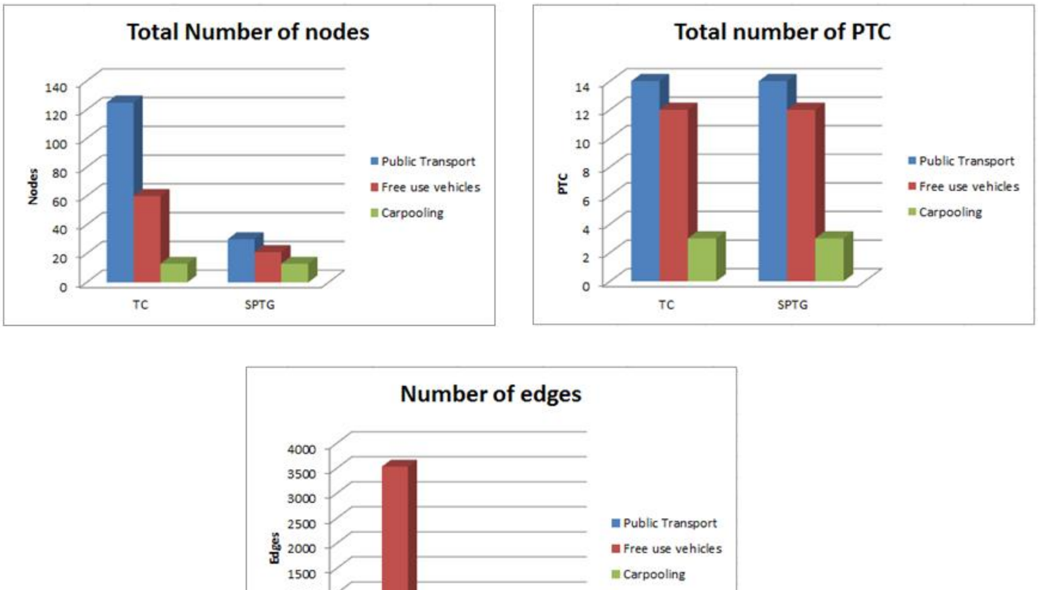
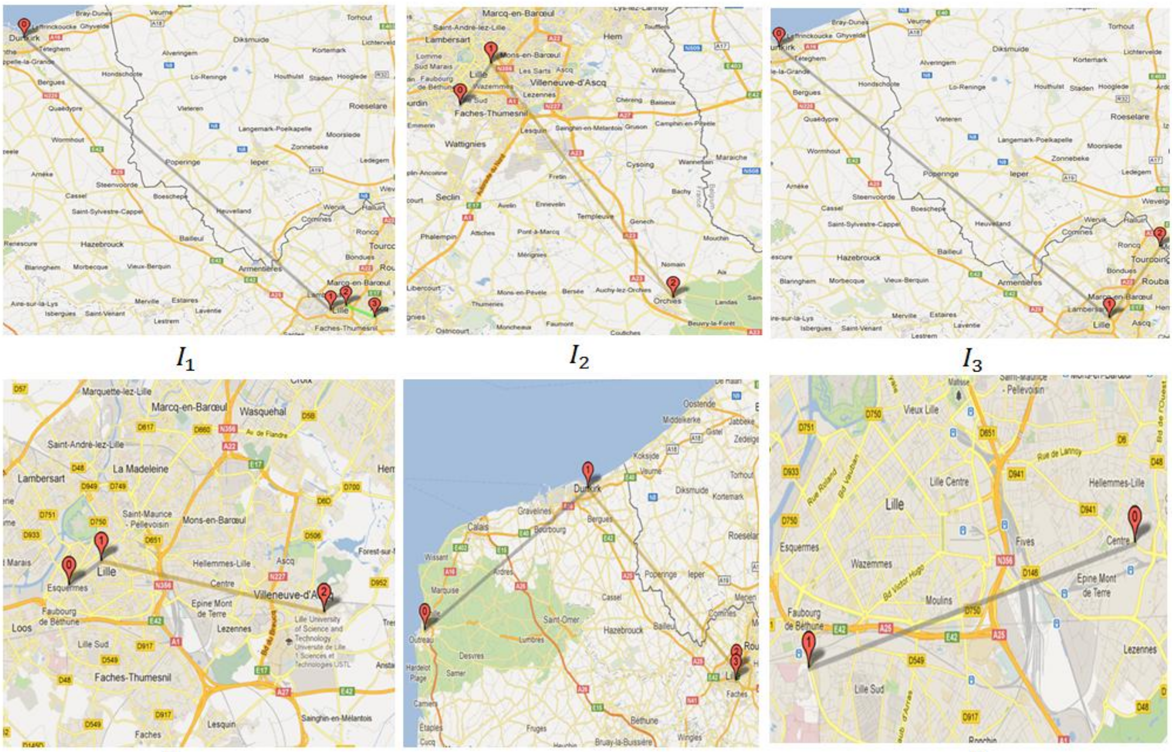


Figure 14 Comparison between the TC and the SPTG

In this figure, we can see a remarkable reduction of the number of nodes and specially the edges number and thereafter a reduction of routes. The number of Co-modal Transfer Point doesn't change since we compute the shortest paths between all the PTCs.
The itineraries obtained for the six requests are presented in Fig.15:



I_1 I_2 I_3

I_4 I_5 I_6

Figure 15 Final itineraries

This figure described the obtained results:
- For I_1 :we obtained a co-modal itinerary with two transport services. Carpooling with the first route (Dunkerque, Port de Lille, [7:45, 8:35]), a subway line 2 with the second route (Port de Lille, Gare Lille Flandres, [8:35, 8:47]) and a subway line 1 with the third route (Gare Lille Flandres, Villeneuve d'Ascq Hotel de Ville, [8:48, 8:58])
- For I_2 :the itinerary is multimodal thanks to one transport service : the public transport and two modes of transport. The first route (CHRB Calmette, Gare Lille Flandres, [7:22, 7:30]) is assured by the subway line 1 and the second route (Gare Lille Flandres, Orchies, [7:37, 7:59]) is assured by the train TER3.
- For I_3 : we obtained a co-modal itinerary composed of two routes. The first route (Dunkerque, Port de Lille, [7:45, 8:35]) thanks to a carpooling car and the second route (Port de Lille, CH_Dron, [8:36, 9:11]) thanks to the line 2 of the subway.
- For I_4 : the itinerary is co-modal with two different transport services: free use vehicle (bike) for the first route (Cormontaigne, Massena, [8:45, 8:52]) and Public transport (Bus) for the last route (Massena, Ascq Village, [8:57, 8:59])
- For I_5 : it is a mono-service itinerary (only public transport) but multimodal thanks to three transport operators. The first operator LigneBCD assured the first route (Boulogne ville, Dunkerque, [6:15, 7:35]). The second operator SNCF assured the route (Dunkerque, Gare Lille Europe, [8:21, 8:55]) and the operator Transpole assured the last route (Gare Lille Europe, Port de douai, [8:55, 9:00])
- For I_6 :the itinerary is monomodal with just one route (Lezennes, CHR Oscar Lambret, [7:07, 7:21]) thanks to the line 1 of the subway.

In order to improve the impact of the number of requests and services, we make some tests. We vary the requests and the number of services and we compare the variation of the number of nodes, co-modal transport points and edges shown in Fig.16.

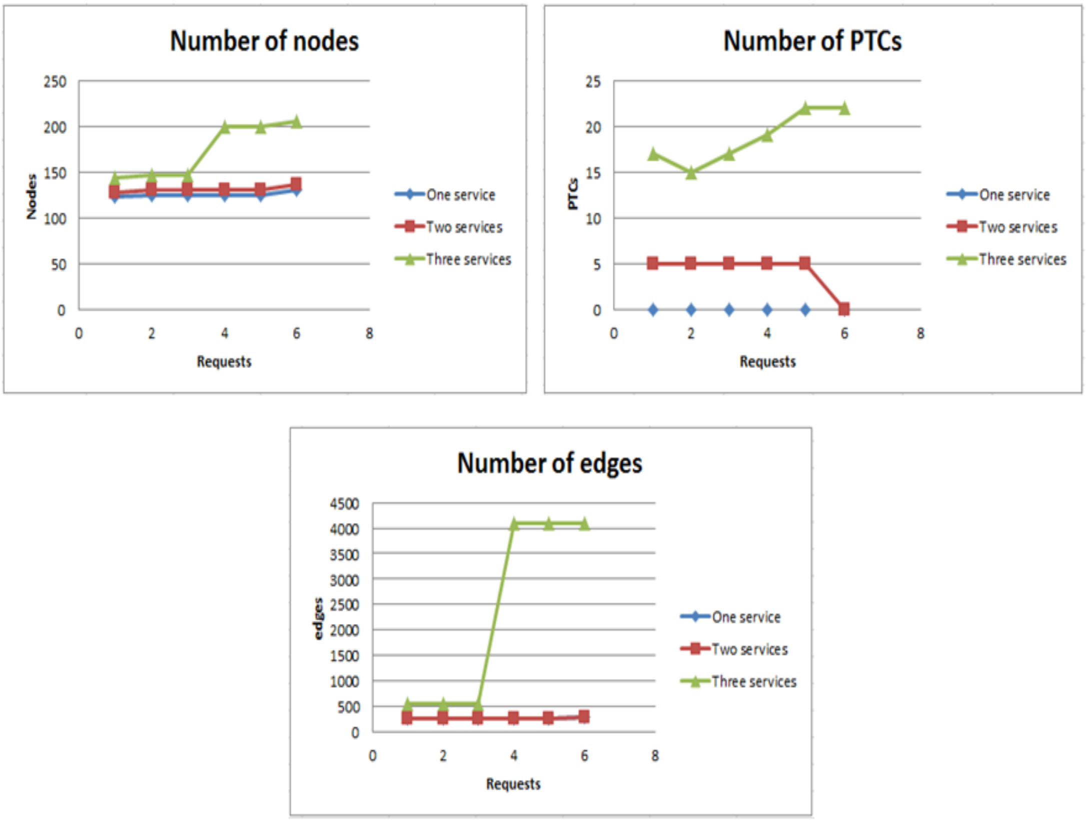


Figure 16 Variation of the number of nodes, PTCs and edges

We notice thatin case of one transport service, the number of PTCs must be null. The number of edges increases in the case of including three transport services. We remark some constancy of the curves due to the similarity between the different requests. In fact, when the departure and arrival points are similar or near geographically, we obtain the same routes and so the same edges.

IX. Conclusions

In this work, we proposed a distributed co-modal approach based on multi-agent system which aims to find an effective itinerary proposition to transport users including public transport, carsharing and carpooling. The system employs different optimization techniques. In fact, the developed Distributed Shortest Path Algorithm (DSRA) allows the system to simplify the resolution of shortest paths in term of time in a distributed system. Then, the systemuses an evolutionary optimization approach in terms of total cost, time and gas emission volume taking into account user constraints and preferences. The employment of multi-agent system, the use of the co-modal and transfer graph and the rapid assignment process to a combinatory problem thanks to an evolutionary method, make our adopted approach very interesting. The alliance of multi-agent systems and different optimization techniques is very important because with agent-based approaches we explore the ability to handle a large problem domain and a short time-scale of the domain while with the optimization techniques, we explore the ability to achieve system optimality or near optimality with a quality assurance.In future work, we intend to develop the evolutionary approach and the coalition of the *RA* generated by the *SupA*. We also aim to employ a genetic process generating more chromosome generations, in order to improve gradually generated solutions to find better solutions and to develop the protocol negotiation between the different RAs.

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