Carpooling Systems Aggregation

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Abstract. Intelligent transportation systems are advanced software applications that support innovative requirements related to several transportation devices. Those applications are vital to mitigate traffic congestion and consequent environmental issues, becoming the transport more efficient and sustainable. In this context, appears the carpooling system idea, which can be described as a facilitator for sharing available seats in a private vehicle that performs a journey.

The main goal of this paper is to argue about the design of a distributed aggregator, which is a new paradigm, to handle information from carpool clubs according to a previously negotiated agreement. The aggregator emerges as a coordinator of carpooling systems, with their own administrations that autonomously manage rewards, penalties and admissions maintaining the privacy and trust among its restricted group.

For this, it is proposed a pure P2P unstructured architecture to support the aggregation of the carpooling systems. The experimental evaluation of this architecture was carried out by developing and installing a demonstrator composed by three instances of carpooling systems, based on a proposed reference implementation, which unify and upgrade, the most common requirements in the market highlighting users' privacy and trust. In order to represent hypothetical carpool clubs each carpooling system instance was populated with its own fictional data.

Keywords: Carpooling · Ridesharing · Sustainable mobility · Carpooling system · Aggregation · P2P architecture

1 Introduction

1.1 Sustainable Mobility

According to International Energy Agency, 80% of primary energy demand is based in fossil fuels, and they are responsible for 90% of CO_2 emissions [1]. A significant part of those emissions is produced by huge traffic jams in big cities. Over the years, many studies focused this environment issue, but few had proposed a real and practical solution to the overuse of private transport. Those studies show an average of 1.45 passengers per vehicle, and the urgency of change those poor numbers [2].

Intelligent Transport Systems (ITS) are vital to increase safety and to solve traffic jams issues. They can make transportation more efficient and sustainable applying information and communication technologies to all modes of passenger and freight transport [3]. In this context, carpooling appears as an emergent transport mode, where

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a carpooling system can be described as a facilitator for sharing available seats in a private vehicle that performs a journey.

The widespread availability of broadband Internet services allows the deployment of powerful tools for carpoolers to meet potential companions and reach an agreement to share a journey [4]. This opportunity created by the Internet became the best way to inspire innovative strategies to support carpool clubs [5].

1.2 Background

Intelligent transportation systems appeared in a spontaneous way based on technological advances considered revolutionary for the urban mobility area. In Portugal, the road transports are responsible for a significant part of energy consumption based in petroleum products. There are strategies to solve this issue, for instance, the use of public transports, bicycle or carpooling also known as ridesharing.

According to a study made by Cetelem (Observador Cetelem Automóvel) there are several reasons for the population, do not join to carpool clubs. Following the Fig. 1, 46% of the population with age of 55 or more older and 38% with ages between 18 and 34 prefer to drive alone. This type of choice is more common in countries such as United States of America (USA) and Germany. In Japan, for instance, most of the people prefer to trust their vehicle to another driver [6].

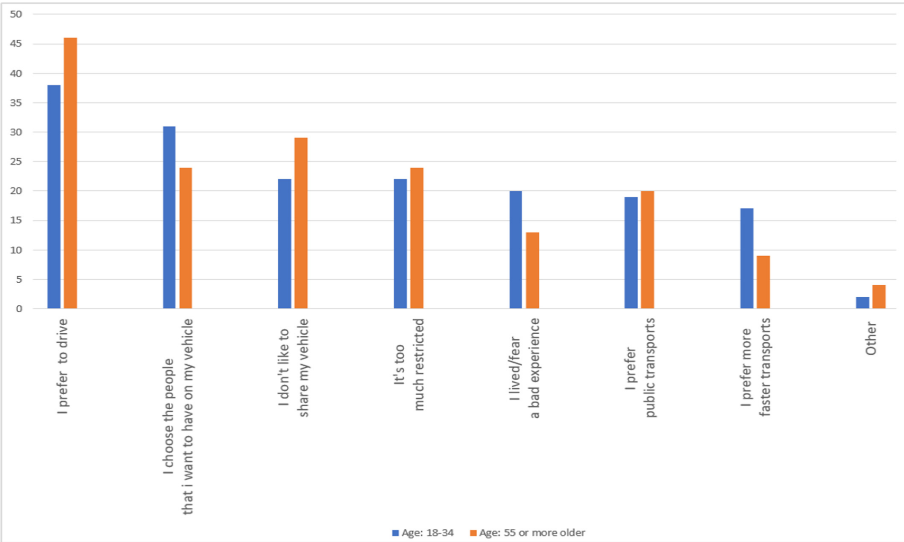

Fig. 1. Reasons for not using carpooling

At the city of Aspen in Colorado, it was carried out a survey asking the residents their opinion about incentives to use carpooling systems [7]. The most common answers were: (i) more preferential parking locations, (ii) additional benefits such as coupons or prizes, (iii) more convenient carpool pass retrieval, (iv) more convenient way to find those traveling similar routes (matching system), (v) emergency ride home to provide flexibility and (vi) financial reward for carpooling.

In Portugal, carpooling still do not have much impact. It is more common the use of carsharing, that consists in renting a specific vehicle, for a given journey. Considering that carsharing is less efficient in terms of resources, the carpooling has a lot of room to grow [8].

The most relevant advantages of carpooling are clearly the economic and the incentive for socialization between passengers. However, as is natural, there are disadvantages associated with travelling with strangers, for instance, lack of privacy and trust [9]. To mitigate these disadvantages, some of carpool clubs recommend that their users should register using social networks, such as Facebook, Twitter, or Instagram, to ensure the veracity of the user profile.

1.3 Related Work

One of the most valuable proposals of ITS to reduce traffic jam and help to save CO_2 emissions is carpooling, that has been recommended since long time ago.

Currently, there is a significant and growing set of carpooling systems. As part of the present work, in order to produce an overview focusing the most frequent characteristics of carpooling systems, it was carried out a study that includes ten carpooling systems that was judged relevant. In practice, it was not possible to have the specification and/or implementation of the selected carpooling systems. However, it was possible to carry out this study assuming the user role, carrying out the installation and registration of the analyzed systems and interfaces.

In Fig. 2 is depicted a graph about ten studied carpooling systems with their basic features. The analysis of the graph in Fig. 2 reveals the fact that the publication of demand announcements is not frequent.

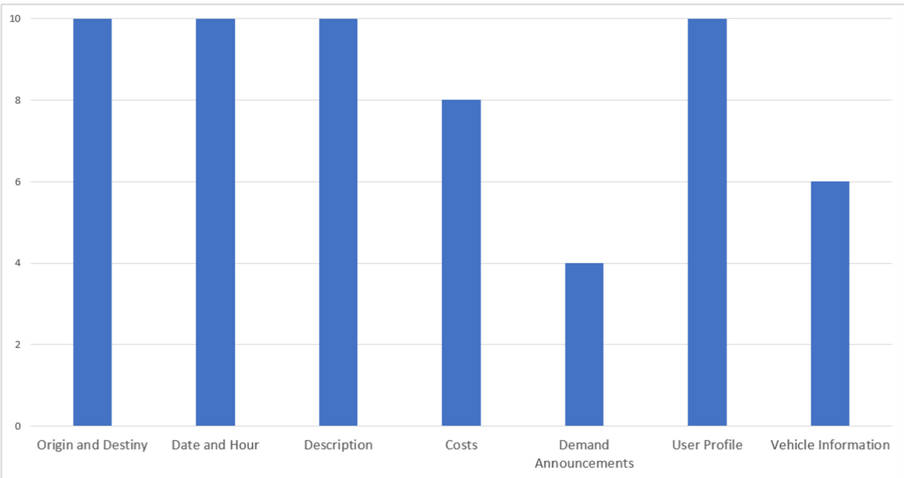

Fig. 2. Carpooling systems basic features

In Fig. 3 is depicted a graph about ten studied carpooling systems with their advanced features. The analysis of the graph in Fig. 3 reveals three features that are not frequent, namely, CO_2 calculator, waypoints and matching system.

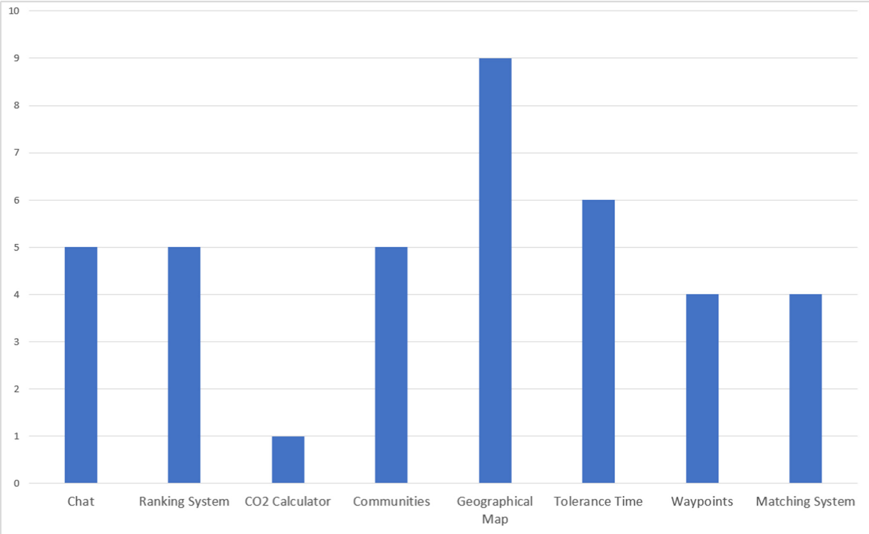

Fig. 3. Carpooling systems advanced features

About the authentication and authorization mechanisms, the studied carpooling systems use social networks or institutional email to ensure the veracity of the user's profile. However, in half of the studied systems, the administrators do not control users.

1.4 Contribution

Currently, this paradigm is becoming more well-known because of growing enhancements in information and communication technologies. In our opinion, the carpooling systems are threatened by a monopoly with a few international players that operate at a global level without a common legal framework compromising privacy and trust of the users. Major worldwide market players in information technology are involved in conflicts related to the reusing and selling of information that belongs to its users [10].

The main contribution of this work is the design of a distributed aggregator, which is a new paradigm, to handle information from carpool clubs according to a previously negotiated agreement. The aggregator emerges as a coordinator of carpooling systems, with their own administrations that autonomously manage rewards, penalties and admissions maintaining the privacy and trust among its restricted group. The aggregator allows the user of a carpooling system to manipulate, transparently, respecting the negotiated agreements, the published announcements by other carpool clubs [11].

1.5 Organization

This paper is organized in four sections. The first section, this one, includes an overview related to sustainable mobility, background, and related work. Additionally, this section, presents the contribution and these document organization. The second section presents a reference implementation for carpooling systems, the aggregator architecture, and the aggregation gateway. The third section refers the experimental evaluation devising demonstration scenarios and the obtained results. The fourth section, the final one, is about conclusion and future work.

2 Proposal

2.1 Carpooling System Reference Implementation

A reference implementation often accompanies a technical standard that describes the expected behavior of any other implementation of it. It is important to establish a reference implementation for carpooling systems in order to define the requirements and behavior of the aggregator.

In the scope of the presented study at Sect. 1.3, it was elaborated a use case diagram [12] that includes the most frequent and relevant use cases. In Fig. 4 is presented the use case diagram that refers two actors, namely: anonymous and registered.

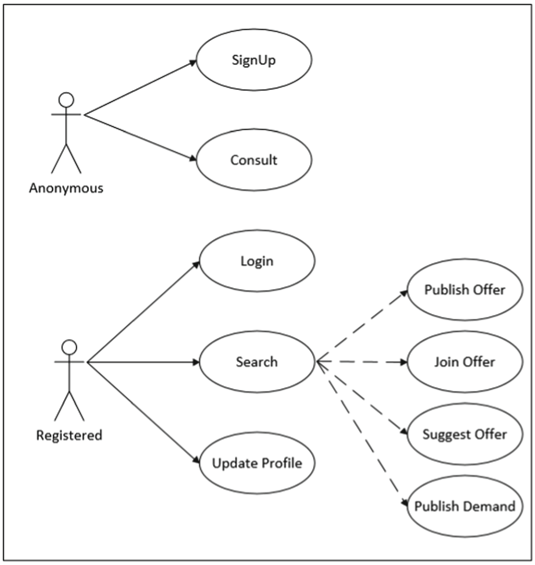

Fig. 4. Use case diagram of the reference implementation

Anonymous users can register (Sign up) or consult (Consult) announcements overviews with the basic information. The registration facility assigns to the user a Universally Unique Identifier (UUID) [13] allowing the users to create their profile indicating the following attributes: first and last name, email address, password, passport photo, birth date and mobile phone number.

Registered users can, after authenticating themselves (Login), search for detailed announcements (Search) or update their profile (Update Profile). Typically, authentication is performed by indicating the user's identifier and a password. As an alternative to the identifier, the email address or the mobile phone number can be typed. The Search case allows the users to access and carry out the actions associated to the announcements, namely: publish an offer announcement (Publish Offer) or demand (Publish Demand), joining an offer (Join Offer) or suggesting an offer announcement to satisfy a explicit demand announcement (Suggest Offer). Only users with a valid driving license and with at least one associated vehicle can publish offer announcements that can be suggested by him (Suggest Offer) to satisfy an explicit demand announcement.

In Fig. 5 is depicted the carpooling system reference architecture with three layers: service layer, logical layer, and data layer.

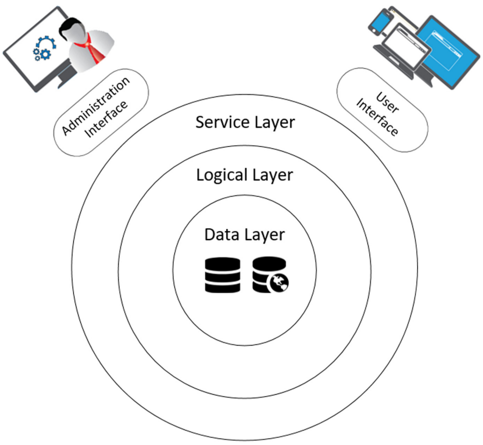

Fig. 5. Carpooling system reference architecture

In order to anticipate requirements associated with the user's privacy and trust, which are not common in the market, but considered to be urgent for the success of the carpooling systems, we suggest to implement the following requirements, such as: (i) confirmation of registration by the administrator; (ii) minimization of personal and historical data; (iii) only provide the necessary strictly information for each moment of interaction between the passenger and the carpooling system; (iv) adoption of pseudonyms to avoid the disclosure of user's real names; (v) additionally, should be considered the current legal framework on data protection.

Service Layer

The service layer is responsible for providing access to the components of the carpooling system. Essentially, this layer exposes a set of services that are intended to be consumed by the interfaces for users, administrators, and sponsors. On the other hand, this layer encapsulates the logic of the components controlling the transactions managed by the carpooling system. Thus, the service layer, that provides a Service API, does the decoupling between the components of the carpooling system and the current interfaces or the interfaces targeted for future development.

Logical Layer

The logical layer deals with the behavior of the carpooling system. In Fig. 6 shows the components that make up the logical layer, which are described below.

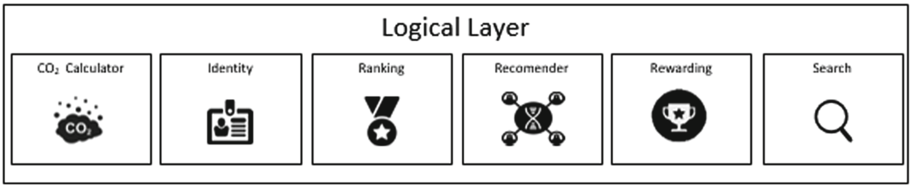

Fig. 6. Logical layer components

The logical layer supports the activities of the carpooling system, for instance, data processing, data search and report building, more generally, all the processing behind the human interface (BackOffice).

CO_2 Calculator

The CO_2 Calculator component calculates the production of CO_2 by a specific vehicle used in a journey (each vehicle model has its own CO_2 emission rate). In Fig. 7 is depicted an example of a journey.

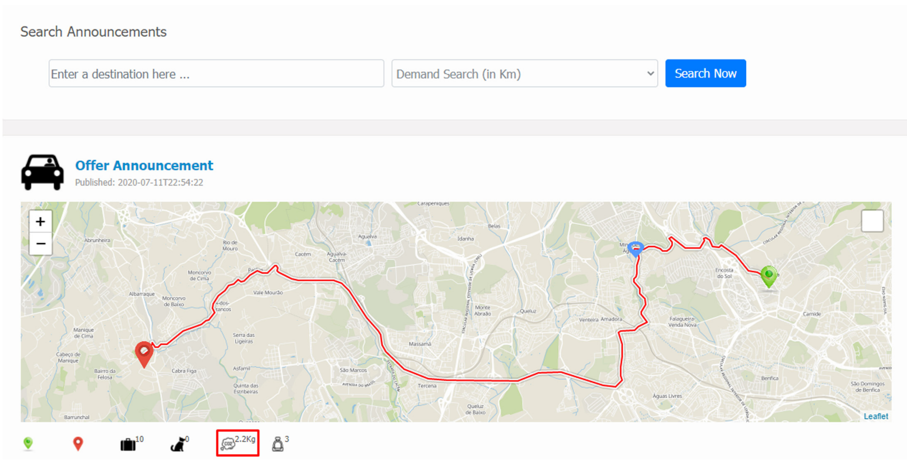

Fig. 7. Offer announcement with CO_2 calculation

The CO_2 rate associated to the vehicle model is 112 g/Km. The distance in this journey was 19.64 km. Consequently, the total of CO_2 released in this journey is 2.2 kg.

Identity

The identity component is in charge of the user's identity management. In Fig. 8 is depicted the domain model of the user. The administrator of the carpool club exclusively accesses the sensitive data, which are first and last name, email, nationality, birth date, identification document and driving license.

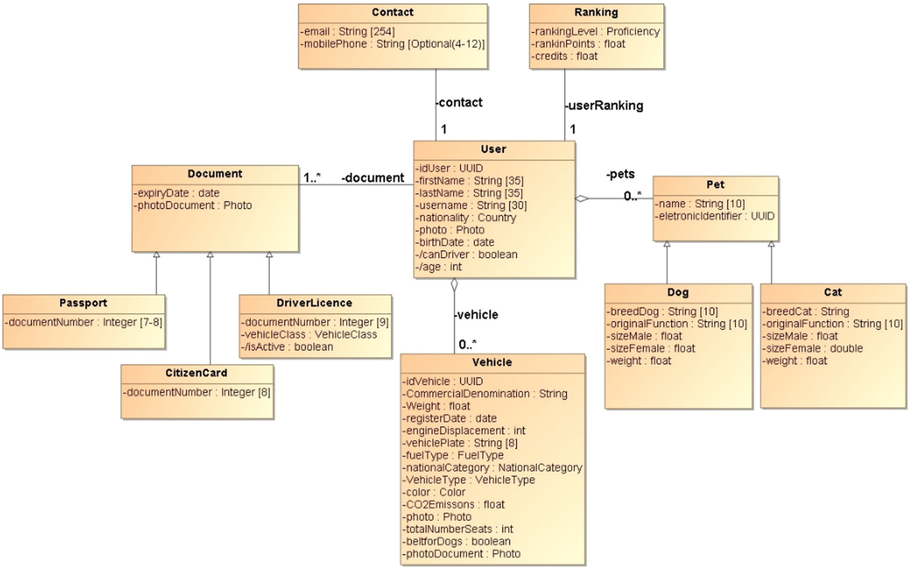

Fig. 8. Domain model of the user

The data that is exchanged between the users are, specifically: username (pseudonym), profile picture, raking data and partial information about the vehicle. For this, the username is generated randomly to not compromise the user's identification.

In addition to vehicle data, the user model also records data about pets, dogs, or cats, which can be indicated in announcements and included in journeys.

Ranking

The ranking component is responsible for managing the ranking value and level of the users.

The administrator of each carpool club defines the rules for awarding points. These points can represent rewards or penalties. The rewards can be, namely: (i) register at the carpool club, (ii) publish an announcement, (iii) subscription of an offer announcement, (iv) evaluation of users and (v) choose an economic vehicle. The penalties can be, namely: (i) unsubscribe an offer announcement or (ii) cancel an offer announcement. Additionally, the rewards points are converted into credits, which are managed by the reward system. In Table 1 shows an example of the rules processed to determine the ranking level.

Table 1. Ranking level assignment rules

Ranking	
Value	Level
0 to 50	Beginner
51 to 100	Amateur
101 to 500	Professional
501 to 2000	Veteran
2001 to 1000000	Master

On the other hand, the ranking value determines the user ranking level. For this, the administrator can define the ranking level assignment rules.

Recommender

The recommender component implements a matching algorithm that determines published offer announcement that satisfy a demand announcement. When a user publishes a demand announcement, there may exist corresponding announcements on the carpooling system database. Because of that, is important to include in the carpooling system the capability to identify offer announcements that correspond. The matching algorithm is parameterized by a geographical or temporal window to find similar origins, destinations or dates and times.

For instance, if the geographical window for origin is 2 km, this means that will be matched announcements with origin within a circle with 2 km radius. For instance, if the temporal window for departure date/time is 10-min, this means that will be matched announcements with departure centred at a 20-min interval.

Rewarding

The rewarding component manages the user's credits, allowing the user to convert them into desired rewards previously recorded by the sponsors of the carpool club. A reward is defined by a description, a quantity, and a validity interval. The rewards can be, for instance: free parking, fuel discounts, and cinema tickets. In Fig. 9 is presented an example of data included in the QRCode.

Barcode format	QR_CODE
Parsed Result Type	TEXT
Parsed Result	The idUser: 56e425f8-11ea-87d9-0a002700000f The User Name: jewell.ziemann58 The Sponsor: XPY

Fig. 9. Example of data included in the QRCode

The conversion of credits into rewards is carried out by generating a QRCode that includes the consumed credits, the name of the sponsor, user's identifier, and the username. In Fig. 10 is depicted the generated QRCode.

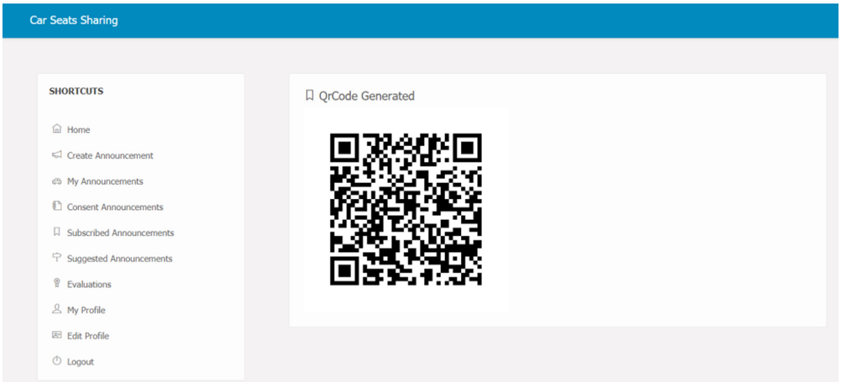

Fig. 10. Generated QRCode

The QRCodes can only be generated for rewards/donations previously configured by the sponsors of the carpool club.

Search

The search component allows finding announcements, which can be archived using a multi-attribute filter, for instance, (i) search through a destination within a circle; (ii) search for announcements subscribed by the user; (iii) search for announcements published by the user. In Fig. 11 is depicted the domain model of the announcement.

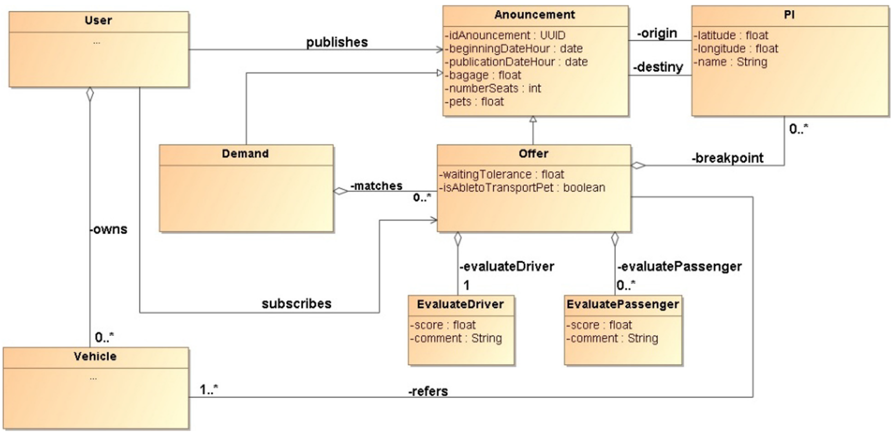

Fig. 11. Domain model of the announcement

The announcement can be classified as Offer or Demand. For an offer announcement, it is mandatory to have associated at least one vehicle, which may have zero or more subscriptions.

Data Layer

The data layer maintains data about the users and announcements. For this, a relational database and a geographic database are putted in place [14].

2.2 Aggregator

Regarding, the recent proliferation of carpooling systems, we propose a new paradigm to facilitate the coordination between carpooling systems respecting its autonomy. This paradigm is materialized by an aggregator, which combines, at runtime, data from multiple carpooling systems avoiding data replication and data centralization according to data protection issues.

The aggregator architecture should facilitate, for the members of a carpool club, the transparent manipulation of the announcements published by other clubs with established agreements. In our opinion, agreements are the desirable way for carpool clubs to negotiate, protecting the interests of their users and offering a more robust service [15].

Data Scraping

In a first approach, the data managed by the aggregator could be acquired directly from the websites of the existing carpooling systems. This process does not require data migration and may involve some improvements in the existing carpooling systems.

However, in addition to the feedback about publication and subscription of announcements and the requirement for the users to have registration, there are still legal problems with the use of this web data without prior agreement.

Multi-tenant Architecture

In a second approach, information aggregation could be performed by adopting a multi-tenant architecture typically with cloud hosting, paying for the use and following the cloud Software as a Service (SaaS) paradigm.

Apparently being a more economical solution, it may be difficult to bear rising costs, maintain privacy and overcome legal obstacles to the concentration of the personal data hosted in unknown jurisdictions [16].

Peer-to-Peer Architecture

In a third approach, the data aggregation could be carried out at runtime adopting a Peer-to-Peer (P2P) architecture, where the participants, equally privileged, simultaneously assume the role of client and server. Typically, this architecture is adopted to distribute content that can be consumed at real time [17].

Due to the unique characteristics of this architecture it was indelibly associated to activities that do not respect intellectual property. In other hand, these characteristics have proven to be suitable to protect user's privacy [18]. This architecture must know all the participant systems, which requires, in a first approach, the existence and maintenance of additional systems to support a discovery protocol. This kind of architecture, designated by hybrid P2P architecture, is considered partially centralized because of the data needed for the discovery protocol [19]. In Fig. 12 depicts the hybrid P2P architecture with a single server, which introduces a single point of failure and bottleneck.

Fig. 12. Hybrid P2P architecture

The need of servers leads to dependent on third parties introducing costs that must be shared. In this scenario, it seems desirable to adopt the P2P architecture, completely decentralized, without servers and avoiding points of failure and bottlenecks.

In Fig. 13 is depicted a pure P2P unstructured architecture, which supports a dynamic interaction between the participants.

Fig. 13. Pure P2P unstructured architecture

Considering the presented arguments, it is proposed that the aggregator follows a pure P2P unstructured architecture.

2.3 Aggregation Gateway

In order to support carpooling systems aggregation, carpooling systems must be upgraded adopting an aggregation gateway, which will be the ambassador of a carpool club as part of a distributed aggregator.

From another point of view, the aggregator is dynamically composed, at runtime, by the online gateways. The local aggregation gateway accesses remote gateways and vice-versa. A carpooling system upgrade is illustrated in Fig. 14 that includes the proposed aggregation gateway.

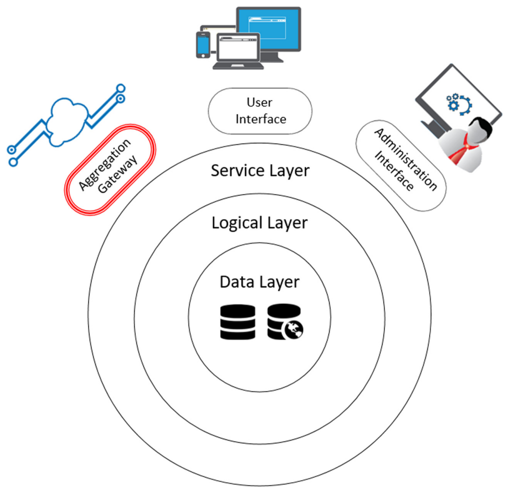

Fig. 14. Carpooling system upgrade

The aggregation gateway extends the carpooling system in order to support the interaction agreement established between carpool clubs. In Table 2 is enumerated the exposed services of the service layer that can be invoked by the aggregation gateway.

Table 2. Aggregation gateway services

Letter	Service	Description
A	GET/user/profile/	Consults user profile
B	GET/announcement/s/	Searches for announcements
C	GET/announcement/	Consults an announcement
D	PUT/announcement/subscription/	Subscribes an announcement
E	POST/announcement/evaluate/	Evaluates a user based on announcement
F	POST/announcement/suggest/	Suggests an offer to a demand announcement

The agreement is previously negotiated and configured by the local administrator. A unidirectional agreement is configured through a Uniform Resource Locator (URL) and a random serial key. A bidirectional agreement can be completed defining a reciprocal configuration.

In Fig. 15 and Fig. 16 is depicted the administrator interface that can be used to configure a set of agreements.

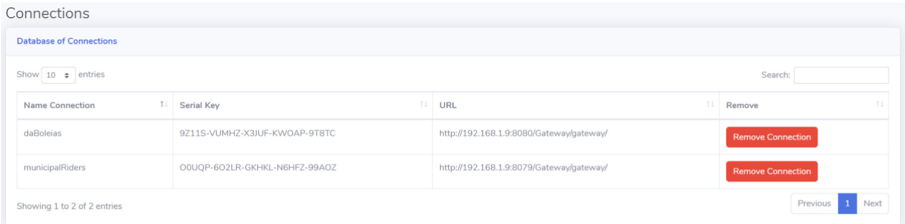

Fig. 15. Agreements management of "daBoleias" and "eventos.Boleias"

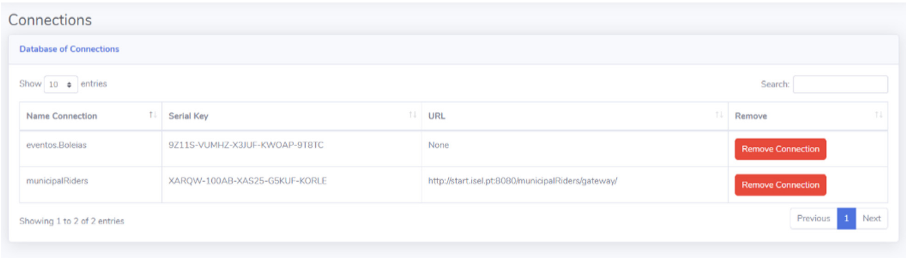

Fig. 16. Agreements management of "daBoleias" carpool club

In the interest of preserve the autonomy of carpool clubs, the aggregation gateway must implement a distributed announcement search and subscription process converting the user's ranking.

Ranking Conversion

The ranking conversion is implemented upgrading the A method (see Table 2) that adopts a rule based on an interchange fee established by the local administrator. However, the interchange fee can be dynamically determined, using the average of the two involved rankings.

Distributed Search

The distributed announcement search is implemented upgrading the B method (see Table 2) assuming a limited quantity of returned announcements. The quantity of return announcements is a configuration parameter managed by the local administrator considering efficiency issues.

Thus, in a first interaction, the local search launches remote searches to obtain a set of announcements for each online carpool club. The returned announcements are loaded in a persistent memory and sorted in order to acquire a previously limited set of announcements. The following announcements are those that remain in memory. When the memory is emptied, it is launched a new distributed search indicating the next iteration number.

3 Experimental Evaluation

The experimental evaluation of the proposed architecture was carried out by implementing a demonstrator composed by three instances of the reference implementation presented in Sect. 2.1. In order to represent hypothetical carpool clubs each instance was populated with its own fictional data.

In Fig. 17 is depicted the interaction diagram between carpool clubs, namely “boleias.Eventos”, “daBoleias” and “municipalRiders”. The systems names are inspired by Portuguese names.

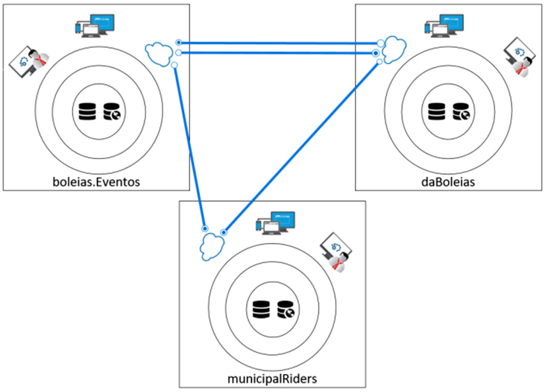

Fig. 17. Demonstrator P2P architecture

In Fig. 18 is depicted the announcements feed of “daBoleias” carpool club.

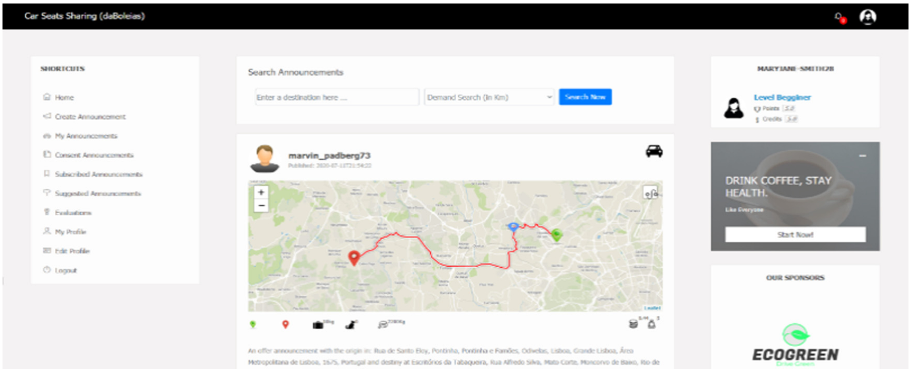

Fig. 18. Feed announcements screen

The announcements are sorted, by default, according to departure date and time. When the user wants to see more announcements, he or she must scroll down. The experimental evaluation covers four scenarios detailed below.

#1 Scenario: User Ranking
Carpooling clubs may have its own rules for adding user ranking points, which causes divergences between user's rankings. For instance, the user Annie Granger with the pseudonym "cindie-satterfield38" registered at "municipalRiders" has a user ranking value of 205 points. However, the same user at "daBoleias" has 41 for ranking value because the interchange fee, configured by the administrator, is 80% and at "eventos. Boleias" club the ranking value is 194.75 due to an interchange fee of 5%.

#2 Scenario: Search for a Journey
Registered users can search for journeys using a multi-attribute filter. For instance, when Arieta Benson, with the pseudonym "maryjane-smith28" registered at "daBoleias" carpool club wants to search for a journey to "Belém Cultural Center" she indicates that destination and the desired radius. The result set may include announcements published locally, by users from "daBoleias", or remotely, by others users from "municipalRiders" or from "eventos.Boleias". In Fig. 19 is depicted an example of the search.

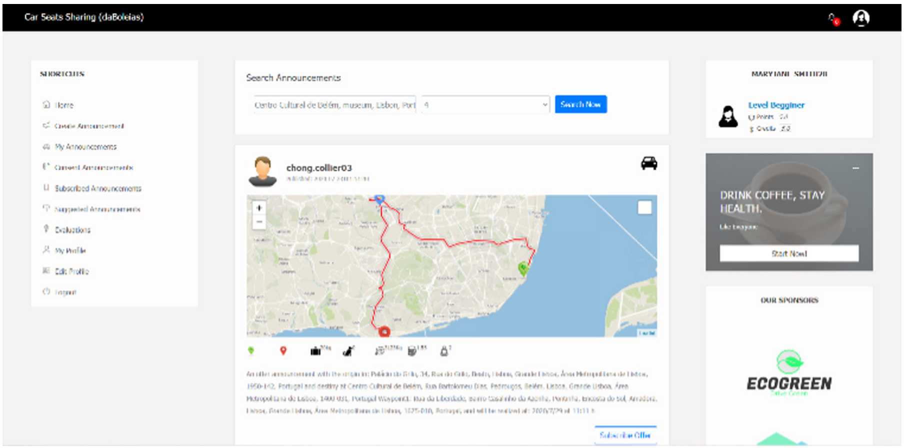

Fig. 19. Offer announcement search screen

In Fig. 20 is depicted the subscription screen used to indicate the pickup point and the weight of luggage. The user can select and subscribe one of the displayed announcements or, if he or she does not select any, he or she can publish a correspondent demand announcement based on existing search filter values.

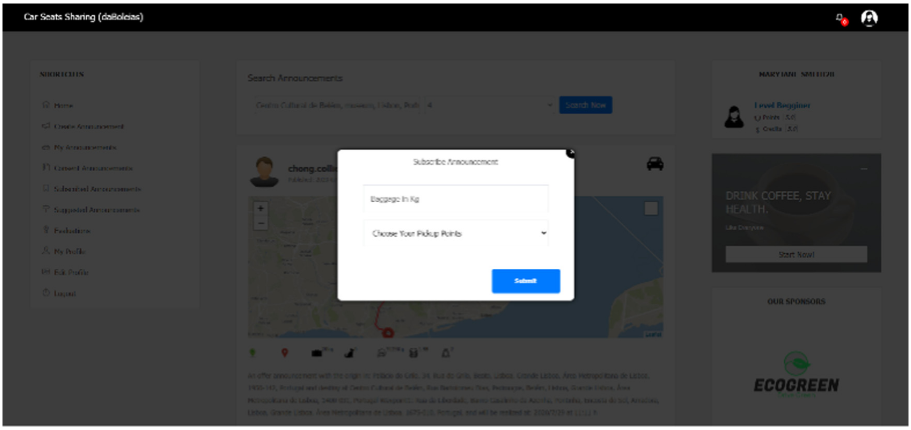

Fig. 20. Subscribe announcement screen

When the user subscribes an announcement, he or she must indicate the pickup point and optionally the weight of the luggage.

#3 Scenario: Consent Subscription
The users that publish offer announcements are notified when a subscription occurs. For instance, the user Marco Robertson, with the pseudonym "chong.collier03" of "municipalRiders" carpool club, receives a notification stating that someone wants to join the journey he announced. After the user "chong.collier03" consents the subscription, "maryjane-smith28" of "daBoleias" carpool club can check more detailed information, such as the users who subscribed the announcement and details about the vehicle.

In order to solve the notification, the user "chong.collier03" must access the consent screen, in Fig. 21, to accept or decline the subscription.

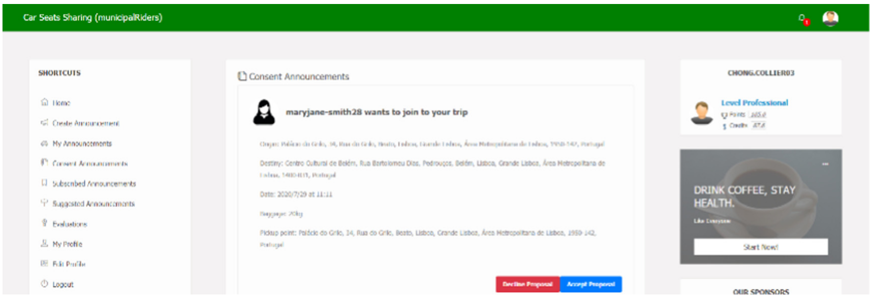

Fig. 21. Consent subscription screen

In Fig. 22 is depicted the screen, available after consent, with additional details about the subscribed announcement.

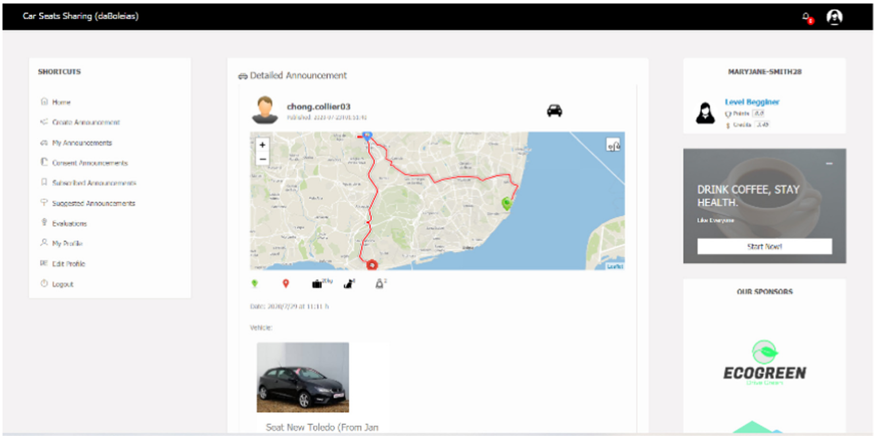

Fig. 22. Screen after subscription consent

After the journey, the users must fill the evaluation form. Each traveler must rate between 1 and 5 stars. This rating allows the calculation, by the ranking component, of the ranking points and credits that will be assigned to each user.

In Fig. 23 is depicted the journey evaluation form of the user chong.collider03 from "municipalRiders" carpool club that evaluates the user "maryjane-smith28" of "daBoleias" carpool club in the context of a journey.

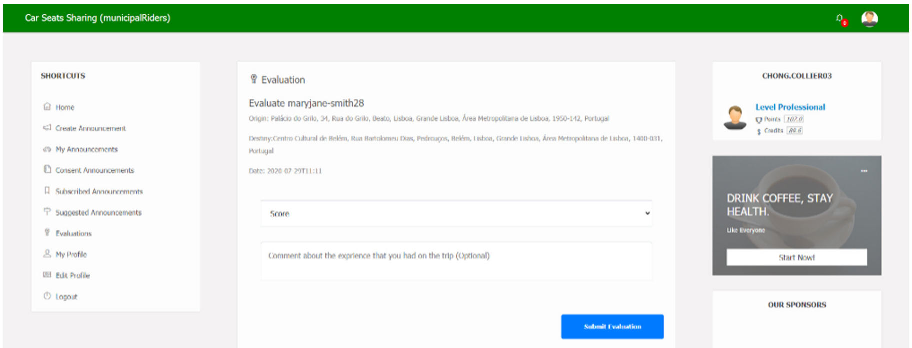

Fig. 23. Evaluation of a user from "daBoleias" carpool club

The user "maryjane-smith28" from "daBoleias" carpool club receives a similar screen with the same goal.

4 Conclusion and Future Work

The presented work is a recent development fitted in the initiatives around sustainable mobility promoted in our laboratory. Regarding, the recent proliferation of carpooling systems, is argue the relevance of the coordination between carpooling systems implementing a pure P2P architecture to support the aggregator dynamically composed at runtime. For this, is devised a carpooling system reference implementation based on our own presented study in order to establish the requirements for the aggregation gateway that extends and integrates the carpooling systems within a distributed aggregator. This approach allows the registered users in a carpool club, to manipulate announcements published by other carpool clubs.

The experimental evaluation is based on our own distributed aggregator that coordinates three instances of the carpooling system reference implementation currently deployed in our laboratory, which can be freely accessed by URL start.isel.pt.

Additionally, is available by URL www.start.isel.pt/daBoleiasVM, also for free use as is, a virtual machine in.ova [20] format (see Fig. 24), which was prepared for "daBoleias" carpool club demonstration that can be considered as a beta version of an autonomous carpooling system.

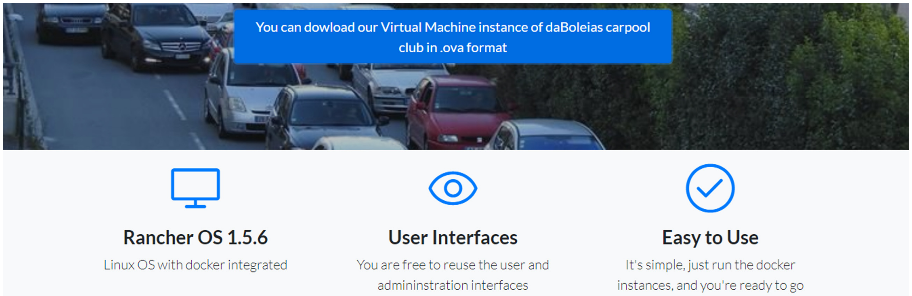

Fig. 24. Download screen for virtual machine

As future work, we intend to follow and adapt to our approach the progresses in Intelligent Carpooling System (ICS) [21], mainly the use of Global Positioning System (GPS) at real time to increase the flexibility of the negotiation for announcements subscriptions [22]. Explore available cloud environments, in order to develop a reference carpooling system as a native cloud application. Finally, we intend to take advantage of emergent improvements related to trust in semantic P2P architectures [23].

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