WeDoShare: A Ridesharing Framework in Transportation Cyber-Physical System for Sustainable Mobility in Smart Cities

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Abstract—**Sustainable urban mobility and traffic congestion are the key challenges in a smart city. Nevertheless, a sustainable mobility approach such as real-time ridesharing as a solution is likely to fail, if not integrated with actions aimed at increasing the awareness of citizens, encouragement through incentives and influencing their behavioral change. This article analyzes the possibility of quantifying an individual contribution towards sustainability and reciprocal incentive approach to encourage voluntary behavioral development towards sustainable mobility solutions. Further, the challenges faced by the interested carpoolers were analyzed. This work proposes an IoT-based framework called *WeDoShare* for real time ridesharing as a solution aimed at resolving the issues of carpoolers and quantifying their sustainability contribution with a reciprocal auto-incentive approach. Additionally, on top of social network, a gamification approach is proposed to involve, spread and engage the citizens in ridesharing activity.**

I. Sustainable Urban Mobility - A Brief Introduction

Sustainable urban mobility is the biggest concern in Smart Cities. Internet of Things (IoT) based solutions to the urban area problems makes a city, its citizen and its governance institutions smarter. However, the real implementation comes with many challenges [1], [2]. The road infrastructure in many urban areas are incapable of accommodating such a large number of vehicles on the roads. As a consequence, there is an increase in traffic congestion, average travel time per unit distance, fuel consumption per unit distance and carbon emission. The pollution caused by carbon emission from vehicles and traffic congestion is the biggest challenge that has arisen in many urban cities [3].

Several studies have been made to solve many smart city problems [4], [5] including the problem of ridesharing [6]–[8]. Mechanisms that are designed for sustainable mobility services can be successful only if they are accepted enthusiastically by citizens in a persuaded and continued way.

Ridesharing has failed in many smart cities. Some of the reasons behind this includes: (1) Lack of coordinating infrastructure which will smoothen the interaction between the on-road car and ridesharing, (2) Absence of trust and security, (3) Unwillingness to make negotiation for direct incentive from a user, (4) Unawareness or negligence towards sustainability, (5) Lack of people engagement in ridesharing, and (6) Most importantly a miss match of status and class. Mechanisms that create and manage effective incentives and pleasant way of doing this can help to break citizens' habits and affect their mobility choices, boost acceptance, and, will ultimately, make a difference in the urban environment. It is very challenging as it requires a combination of societal input, advanced IoT tools, and a common platform to integrate all agents involved in the process.

This article proposes a framework called WeDoShare (Fig. 1) that aims to provide an IoT-based platform similar to iTour [2], for easy integration of users within a set of IoT services. Such a platform will engage citizens in ridesharing

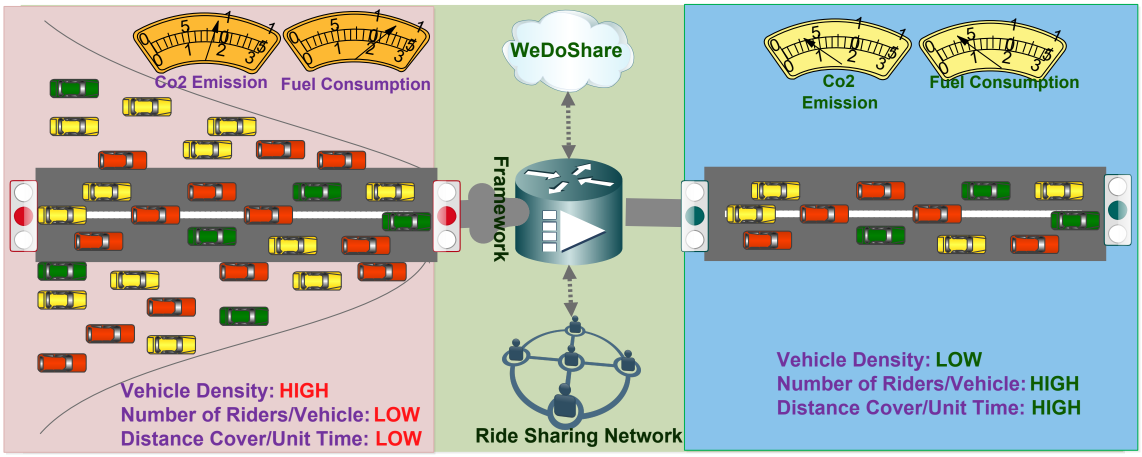


Fig. 1: Conceptual view of WeDoShare in an Internet-of-Things (IoT) based transportation Cyber-Physical System (T-CPS).

by spreading awareness, impacting in behavioral change and voluntary behavioral development towards participation. It provides a mechanism for auto encouragement among participants, personal or as a group sustainability contribution analysis, fuel saving statistics and carbon dioxide emission statistics.

II. RideSharing Problem Analysis in Smart Cities

Increase in Single Occupancy Vehicles (SOVs) is a key contributor towards the traffic congestion problem [7]. It also accounts for various other problems such as: increase in fuel consumption, carbon emission, illegal parking and delay in the travelling time. The presence of a large number of SOVs in cities at the peak hour has significantly escalated the rush and collision problem. This also add extra greenhouse gases and toxins like carbon dioxide and carbon monoxide.

Most of the urban cities, nowadays suffer from the problem of traffic congestion on a large scale [9]. This has significantly increased the cause of worry for the commuters because of the following: (1) It has drastically reduced their comfort of travel, (2) Driving is no longer fun due to the rush, (3) Upsurge in travelling time, as a matter of which productivity in professional life reduces, (4) Burning of extra fuel on a regular basis, (5) Chances of collision increases, (6) Rush hour driving increases the vehicle maintenance cost, and (7) Parking problem. An effort should be made to reduce the number of on road SOVs at the peak hours following which the traffic jam and the problems mentioned above will be reduced.

In recent years, many ridesharing mobile apps like Uber, Lyft, Gett, Juno, Curb, Wingz, Via, and Bridj have introduced. The ridesharing feature of these apps tries to fill all the seats of the cars that are headed toward popular destinations. In reality it is not contributing to reduce the on-road private vehicles. Ridesharing systems, such as [10]–[12] match passengers to SOVs to reduce travel costs, emissions and congestion. Most of these approaches targets single objectives, while real application may have other objectives. Our proposed model is completely different and it is based on social ride-sharing with continuous engagement. Further the key challenge of smart city solutions is the continuous involvement of citizens. This article try to minimize the gap between research and real applications, and handle the incorporated policies for a flexible ridesharing approach, for dynamic objectives.

III. Ridesharing and its benefits

The unused seats of on-road SOVs makes it a liability for the traffic and sustainability. Ridesharing can be a great effort towards maintaining a healthy traffic and sustainable environment [13]. It provides numerous benefits such as the following:

(1) Reduction in traffic congestion, (2) Reduction in carbon footprint and Travel cost, (3) Relax and Usable commute time while riding with other's vehicle, (4) Partial solution to parking problems, (5) Road safety due to reduced on-road SOV density, and (6) Improvement in mental and physical health due to drive less and getting chance to socialize at commute time.

A. Ride Sharing Data Through Crowdsourcing: A Case Study

The proposed framework is developed by collecting survey responses in the city of Bhubaneswar, Odisha, India. The data were collected through various questionnaires, web based responses, physical and verbal level survey. These are all real-data collected from different sources. This data can also be referred as the feedback data from the direct users.

It was observed that the SOV commuters contributes about 60% of the traffic in peak hours. Among this SOV commuters, 90% was comprised of the middle-class or working-class section of our society. A major fraction of this working class agrees that SOVs are a major contributor towards the problem of traffic. It was seen that almost all of them were aware of the ill effects of traffic jam like pollution, wastage of time and fuel. Around 80% of them were in favour of sustainable development and were willing to contribute, but lacked a potential method to contribute. When asked about ridesharing, a significant proportion of them agreed with the concept and were aware of the related benefits. Nearly 70% of them happened to be in favour.

B. Willing to Ride Share but not Participating, why?

The multifarious reasons behind the reluctance of the individuals includes the following: (1) A Ride Share User (RSU) may find it difficult to identify the on-road Ride Share Provider (RSP). (2) Since, both parties are strangers to each other, it may arises a concern for trust, safety and security. (3) Many a times, the RSU is reluctant in requesting an unknown person for a rideshare under the assumption that the latter would deny. (4) There is no surety that the on-road RSU and RSP that they have the same or common current travel plan. An unfavorable situation will arise if the fare expected by the RSP and the fare paid by the RSU mismatches. Negotiation for the fare would be an awkward scenario for both the parties. But if a RSP want to provide free rideshare, it may happen that the RSU feel guilty of taking a favour from unknown person. (5) Ride Sharing may extend the regular travel time. Depending on the current traffic and the available time to reach the destination, it is always a question whether it is possible to participate in ridesharing. For the RSUs, it is difficult to rely on ridesharing because for the required travel plan, they are not sure about the probability of getting an RSP. For a connecting rideshare, the proportion of area to be covered through walking is undetermined. (6) The possibility of compatibility of RSU in nature with the RSP is a great concern. (7) Absence of direct benefit or social recognition or social aid for ridesharing participants. (8) There are citizens who believe that they should contribute towards the problem of traffic congestion and sustainable development but limit themselves under the impression that individual effort will not contribute towards the solution. They do not intend to form a group which would make a significant contribution because it would consume a good amount of time in forming, organizing and coordinating the group which is practically impossible. These challenges induce the need of a system or infrastructure which could help in overcoming the setbacks.

IV. WeDoShare: A Novel RideShare Framework in Transportation Cyber-Physical System

The objective is to reduce SOVs. This is possible if all the stakeholders work together as a group. The major stakeholders among citizens are SOV owners, city transport department, and city police. If a framework is designed which would facilitate the coordination and cooperation among them, then it can attract all such SOV owners into participating in ridesharing and contributing towards making a better smart city, sustainability and availing the benefits of ridesharing. This work proposes an IoT-based framework called *WeDoShare* to address the issues of ridesharing and promoting long term engagement of SOV owners in ridesharing. The proposed *WeDoShare* framework is shown in Fig. 2. The first layer of *WeDoShare* consists of a LoRa [14] based IoT infrastructure for real time sensing and communication. The second layer supports backend communication. Third layer is the presentation layer. The *WeDoShare* architecture is shown in Fig. 3.

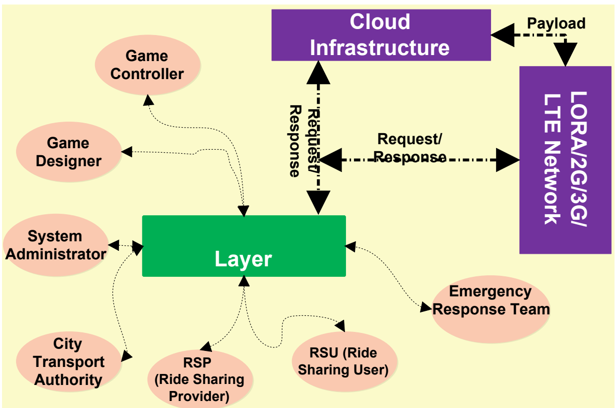


Fig. 2: A broad architecture of WeDoShare.

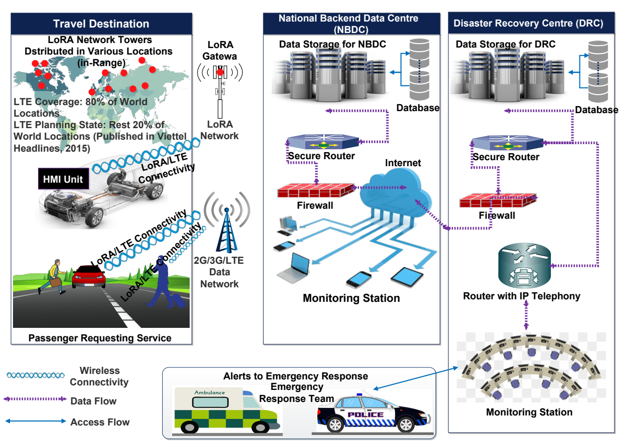


Fig. 3: WeDoShare: A detailed architecture using LoRA/2G/3G/LTE network distribution and backend infrastructure in T-CPS.

It may be noted that for a design alternative of WeDoShare both cloud-computing and edge-computing IoT paradigms can be considered. However, there are several limitations of edge computing over cloud computing for this specific application domain. Edge computing offers lots of promises and at the same time it has potential problems, specifically in terms of security and computational capabilities [15]. The limitation in edge computing is that the chip on the device may not be powerful enough to do everything and it may have to rely on the cloud because the power and the storage it can get is way wider than on the edge device. The cloud provider does not have control over the device, the result may not be trusted if someone tamper the device. Therefore, it doesn't guarantee enough trust or security. Thus, the proposed WeDoShare framework is based on a standalone HMI unit connected to the cloud service.

A. Infrastructure Layer

The proposed *WeDoShare* is based on cloud computing architecture. It has three basic building blocks such as Human Machine Interface (HMI) unit, LoRA/LTE network distributed throughout the destinations and Information and Communication Technology (ICT) infrastructure for data handling and decision making. The proposed HMI based solution is a hardware communication medium which handles all the necessary transactions with the cloud framework with minimum data transmission rate and latency. The proposed architecture gives primary emphasizes on important aspects such as security, privacy, safety, cost and continuous engagements. Therefore, the cloud based model is prefered for the proposed WeDoShare framework. The proposed HMI unit and network distribution mechanism are capable to transmit/receive information via four widely used different data transmission technologies such as LoRA/2G/3G/LTE. In addition to that, the system uses very minimum transmission rate as only few bytes of location information and user responses are need to be transferred to the cloud system. Therefore, current proposed communication technologies such as LoRA/2G/3G/LTE are the minimum requirements for the smooth operation of the large scale system deployments.

It may be noted that in the current scenario, the 5G network distribution is only limited to less than 10 percent and according to the world 5G network coverage statistics, the coverage may meet 10% by the year 2023. The HMI unit contains necessary modems which will also be compatible with 5G based services which doesn't require any further additions in the auxiliary hardware during 5G based communication.

The complete architecture has two distinct back-end stations such as National Backend Data Centre (NBDC) and Disaster Recovery Centre (DRC). The NBDC is an established infrastructure to manage vehicle booking, location tracking, real-time sensing, transactions and historical data management. Further, the DRC is an infrastructure to provide emergency services during any situations. The detailed architecture of the HMI unit is portrayed in the Fig. 4. The HMI unit is an embedded platform with LoRA transceiver, 2G/3G/LTE modem and auxiliary sensors managed by android OS. The platform is capable to communicate with LoRA/2G/3G/LTE. The sensors, LoRA modem and 2G/3G/LTE modem are enclosed in an IP Enclosure. The main computing board is an ARM Cortex A9 motherboard with auxiliary extension board for sensor interfacing. The LCD screen is connected to the ARM board with HDMI interfacing and the wireless modules such as LoRA/2G/3G/LTE are interfaced with RS232 connection with the main board.

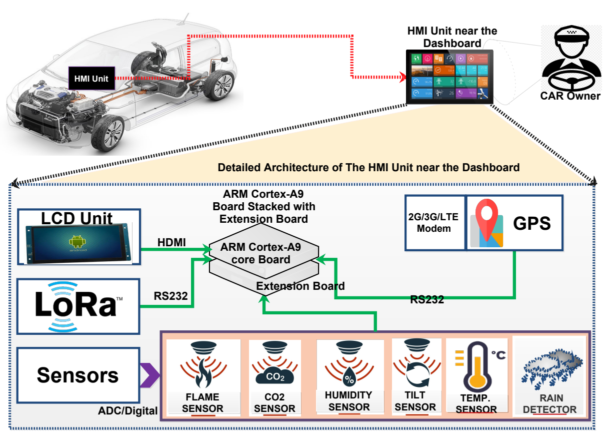


Fig. 4: Internal structure of the HMI unit at the dashboard.

B. Central Control Unit: CCU

This is a cloud based computational unit which behaves like an operating system of the *WeDoShare* system. It takes real time sensing data such as location, real time traffic status, CO_2 level, sound pollution level etc. from layer 1. It provides a back-end facility for the end user at the presentation layer to perform Human Machine Interaction (HMI).

C. Presentation Layer

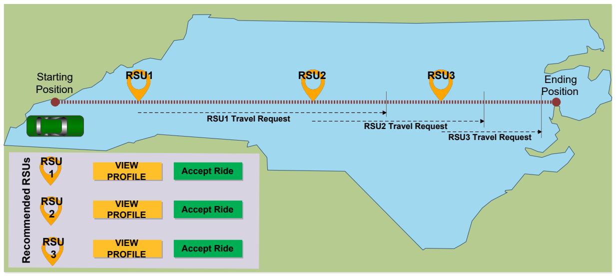
On top of the CCU different type of HMI functionalities are created. The features of such functional units are described as follows:

1) Registration and Authentication: To participate in the *WeDoShare* system, one has to be a car owner. One has to register himself by providing an identity document, Driving Licence Number, Vehicle Registration Number, Mobile number finger print and occupation. The user can mention the features that is require in a co-traveller. The CCU will make a pre-verification of the genuineness and authenticity of the individual then acknowledge the registration status. It will play a vital role to take the participants in confidence.

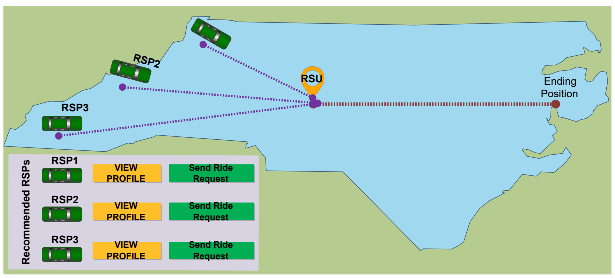
2) Smart Map: As a RSP or RSU one can interact with the *Ride Share* system through smart map. As a RSP one can switch on his smart map in his HMI device. It will ask the RSP to set starting and ending point of his current journey and number of RSU to be accepted. As per one's preferences or past history of co-travelers it will suggest RSPs some most suitable RSUs locations and their destinations. Among them, a RSP can send an invitation to the RSUs or receive requests from RSUs one may accept them. The conceptual design of RSU and RSP interaction is presented in Fig. 5a and 5b, respectively. For security reasons, at realtime interaction between RSU and RSP one can view restricted version of the profile of others such that personal identity will not be disclosed.

3) Auto Incentive: Once an RSP accepts an RSU and provides the ride then the system will automatically credit one *Ride Coin* (RC) which will be deducted from the RSU. The *WeDoShare* system provides some amount of RC as an initial seed coin which will be deducted once the user earn enough RCs. This RC system solves the problem of negotiation between RSU and RSP. One can earn by becoming RSP and can spend RCs by becoming RSU. As a result the RSUs can use this system with conveniently.

4) Travel Time Estimator With or Without WeDoShare: Once a participant plans to use *WeDoShare* system as an RSU, with a particular travel plan for a particular time of the day, the system will show the frequency of availability of the ride shares. If direct ride frequency is less then it will



(a) for RSU



(b) for RSP

Fig. 5: Smart maps used in WeDoShare.

show the possible two or three connecting options and the frequency at each sub part. It will also show the distance that need to be covered by walk in the connected regions. For an RSP with a particular travel plan, *WeDoShare* will show the estimated travel time with and without *ride sharing* and current on road density of RSU in the same route. By considering the current traffic status the system will show an approximation of travel time with and without *WeDoShare*. This will help the user in deciding whether to go for *WeDoShare* or not. The RSU travel time estimator is presented in Fig. 6.

5) Real Time RSU and RSP Suggestions: Based on the personal profile details which was registered and the mentioned preference on the nature of co-RSU or co-RSP, the system will analyse real time active users and suggest only if it matches with the preference.

6) Sustainable Points: Reduction of on-road SOV will contribute towards traffic jam reduction and less traffic signal waiting time. This results reduction in fuel consumption, sound pollution, air pollution and travel time. This contribution will be a sustainable devlopment contribution. As both RSP and RSU are equally responsible for this development the system will assign sustainable development point or green point (1 GP/km) to both. This GP will be the measure of one's contribution towards sustainable development. *WeDoShare* will keep track of the number of on-road SOVs reduced and total GP of the system. This is a parameter of the contribution of whole RS system towards sustainable development.

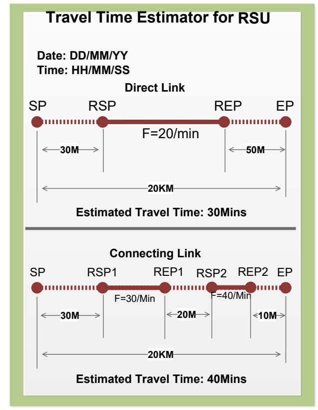


Fig. 6: RSU travel time Estimator.

V. WeDoShare Social Nework

Many solutions are presented through Smart Cities considering technical and societal point of views. However, the solutions provided again appear with many challenges. The key challenge here is to promote and facilitate the growth of individuals and conjoint behavior of the citizens to support and foster the *WeDoShare*. One of the major dimensions and important issues for the solution of the ridesharing is the Behavioral Change (BC) [16]. The continuous involvement and contribution to *WeDoShare* can bring significant effect in BC and will add a lot to the sustainable development. It is important to explore the potentiality of Social Network and to use the gamification as a effective tool. The objectives of BC are always dynamic in nature. Seamless involvement of the stakeholders will make *WeDoShare* successful. The continuous engagement of people in *WeDoShare* as a Social Network (WDSSN) has equal importance as of the design of *WeDoShare*. The WDSSN keeps RSPs and RSUs involved in the process which results in better functioning of the system for long future.

WeDoShare Social Network (WDSSN) provides a mechanism to form a social network with primary objective of promoting *WeDoShare*. It has facilities of inviting the car owners to join in the group. The group expands with increase in inclusion of car owners. The members can invite other car owners to the group. The group, in return forms a large Network. The conceptual picture of WDSSN is presented in Fig. 7. The WDSSN aims at dispersing the benefits of ridesharing in a large extent to the members. This will result in addition of many new and old friends to the WDSSN. In addition to this, there will be an increase in trust among the co-passengers and that will make the co-passengers feel more secure. This activity has a fair chance of change in a citizen's attitude towards ridesharing in a positive direction. RSPs & RSUs will definitely enhance their trust and they can travel satisfactorily if they both belong to the same network or may be 2/3 hops distance apart in the network.

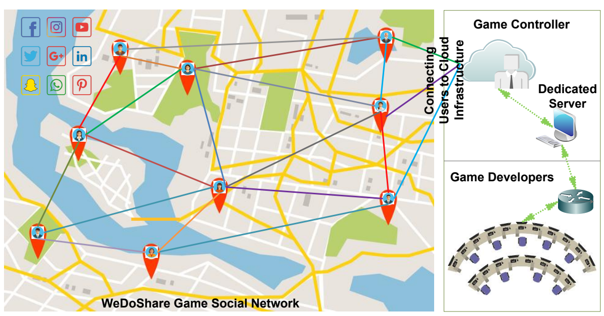


Fig. 7: *WeDoShare* Social Network (WDSSN).

Further, there will be a game facilitator which will float different interesting ridesharing games. A winner or a set of winners are selected based on their performance in games and they will be awarded different badges/points/stars to recognize their contribution towards sustainable development. For example: (1) A gold/ silver/ bronze badge award to the participants if their Green Point (GP) score crosses a certain threshold, (2) A certificate from the Transport department as a sensible citizen for his/her sustainable contribution by winning a challenge, (3) The city transport authority may issue some coupons to the winners in the game which can be reimbursed in some facility centers like petrol pump, shopping malls, and theaters.

VI. Conclusions and Future Directions

Sustainable mobility is one of the major concern in smart cities. This article presented an IoT framework called WeDoShare. In WeDoShare, willing citizens can participate to minimize many existing challenges of smart cities associated with on-road traffic. This article presents the issues and challenges of the sustainable mobility. The effectiveness of the proposed WeDoShare framework will be proved through in-depth evaluation in a smart city by involving all stakeholders.

We continue our work to extend the proposed framework to support the dynamic gamification approach aiming continuous engagement of citizens in WeDoShare. Further, we plan to provide an experimental evaluation of the usability and practical effectiveness of the proposed framework in different urban areas.

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