Energy sharing system among vehicles on a vehicular network

Walter Balzano, Antonio Lanuto, Erasmo Prosciutto, and Biagio Scotto di Covella

Abstract In today's mobility landscape, characterised by an accelerated transition towards electric vehicles, significant challenges emerge related to the management of battery recharging. This paper proposes a solution for energy sharing between electric vehicles, inspired by the effectiveness of wireless charging technologies for smartphones and integrating the use of VANET networks. Through communication techniques such as V2V and V2G, we aim to develop a system that not only alleviates charging issues, but also promotes more sustainable mobility and optimised use of energy resources.

Key words: Energy Sharing ; VANETs ; Client-Server

1 Introduction

The rise of electric vehicles (EVs) represents a major step towards more sustainable mobility. An MIT study, 'Insights Into Future Mobility', compares vehicles in different configurations, showing that battery-powered all-electric vehicles emit about 200 grams of CO_2 per kilometre, significantly less than the more than 350 grams per kilometre of petrol-powered vehicles [5]. EVs help improve air quality by reducing or eliminating emissions of pollutants such as nitrogen oxides and particulate matter, which are common in combustion vehicles. But the advantages of electric vehicles do not stop at environmental aspects alone, but also issues such as lower operating costs. A study from the U.S. Department of Energy Office of Scientific and Technical Information highlights that the estimated scheduled maintenance cost for

University of Naples, Federico II
Balzano W. e-mail: walter.balzano@gmail.com · Lanuto A. e-mail: antoniolanuto@outlook.it · Prosciutto E. e-mail: erasmo.prosciutto@gmail.com · Scotto di Covella B. e-mail: biagioscottodicovella@gmail.com

a light-duty battery-electric vehicle totals 6.1 cents per mile, whereas for a conventional ICE vehicle, it's 10.1 cents per mile [8].

Energy sharing among vehicles is an innovative concept that aims to reduce the carbon footprint of transportation. In this model, vehicles share their excess energy with other vehicles or the electricity grid, which can help reduce greenhouse gas emissions and promote the use of renewable energy sources.

Electric vehicles are the primary vehicles that can share energy among each other. This is made possible through the use of advanced technology, such as vehicle-to-grid (V2G) [4], vehicle-to-vehicle (V2V) [6] and wireless charging [1]. V2G technology allows electric vehicles to share their excess energy with the electricity grid, which can help balance the supply and demand of electricity. When an electric vehicle is parked, it can be connected to the grid and supply electricity during times of peak demand. This can help prevent blackouts and other energy-related problems.

V2V technology enables vehicles to share energy with one another through a wireless communication system. This allows vehicles to exchange energy while driving, which can extend the range of electric vehicles and reduce the need for frequent charging. The technology behind V2V energy sharing is still in development, but it has the potential to revolutionize the transportation industry.

Wireless charging allows electric vehicles to charge wirelessly, eliminating the need for cords or charging ports. It can be done in a parking lot, a garage, or even on the road. This technology is still in the early stages of development, but it has the potential to make charging electric vehicles more convenient and accessible.

Energy sharing via electric vehicles can optimize the use of existing infrastructure, reducing the need for new construction. This system allows vehicles to feed energy into the grid during peak demand, alleviating the need for new power plants and transmission lines. This approach not only generates significant economic savings but also helps to decrease the environmental impact of building new infrastructure, promoting more efficient and sustainable use of energy resources.

Energy sharing can also help reduce the cost of electric vehicles ownership by allowing owners to earn money by sharing their excess energy. This can create a new revenue stream for owners and reduce the cost of owning an electric vehicle. As the technology behind energy sharing becomes more advanced and widely adopted, the potential benefits for owners are expected to increase.

There are currently about one billion cars on the road in the world (source: report.rai), of which only 0.2% are electric. Recent research [3] has shown that sales of electric cars are increasing exponentially year by year. Currently, the market for electric cars is booming, but many users and potential buyers are still hesitant about buying an electric car, mainly because of the timing of charging the batteries of electric vehicles. In fact, electric vehicles currently require at least 30 minutes to recharge up to 80% using the fastest charging stations. And it is in this scenario that we introduce a possible solution to make recharging faster and less dependent on fixed charging stations.

2 Related Work

In recent years, the scientific community's interest in the concept of energy sharing between vehicles has grown significantly. This has led to various research papers exploring various perspectives and approaches to optimise the energy efficiency and reduce the environmental impact of electric vehicles. Some of these facets are addressed, for example, in a recent paper [7], in which the authors examine the main issues related to energy exchange between vehicles, such as energy exchange prices, vehicle parameters, and user privacy and security issues.
A key issue concerns the development and regulation of energy exchange costs and markets. In this regard, the article [9] aims to optimally implement vehicle-to-vehicle (V2V) energy exchange in the Internet of Things for Vehicles (IoEV) environment, making use of a blockchain-based system.
Vehicle-to-vehicle energy sharing is also based on the idea of a world in which each vehicle can recharge its energy in a fast and distributed manner. An interesting contribution to this topic is presented in the article [10], which explores the study of an interactive network between buildings and vehicles, using energy flexibility evaluation criteria that can be quantified.
In our paper, a crucial aspect is to understand the relevant energy sources in the system. In particular, we take inspiration from the approach outlined in the landmark article [2], in which the most relevant web sources are carefully chosen through a detailed analysis of a hypergraph in a social multimedia network. This approach could provide a meaningful starting point for the selection of vehicles, enabling the identification of those that offer an energy situation consistent with the user's needs.

3 The idea behind the Energy Sharing

To understand the idea behind the energy sharing system to be developed, let us first introduce an example and then go into the specifics later. The basic idea is developed from what already exists: the exchange of energy between two smartphones using the physical principle of electromagnetic induction. Just as two smartphones exchange energy, replacing mobile phones with two cars, we hypothesise an exchange of energy between neighbouring cars. Specifically, we imagine that we are within a vanet network, and we imagine that we have access to information such as vehicle location, vehicle energy level, and also the destination and relative route being taken. With this information, a vehicle that is in our system and needs a significant amount of energy, either to complete its journey or to arrive safely at the next charging station, can request and receive energy from a nearby vehicle willing (according to certain parameters later explained) to give up energy. Two types of energy exchange systems are hypothesised:

- Normal Sharing System
- Emergency Sharing System

These two systems work simultaneously, but have two different tasks. In particular:

1. The first assumes a system condition where the user would not need energy to complete the journey or to arrive at the first charging station, but may request extra energy from another car so as not to have to stop at the charging station to recharge the car or for his or her own safety in completing the journey.
2. The second, on the other hand, assumes an emergency situation in which the car to be assisted does not have enough energy to reach the nearest charging station and may, as a result, stop suddenly. In this case, the system sends a car (or a user) to 'rescue' in order to help the car in trouble and provide it with the energy it needs to get to the next charging station.

In both cases, the system takes into account a number of values that allow it to determine which car is suitable for the energy exchange.

4 Development Environment

The implementation of the energy sharing system in a Vehicle Ad-hoc Network (VANET) requires each car to have the capability to set its travel route autonomously. This enables the system to calculate the energy threshold of each vehicle, a concept we define as ***T.E.S.*** (Threshold Energy Sharing). The T.E.S. is a critical value, representing the ratio of a car's remaining energy in terms of kilometers to the preset energy level required to reach the next charging station. This equation is pivotal:

$$T.e.s = \frac{E_{Remaining-Km-Possibly}}{E_{Remaining-Km-C.Station}} \tag{1}$$

This system's scalability and adaptability are significant, as it can dynamically map the number of cars in need of energy and those capable of assisting nearby. A unique feature is the dynamic calculation interval, $\boldsymbol{\Delta}_t$, allowing T.E.S. values to be updated based on vehicle density and network traffic patterns.

4.1 Enhanced Vehicle Status Dynamics

Each vehicle's status within the network is more than just its T.E.S. value. We introduce a comprehensive variable named "**Status of Car**," encompassing various operational states. The enhanced states are:

- **Ready** - Vehicle is fully prepared for energy exchange.
- **Pairing** - Vehicle is matched with a partner and is preparing for energy transfer.
- **Charging** - Vehicle is actively engaged in energy exchange.
- **Not Ready** - Vehicle is currently unable to participate in energy sharing.
- **Navigation** - Vehicle is in transit, potentially adjusting its route based on T.E.S. and network conditions.
- **Standby** - Vehicle is in a low-power state, conserving energy but still connected to the network.

5 Refined System Structure

Our energy sharing system's structure leverages a sophisticated multigraph approach, as depicted in Figure 1. This structure not only manages the distribution of vehicles and charging stations but also incorporates real-time traffic data and environmental factors, making the system more responsive and efficient. The graph G=(V, E) now includes dynamic nodes and edges, reflecting the ever-changing nature of the network.

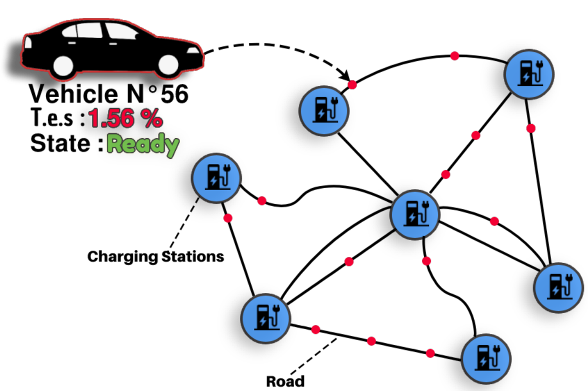

Fig. 1 Advanced Multi-graph Representation of the Energy Sharing Algorithm

6 Enhanced Algorithmic Approach

The algorithm, at its core, is designed to be highly adaptable, catering to varying scenarios within the network. We distinguish between two primary modes of operation:

6.1 Enhanced Normal-Sharing

This mode represents the standard operational state. Here, the categorization of vehicles is refined:

- **Energy Provide Car -** These are high-capacity vehicles, potentially with renewable energy generation capabilities (like solar panels), serving as mobile charging stations.
- **Client Normal Car -** Regular users of the network, now with enhanced decision-making algorithms for selecting optimal energy providers based on efficiency, cost, and proximity.

6.2 Advanced Emergency-Sharing

This mode is activated under critical conditions. The system becomes more proactive in this state, with the following refined categories:

- **Client Emergency Car -** Cars in critical energy states can now activate an advanced AI-assisted emergency protocol, optimizing their chances of receiving timely assistance.
- **Neutral Car -** These vehicles act as intermediaries, capable of relaying information or even small amounts of energy to support the network.
- **Energy Special Car -** In emergencies, these vehicles can act as mobile energy hubs, providing substantial support to those in dire need.

This enhanced approach ensures that the energy sharing system is not only efficient and scalable but also robust and capable of adapting to various scenarios, ranging from everyday commutes to emergency situations.

7 Case Study: Implementing an Advanced VANET-based Energy Sharing System in an Urban Environment

7.1 Scenario Overview

In this case study, we examine the deployment and operation of an advanced Vehicle Ad-hoc Network (VANET) energy sharing system in a bustling urban setting. The scenario chosen is a typical weekday in a densely populated city center, characterized by heavy traffic, a diverse mix of electric vehicles (EVs), and a network of charging stations. The focus is on demonstrating the system's ability to facilitate efficient energy distribution among EVs, adapt to varying energy demands throughout the day, and respond effectively to emergency energy needs.

7.2 Dynamic Energy Management during Peak Hours

During the morning rush hour, a high volume of EVs enters the city. The system actively monitors and calculates the Threshold Energy Sharing (T.E.S.) values for each vehicle. Vehicles with higher T.E.S. values are identified as potential energy providers, while those with lower values are marked as potential energy receivers. As the day progresses, the system continuously updates these values and vehicle statuses, optimizing energy distribution and ensuring that vehicles with lower energy reserves can receive support from those with surplus energy.

7.3 Emergency Energy Sharing in Critical Situations

A critical test of the system occurs when an EV, heavily utilized throughout the day, finds its energy reserves depleted, insufficient to reach the nearest charging station. The driver activates the Emergency-Request-Energy-Sharing (E.R.E.S.) protocol. The system quickly classifies the vehicle as a Client Emergency Car and broadcasts an emergency signal to nearby vehicles. An Energy Special Car with a high T.E.S. value responds and navigates to the client's location. A secure energy transfer is conducted, enabling the client car to safely reach a charging station or its destination.

This case study shows a potential application of the advanced VANET-based energy sharing system in an urban context. The system not only improves the efficiency of energy distribution among electric vehicles, but also demonstrates its robustness in responding to emergency situations. The knowledge gained in this scenario provides valuable data for further refinement of the system. Future research could explore integration with smart city infrastructure, improvement of artificial intelligence algorithms for predictive energy management, and incorporation of renewable energy sources to further increase the sustainability and efficiency of the system.

8 Economic Structuring of the Energy Exchange System

The energy sharing system just described also lends itself well to developments in the economic field and is well suited to a profitable energy exchange not only for those who receive energy, but also for those who give it away. It is therefore intended to present a possible basis for the regulation of remunerated energy exchange. In particular, in the pay system we can banally distinguish two categories of users: the buyer and the seller of energy. Specifically, the pay system is managed by an algorithm which, on the basis of certain parameters later explained, provides the cost that a buyer user must give up in order to provide himself with the amount of energy required to complete his journey. With this in mind, a higher reward must be imagined for those who perform an emergency sharing system, compared to those who perform a normal sharing system.

On the other hand, we have some rules for even cars that can actually perform energy exchange, in detail, we have that a client car in emergency mode, can request energy from both cars in emergency mode and cars in normal mode. Unlike a client car in normal mode, which can only request energy with provider cars in normal mode.

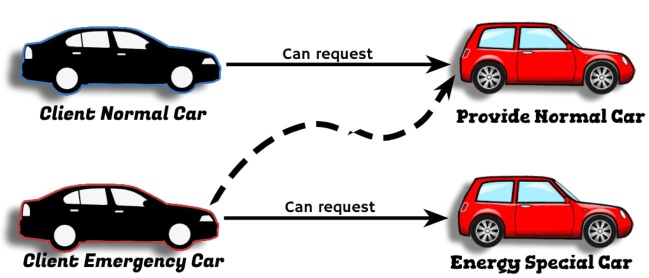

Fig. 2 System exchange rules

9 Future Uses

Let us conclude the discussion so far by introducing several possible scenarios in which energy sharing could be applied. In particular, we want to talk about how energy sharing can have a very strong source of economic development, as it is possible to imagine energy exchange both as an effective help for those who receive energy, but also as a source of economic gain for those who give energy. With this in mind, it is not far-fetched to imagine possible investments by energy companies in this new market. Indeed, assuming that the surrendered energy is somehow bought by the receiving users, it is also possible to imagine the introduction of ***M.E.R.*** cars (mobile energy rechargers) into the energy sharing system. ***M.E.R.***'s are nothing but new types of cars, equipped with any type of battery, and entering our system in the form of mobile recharging stations. These cars could be operated by external companies, which, for profit, would introduce new charging methods for users into the system. We can therefore say that energy sharing winks a lot at being a revenue-generating system, not only for companies that want to invest in it, but also for individual users who decide to be 'special' users, i.e. users with ***M.E.R.*** cars. Obviously, energy sharing being a new system for recharging cars, it can be declined in various fields and various uses.

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