# Examining Distributed Ledger Technology (DLT) for V2X Communication: A Self-Organizing Renewable Energy Grid using the IOTA 2.0 Framework

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# TABLE OF CONTENTS

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# CHAPTER ONE

# INTRODUCTION

## 1.1   Problem Statement

With driverless cars already operational in a number of countries, autonomous driving systems are rapidly becoming a reality as a mode of intelligent transportation. It has been predicted that by 2025 there will be over eight million vehicles on our roads with level three and above autonomy [1], based on the SAE definitions for automation systems for on-road motor vehicles [2]. Vehicle-to-everything (V2X) communication is an over-arching term that encapsulates vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P). With the projected rate of growth in vehicles of this magnitude, finding a way for these vehicles to communicate with each other, with users and with their environment that is secure, scalable and standardised remains an open research question [3]. From a security perspective, a number of challenges still exist including availability (flooding, blackhole and greyhole attacks), data privacy (eavesdropping, location tracking, non-repudiation), data integrity (injection, replay and spoofing attacks) and authenticity (Sybil and man-in-the-middle attacks) [3]. From a scalability perspective,  it is estimated that 125 million cars with embedded connectivity will ship between 2018 and 2022, which will lead to higher traffic and usage of autonomous vehicle services and applications and their supporting DSRC and C-V2X protocols. In addition to this, as the industry moves towards autonomy, these supporting services and applications will also need to be autonomous to capture the benefits and opportunities of autonomous vehicles. In terms of standardization, there is no universal standardised framework for V2X integration. Many of the standards for 5G communication are still under development, and standards differ across countries, geopolitical areas and consortiums [4]. The lack of operability among heterogeneous devices poses a challenge to adoption rates of autonomous vehicles [3].

## 1.2    Rationale For Research

Approximately 94% of all serious accidents on roads are due to human error [5]. Autonomous vehicles have the capability to dramatically increase safety on our roads, which is beneficial on both an economic and societal level. From an environmental perspective autonomous vehicles can provide smooth traffic control, a reduction traffic congestion and vehicle ownership, cutting fuel cost and vehicle emissions [5]. The current challenges for V2X communication outlined in the problem statement (security, scalability and standardisation) could hinder the rollout and adoption of autonomous vehicles and inevitably the benefits that come with them. In order to solve for these issues a ubiquitous communication platform for frictionless data and value transfer between machines and humans that is secure, scalable and standardised may be the solution to this problem.

This is the promise by the open-source IOTA Framework. The IOTA framework is a relatively new Distributed Ledger Technology (DLT), a term synonymous with the recent blockchain paradigm. A distributed ledger is a database of recorded transactions between two parties that is shared and synced across multiple sites, institutions or geographies that is accessible by multiple people. The core principle of the IOTA network  is "The Tangle", which is a Directed Acyclic Graph (DAG) data structure that the network is formed around. The IOTA Foundation (a non-profit organization and creator of IOTA) defines the Tangle as the first distributed ledger technology solution built for the "Internet of Everything" that enables relationships between machines and humans through a network designed for exchanging value and data [6].

From a security perspective, distributed ledger technologies provide accurate and immutable records for data exchanges and interactions between users, vehicles and infrastructure. They are more resistant than the traditional client-server architectures to the aforementioned cyber-attacks such as Sybil and man-in-the-middle attacks due to the removal of the centralized server as a single point of failure [7]. Once a transaction is confirmed and added to the network, it cannot be modified or tampered with. Each time a transaction is added to the network, a cryptographic problem needs to be solved, which requires some  computational power. This is called "Proof-of-Work" (PoW). The Tangle network uses PoW to discourage spamming through adapting the difficulty of the

cryptographic problem to be solved if a node tries to spam the network. This has the potential to reduce the likelihood of Brute-Force and DDoS attacks on AVs and their supporting infrastructure.

From a scalability perspective, the Tangle network operates in such a way that it is more performant the more nodes participate in the network. In essence, it gets faster the more users it has [8].

From a standardisation perspective, the IOTA framework is open-source, feeless and can be run on any type of computing device that is connected to the internet. This is in contrast to the current state-of-the-art in V2X communication protocols. Already there are two protocols for V2X communications, namely the DSRC protocol developed in the US [9] and the ITS-G5 protocol developed to be the European standard [10], showing a divergence in approaches on a global level.

In recent years, DLT networks, particularly Proof-of-Work (PoW) networks have faced scrutiny over the energy cost of running their underlying networks. Each time a transaction is added to the network, a cryptographic problem is presented to the network to be solved or "mined" by a "miner", which requires computational power and thus consumes energy. As a reward for this work, the miner that solves the problem first gets rewarded. Most notably, the Bitcoin network has been estimated to consume between 73 and 78.3 terrawatt-hours (TWh) per year due to this mining approach [11]. The Tangle network, by comparison, has no miners and all PoW is done on the node where the transaction originates, thus resulting in a drastic reduction in energy consumption to run the network. A recent paper classified the IOTA network as "exceptional" when comparing the network to other networks and payment protocols such as Bitcoin, Ethereum, VISA and Mastercard [12].

In order to explore the IOTA framework, a use-case scenario is presented in this research proposal. The use-case scenario to test the applicability of the IOTA framework will be a **smart connected energy grid** simulation**.** The general idea is that charge points and autonomous vehicles can communicate over the IOTA network to optimise the supply and demand of energy consumption and production, utilising the

autonomy of the vehicles to self-organise and charge themselves without human intervention.

In terms of the use-case scenario; there are many potential advantages to investigating this use case:

1) The ability for the IOTA framework to provide seamless data and value transfer between charge points and autonomous vehicles can be tested.

2) When there is excess energy being produced by energy sources (solar, wind) the supply can be more dynamically priced so that energy becomes cheaper as a function of its supply and demand.

3) Machine learning models can be deployed to create a smart grid; where vehicles can forecast the generation of energy at charge points at any point in time.

4) Autonomous vehicles could collectively provide a battery storage system for a glut of renewable energy.

5) Autonomous vehicles could sell energy back to the grid when the demand is high using the IOTA protocol.

6) Private charge points could potentially be connected to the IOTA network and used as a revenue stream, promoting the production of renewable energy charge points.

The IOTA framework has already been proven to work in a number of use cases, and this is further expanded upon in the literature review. However, as of September 2021 the IOTA foundation launched IOTA 2.0 with a number of radical upgrades, including a fully decentralized network, more robust security features, marking an important milestone in the IOTA foundation history [13]. The IOTA foundation have also, as of 2021, introduced smart contract capabilities [14]. Smart contracts are digital contracts stored on a blockchain that automatically get executed when predetermined conditions are met [15]. Combining the IOTA framework with smart contract functionality could have huge potential for automating service and applications within the autonomous vehicle eco-system. As of today this space has been relatively unexplored.

## 1.3   Purpose and Scope

This research has two purposes. The predominant purpose is to examine the demonstrate the benefits and limitations of the IOTA 2.0 Framework for V2X communication (data and value transfers).  To be specific, this research will:

1) Compare DLT to the current state-of-the-art to traditional architectures.
2) Identify the benefits and limitations of the IOTA Framework.
3) Quantify the ease of developing decentralized applications using the IOTA framework.
4) Propose an approach to deploying next-generation applications for autonomous vehicles.
5) Highlight future applications and areas for future research.

The scope of this research will be limited to a simple use-case scenario: A smart grid, with a set number of energy producers and energy consumers,  where the connected autonomous vehicles (the consumers) can decide when to go and get charged at charge points (producers), based on availability of energy at nearby charge points.

## 1.4   Hypothesis

In order to examine the new IOTA 2.0 framework and its applications in detail, the following hypothesis is proposed:

**The IOTA framework can be used as a viable V2X communication layer that allows for secure and scalable data and value transfer between autonomous vehicles and charge points in a self-organizing renewable energy grid.**

# CHAPTER TWO

## Literature Review

The IOTA framework has already demonstrated value in a number of areas. In [16] a DLT-based charging and billing mechanism for EAVs was proposed to demonstrate machine-to-machine (M2M) micropayments for electric vehicles. The study conceptualised the charger-to-vehicle relationship using a Raspberry Pi and a temperature sensor; and created a framework that demonstrated the viability of using the Tangle for transferring value from one machine to another. In [17] the authors examined the Tangle as a viable alternative to the shortcomings of traditional blockchains for vehicular applications, namely large transaction confirmation times, concluding smaller transaction delays as well as high performance using the encryption mechanism provided by the Tangle.

From an implementation perspective, Jaguar Land Rover, in collaboration with the Mobility Open Blockchain Initiative (MOBI) have demonstrated a system using the IOTA framework that allows drivers to earn cryptocurrency by allowing their cars to report useful road conditions including potholes and traffic congestion to authorities and navigation providers [18]. Another interesting project based on the IOTA framework was carried out by the research institute ElaadNL who have created "the first ever IOTA-based EV charging station" [19]. This research group built both the charging station hardware as well as the IOTA software and demonstrated how IOTA can be used to monitor energy usage.

In [20] and [21] the use of the IOTA framework for access control of IoT systems (information which would traditionally be stored on a centralized server) was investigated. Both studies proved that the framework was lightweight enough to create a decentralized and scalable access control framework solution for IoT devices.

From the perspective of the use case scenario, a self-organizing connected renewable energy grid, there have been a number of approaches to this. [22] looked at modelling shared autonomous electric vehicles from the perspective of the benefits to the energy

grid. Using a case study in Tokyo, this research showed that shared autonomous electric vehicle fleet would only need to be about 10 – 14% in comparison to a fleet of private cars based on today private vehicle ownership levels. Optimising the charging schedules of this  reduced fleet size of connected autonomous electric vehicles has the potential to act as an energy storage solution for surplus renewable energy. This was demonstrated in [23] where it was proposed that autonomous electric vehicles could absorb 50% of the yearly excess renewable energy generation that would have to be otherwise curtailed, in a forecasted model for Germany in 2030. Linking these ideas using V2X communication over the IOTA network for data and value transfer between machines is the core idea of the use-case scenario for this research.

# CHAPTER THREE

## Methodology

### 3.1 Research Design

This research will comprise of a comprehensive study of the literature and IOTA documentation and a computer model or simulation. Simulation in this context is defined as the use of computer software for quantifying and building an operating model of real world processes, facilities, events and systems [24]. In this cases the process involved will be the charging of autonomous vehicles, the facilities will be the charge points and vehicles and the events will be the deterministic organisation of autonomous vehicles and charge points as a function of energy availability and proximity. The simulation will be modelled and built on the IOTA technology using the Python language and libraries, with the best available real-world data (including but not limited to population densities in Ireland [25], location of charge points in Ireland [26], renewable energy generation data [27]).

### 3.2 Procedure

A systematic procedure will be taken in order to achieve the research objectives outlined below:

**Objective 1: Identify the benefits and limitations of using IOTA framework for V2X communication in comparison to traditional communication architectures**

**Objective 2: Develop a simulation powered by the IOTA framework that can demonstrate the benefits of a smart connected grid in comparison to a traditional energy grid**

**Objective 3: Quantify the difficulty in building an application on the IOTA framework**

**Objective 4: Use the outputs from Objectives 1-3 to highlight areas for future research and development**

## 3.3 Project Plan

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Project Plan for Dissertation** | | | | | | | | | | | | | | | | | | | | | | | | |
| | Month | November | | | | December | | | | January | | | | February | | | | March | | | | April | | | |
| | Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 1 | Read Literature & Learn IOTA Framework | � | ▪ | ▪ | ▪ | ▪ | | | | | | | | | | | | | | | | | | | |
| 2 | Finalise Objectives | | | | ▪ | ▪ | | | | | | | | | | | | | | | | | | | |
| 3 | Write Literature Review | | ▪ | ▪ | ▪ | ▪ | ▪ | | | | | | | | | | | | | | | | | | |
| 4 | Devise Research Approach | | | | | | ▪ | ▪ | ▪ | | | | | | | | | | | | | | | | |
| 5 | Write Up Research Approach | | | | | | | ▪ | ▪ | ▪ | | | | | | | | | | | | | | | |
| 6 | Develop Simulation | | | | | | | | | ▪ | ▪ | ▪ | ▪ | ▪ | ▪ | | | | | | | | | | |
| 7 | Analyse the Result | | | | | | | | | | | | | ▪ | ▪ | ▪ | ▪ | | | | | | | | |
| 8 | Write Up Remaining Chapters of Dissertation | | | | | | | | | | ▪ | ▪ | ▪ | ▪ | ▪ | ▪ | ▪ | ▪ | ▪ | ▪ | | | | | |
| 9 | Draft Submission | | | | | | | | | | | | | | | | | | | | ▪ | ▪ | | | |
| 10 | Review Changes from Draft Submit | | | | | | | | | | | | | | | | | | | | | ▪ | ▪ | | |
| 11 | Print, Bind, Submit | | | | | | | | | | | | | | | | | | | | | | | ▪ | ▪ |
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# References

[1]     ABIResearch. "ABI Research Forecasts 8 Million Vehicles to Ship with SAE Level 3, 4 and 5 Autonomous Technology in 2025." https://www.abiresearch.com/press/abi-research-forecasts-8-million-vehicles-ship-sae-level-3-4-and-5-autonomous-technology-2025/ (accessed October 31, 2020, 2020).

[2]     *Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*, S. International, 2021. [Online]. Available: https://www.sae.org/standards/content/j3016_202104/

[3]     A. Alnasser, H. Sun, and J. Jiang, "Cyber security challenges and solutions for V2X communications: A survey," *Computer Networks,* vol. 151, pp. 52-67, 2019-03-01 2019, doi: 10.1016/j.comnet.2018.12.018.

[4]     A. Moubayed and A. Shami, "Softwarization, Virtualization, & Machine Learning For Intelligent & Effective V2X Communications," *IEEE Intelligent Transportation Systems Magazine,* pp. 0-0, 2020-01-01 2020, doi: 10.1109/mits.2020.3014124.

[5]     NHTSA. "Automated Vehicles for Safety." NHTSA. https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety/ (accessed 19th Oct, 2021).

[6]     I. Foundation. "What is IOTA." The IOTA Foundation. https://www.iota.org/get-started/what-is-iota (accessed October 19th 2021).

[7]     R. Zhang, R. Xue, and L. Liu, "Security and Privacy on Blockchain," *ACM Computing Surveys,* vol. 52, no. 3, pp. 1-34, 2019-07-27 2019, doi: 10.1145/3316481.

[8]     Interestingengineering.com. "IOTA : A Cryptocurrency With Infinite Scalability And No Fees." https://interestingengineering.com/iota-a-cryptocurrency-with-infinite-scalability-and-no-fees (accessed October 19th, 2021).

[9]     K. Abboud, H. A. Omar, and W. Zhuang, "Interworking of DSRC and Cellular Network Technologies for V2X Communications: A Survey," *IEEE Transactions on Vehicular Technology,* vol. 65, no. 12, pp. 9457-9470, 2016-12-01 2016, doi: 10.1109/tvt.2016.2591558.

[10]    R. F. Atallah, M. J. Khabbaz, and C. M. Assi, "Vehicular networking: A survey on spectrum access technologies and persisting challenges," *Vehicular Communications,* vol. 2, no. 3, pp. 125-149, 2015-07-01 2015, doi: 10.1016/j.vehcom.2015.03.005.

[11]    L. Badea and M. C. Mungiu-Pupazan, "The Economic and Environmental Impact of Bitcoin," *IEEE Access,* vol. 9, pp. 48091-48104, 2021-01-01 2021, doi: 10.1109/access.2021.3068636.

[12]    A. A. Sori, M. Golsorkhtabaramiri, and A. M. Rahmani, "Cryptocurrency Grade of Green; IOTA Energy Consumption Modeling and Measurement," in *2020 IEEE Green Technologies Conference(GreenTech)*, 2020-04-01 2020: IEEE, doi: 10.1109/greentech46478.2020.9289803.

[13]    T. I. Foundation. "IOTA 2.0: Details on Current Status and Next Steps." https://blog.iota.org/iota-2-0-details-on-current-status-and-outlook/ (accessed.

[14]    T. I. Foundation. "IOTA Smart Contracts Protocol Alpha Release." The IOTA Foundation. https://blog.iota.org/iota-smart-contracts-protocol-alpha-release/ (accessed October 21st 2021).

[15]     IBM. "What are smart contracts on blockchain?" IBM.
         https://www.ibm.com/topics/smart-contracts (accessed October 21, 2021).
[16]     D. Strugar, R. Hussain, M. Mazzara, V. Rivera, J. Young Lee, and R. Mustafin,
         "On M2M Micropayments: A Case Study of Electric Autonomous Vehicles," in
         *2018 IEEE International Conference on Internet of Things (iThings) and IEEE
         Green Computing and Communications (GreenCom) and IEEE Cyber, Physical
         and Social Computing (CPSCom) and IEEE Smart Data (SmartData)*, 2018-07-
         01 2018: IEEE, doi: 10.1109/cybermatics_2018.2018.00283.
[17]     P. C. Bartolomeu, E. Vieira, and J. Ferreira, "IOTA Feasibility and Perspectives
         for Enabling Vehicular Applications," in *2018 IEEE Globecom Workshops (GC
         Wkshps)*, 2018-12-01 2018: IEEE, doi: 10.1109/glocomw.2018.8644201.
[18]     J. L. Rover. "ON THE MONEY: EARN AS YOU DRIVE WITH JAGUAR
         LAND ROVER." https://www.jaguarlandrover.com/news/2019/04/money-earn-
         you-drive-jaguar-land-rover (accessed October 19th, 2021).
[19]     Elaad. "IOTA Charging Station." https://www.elaad.nl/projects/iota-charging-
         station/ (accessed.
[20]     S. K. Pinjala and K. M. Sivalingam, "DCACI: A Decentralized Lightweight
         Capability Based Access Control Framework using IOTA for Internet of
         Things," in *2019 IEEE 5th World Forum on Internet of Things (WF-IoT)*, 2019-
         04-01 2019: IEEE, doi: 10.1109/wf-iot.2019.8767356.
[21]     R. Nakanishi, Y. Zhang, M. Sasabe, and S. Kasahara, "IOTA-Based Access
         Control Framework for the Internet of Things," in *2020 2nd Conference on
         Blockchain Research & Applications for Innovative Networks and Services
         (BRAINS)*, 2020-09-01 2020: IEEE, doi: 10.1109/brains49436.2020.9223293.
[22]     R. Iacobucci, B. Mclellan, and T. Tezuka, "Modeling shared autonomous
         electric vehicles: Potential for transport and power grid integration," *Energy,*
         vol. 158, pp. 148-163, 2018-09-01 2018, doi: 10.1016/j.energy.2018.06.024.
[23]     D. Dallinger and M. Wietschel, "Grid integration of intermittent renewable
         energy sources using price-responsive plug-in electric vehicles," *Renewable and
         Sustainable Energy Reviews,* vol. 16, no. 5, pp. 3370-3382, 2012-06-01 2012,
         doi: 10.1016/j.rser.2012.02.019.
[24]     R. M. Happach and M. Tilebein, "Simulation as Research Method: Modeling
         Social Interactions in Management Science," in *Collective Agency and
         Cooperation in Natural and Artificial Systems*: Springer International
         Publishing, 2015, pp. 239-259.
[25]     U. o. Southhampton. *Ireland - Population Density*,
[26]     ESB. "ESB Charge Points Ireland." https://esb.ie/ecars/charge-point-map
         (accessed October 21, 2021).
[27]     E. Commission. *Photovoltaic Geographic Information System*, European
         Commission,