IOTA-Based Efficient and Reliable Scheme for Internet of Vehicles

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Abstract Distributed Ledger Technology (DLT) has become popular with the creation of the Bitcoin Blockchain. However, it does not fully address issues such as scalability, transaction fees, and quantum security in application to the Internet of Vehicles (IoV). The IOTA Foundation has claimed to handle these issues: The Tangle. Directed Acyclic Graph (DAG)-based DLT named IoTA, encapsulating Tangles on the IoV environment. In this research, we demonstrate tip selection strategies to affect the IOTA tangle's structure and behavior in IoV. Our proposed scheme describes Tangle's implementation within the IoV use case scenario, providing a highly scalable and fee-less DLT mechanism. We use bundle constructing algorithms for making secured transactions among vehicles across the consensus process. This strategic platform strikes a good balance between the punishment of lazy or busy tips and managed to tackle the left-behind tips, reducing computational latency and approving higher inter-arrival data rates. Our findings show that the random data execution

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rate (α) and the transaction data arrival rate (λ) are effective. Finally, our scheme shows an efficiency of 80% node execution and low latency-based reliable fee-less data delivery over the IoV network ends.

Keywords Internet of vehicles · Directed acyclic graph · Tangle · IOTA

1 Introduction

The rapid rise of the Interconnected IoT devices allows the flow of information through the Intelligent Transportation System (ITS), which has mobilized the Internet of Vehicle (IoV) ecosystem. The IoV ecosystem is a network of IoT-enabled vehicles integrating information into the network such as real-time traffic problems, vehicles' locations, distance-based incentives, increasing traffic, and even route guidance in terms of traffic efficiency. These data are gathered through the use of sensors and devices within vehicles. The increasing number of vehicles linked to the IoT has turned the IoV ecosystem into an interactive network of significance with the continued evolution of communication and computing technologies [1, 2].

The IoV leads to a massive increase in vehicle data collected through the IoV ecosystem integrating cloud computing services (see Fig. 1). Consequently, the overwhelming amount of data collected through IoV [3] can be outsourced to a centralized cloud. Over the next five years, global IP traffic is expected to increase fivefold, with monthly IP traffic reaching 31 gigabytes per capital in 2021. Therefore, the emerging technological pattern of the next wave of IoV is expected to be featured decentralization, distributed management, and distributed storage. However, as decentralized infrastructure is adopted, data and communication must have high-security and privacy-preserving requirements [4].

Blockchain platforms have gained much attention in IoV solutions recently for lifetime maintenance and control of ITS apps [5]. Blockchains are secure; however, their degree of security depends on the network's amount of hash power. The people rely on mining, and more massive mining machines impose a challenge that affects the network [6].

IOTA is a permissionless, open-source, distributed ledger, which uses "Tangle" as its underlying technology, and the DAG-based data structure is used to store the ledger state as Tangle has no chain, no blocks, and no miners either. In addition to the data structure, the IOTA also takes a different approach to consensus. A DAG consensus mechanism could be a way to overcome inefficiencies in the Blockchain. Since all parties decide on the longest chain and discard forking and branching, Blockchain has a limited throughput Transaction Per Second (TPS). In comparison, the Tangle allows the ultimate merger of different branches of DAG, leading to a rapid overall performance.

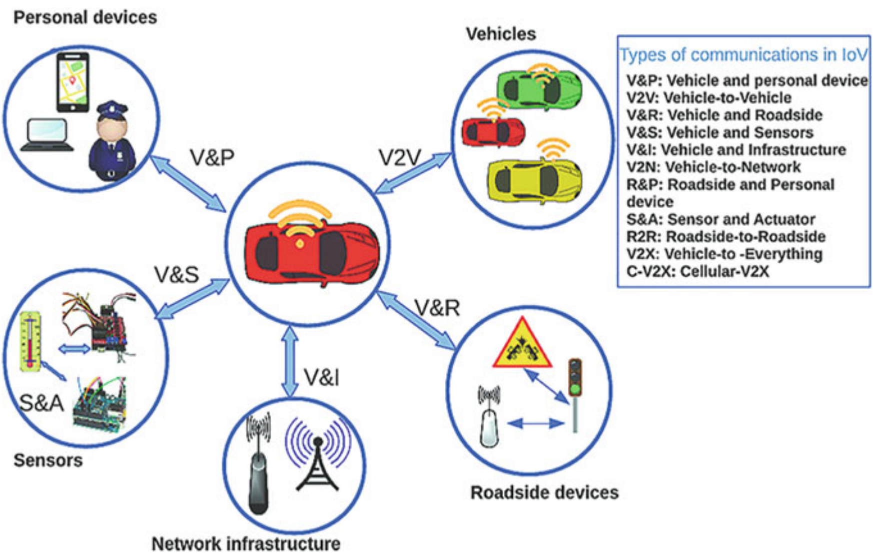

Fig. 1 Generic IoV ecosystem scenario

This research aims to introduce the IOTA concept in the IoV platform and explain its exciting features, incorporating the algorithmic approach to explain its step-by-step functionality and simulations that established the viability of IoTA in the IOV ecosystem. Therefore, we address these research objectives:

RO1: To propose an IOTA-based IoV scheme incorporating an algorithmic approach for fee-less transactions.

RO2: To establish efficient data transfer for IOTA in heterogeneous active vehicles within IoV network.

In this paper, we use the IOTA [7] to overcome the shortcomings of existing public blockchain technologies, focusing on tackling critical limitations such as transaction fees verification rates and the lack of scalability and sustainability. This research presents a fast, fee-less, secure, lightweight, and distributed ledger platform for vehicular networks. The IOTA decentralized ledger is structured as a Direct Acyclic Graph (DAG) called the Tangle—a novel strategy to distributed ledgers due to fee-less and quantum secure transactions and without theoretical scaling limitations. A miner is not required, and a zero transaction fee is possible in the IoV ecosystem. Nevertheless, IOTA's structure is promising, and several experimental studies have been done on the IOTA scenario. More precisely, the key contributions to this work are summarized as follows:

1. We present the IOTA concept for IoV to allow vehicles to connect and execute microtransactions in real-time without any fees.
2. We use DAG to store and verify network transactions for the IOTA consensus mechanism without any fees.

Table 1 Essential abbreviations

Short form	Full form or definition
AWRS	Anti-Withholding Reward System
BWH	Block Withholding
DAG	Direct Acyclic Graph
DLT	Distributed Ledger Technology
FAW	Fork-After-Withholding
IOTA	Open-source distributed ledger and cryptocurrency for Internet of Things
IoV	Internet of Vehicles
ITS	Intelligent Transport System
MWM	Minimum Weight Magnitude
PIR	Partial Initiative Release
PoS	Proof of Stake
PoW	Proof of Work

3. We present two algorithms to create transactions to approve different tip selection strategies.
4. We perform a transaction simulation scenario to analyze a tangled structure and confirm the viability of the new scheme.

The remainder of this paper is organized as follows: Sect. 2 presents recent works related to Distributed Ledger Technology for the IoV. Section 3 describes the essential information about the IOTA Tangle. Section 4 presents the research methodology. Section 5 describes our new scheme and algorithm. Section 6 provides simulation and results. Section 7 concludes the paper. Essential abbreviations are shown in Table 1.

2 Background and Related Work

In this section, we discuss the relevant background and related works to the state of the art of IOTA in IoV.

Christopher Natoli et al. proposed an evaluation framework [8] with insight into a system model, desired properties, and analyzed criteria. They explored the membership selection consensus and an integrated structure that influenced each other in existing systems. Roland Schmid and Roger Wattenhofer showed a Byzantine Fault Tolerance (BFT) [9] protocol to achieve an optimistic latency of just two message delays despite tolerating byzantine failures throughout the “fast track”. A generator block governed the transactions included in a new block; however, the block was not included in the block graph.

Hanqing et al. proposed an attacking model in a proof of work Blockchain that an internal and external attacker [10] consist of two phases. They demonstrated the original system became the two attackers' multi-attacker scheme: the internal and external attackers [11]. A semi-honest mining strategy in a multi-attacker system called the Partial Initiative Release (PIR) was used. Muoi Tranand and Inho Choi presented a stealthier Bitcoin attack—EREBUS attack. It allowed a network adversary to control a targeted Bitcoin node's peer connections for route manipulation without control-plane evidence of the attack. They used real bitcoin address messages from their live node to obtain highly accurate results.

Federico Matteo Bencic and Ivana Podnar Zarko analyzed distributed ledger technology to emphasize the features relevant to distributed systems. It showed the DAG [12] paradigm usage in the context of distributed ledgers and compared them with Blockchain-based solutions. They differentiate between the Blockchain and DAG consistently to optimize scalability, performance, and speed. Yixin Li and Bin Cao identified a DAG-based ledger and the corresponding consensus algorithm as a promising technology for IoT [13]. DAG framework solved certain limitations such as long confirmation delay, high transaction fee, high resource consumption, and low transaction throughput. They showed the trade-off between delay [14] in confirmation and security, which can act as a reference for the practical implementation of DAG [15].

Research in IOTA is emerging. This includes research article [16, 17]. The IOTA foundation provided the IOTA blogs, and developers have published several articles on features, specifications, and in technology [18–21] of IOTA.

3 IOTA: A Permission-Less Distributed Ledger

In this paper, we present the Tip selection Algorithm (TSA), which is biased toward the ones with larger cumulative weight. In the IOTA network, each node's weight is used to achieve a consensus ultimately. In the Tangle, the node's weight is proportional to how much effort the issuing node invests [22]. The acceptance of a new transaction indicates the validity of its history [23] and implies that every account has positive balances and ensures no double-spending or new illegal token making (see Fig. 2).

In a Tangle graph, the first transaction is called the genesis. In the beginning, all IOTA [24] tokens have been created, and no new ones will ever be made. All of the tangle transactions directly or indirectly approve of the genesis. When a transaction is accepted, it becomes part of a consensus and cannot be changed fundamentally. This is achieved by allowing each transaction to perform a small Proof of Work (PoW) calculation, and this PoW is a minor effort for each transaction, making it expensive to spam or fork the main Tangle after consensus has been established.

In Fig. 3, orange node depicts "unconfirmed transaction", green nodes depict "confirmed transaction', gray nodes depict the newest transaction referred to as "tip", and red nodes depict transaction deadlocks. Tips contain the newest transaction across

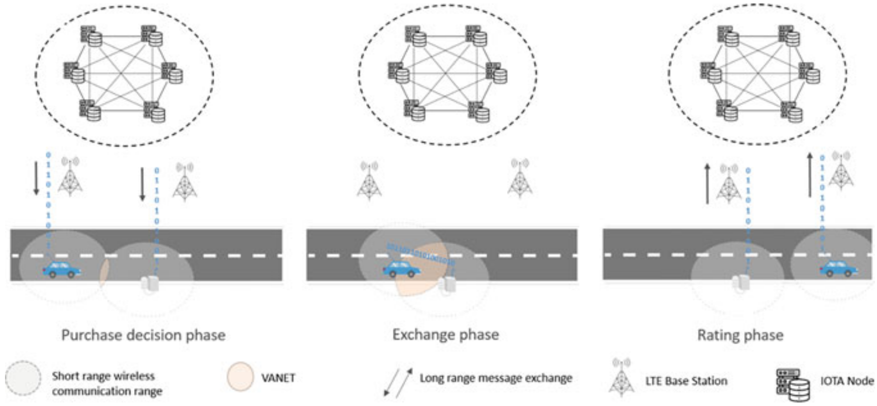

Fig. 2 IoTA cluster working pattern in IoV ecosystem [33]

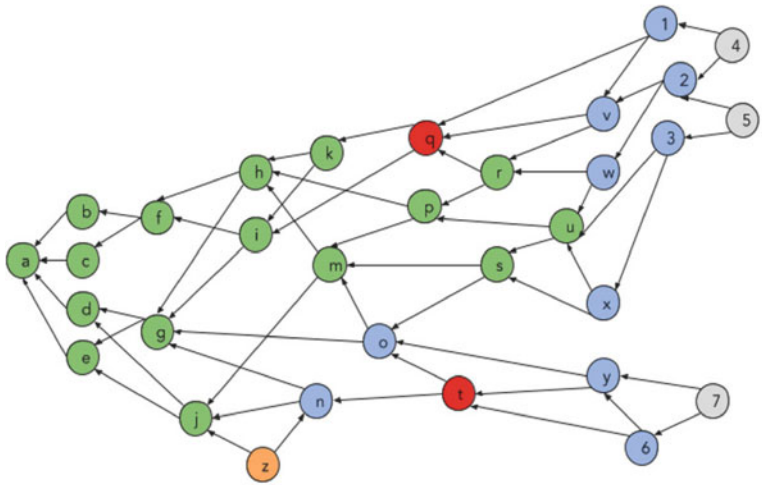

Fig. 3 A typical IoTA tangle communication

the network and have not been indicated by other transactions. Tips “4”,“5” and “7” contain the newest transaction just been added to the network. The IOTA architecture uses Trinary logic based on trits and trytes instead of binary logic [25]. The distributed IOTA ledger platform improves throughput and scalability, offers zero transaction fees, and scales with usability in the IoV ecosystem.

4 Research Methodology

Our solution uses IOTA technology to transfer a message from one vehicle to another vehicle to make a secure transaction over the insecure Internet. Transactions are broadcast via bundle which consists of multiple transactions. In this approach, vehicles must perform several steps for transaction processing.

Address generation and address validation are essential to realize why seeds, addresses, and address validation are required [26] when two vehicles want to share a data seed should be generated as randomly as possible because this acts like a password to a user's account [27]. The address is only the final result that comes from the Seed, Private Key, through digests. A node first creates a bundle to add a transaction to the Tangle. IOTA uses an Unspent Transaction Output (i.e., Utransaction) scheme, which means that inputs (i.e., addresses) are needed to transfer tokens from them to the outputs (i.e., addresses). Once all transactions have taken place, the list of the approved transactions should be attached to the bundle. After bundle construction, we attach a transaction to the Tangle. However, every new transaction must approve two previous non-confirmed transactions (i.e., tips), a process called validation. The node performs the Tip Selection Algorithm.

After tip selection, validation is completed. Verifying a site on the Tangle is a recursive process. A node must ensure that the transaction only references verified transactions and does not set a negative account balance for transaction verification. A valid transaction must include a hash [28] to fulfill the Hashcash requirements, which means that the PoW was done on this transaction. The last step before a node issues a transaction is performing a Proof of Work (PoW). Once the bundle is constructed and signed and the tips are added to the bundle, the PoW must be done for each transaction in the bundle. In each bundle transaction, we must fill the trunk and the branch and find a nonce (see Fig. 4). Every transaction in a bundle requires a nonce to be accepted by the Tangle network (see Fig. 3). The IOTA team designed

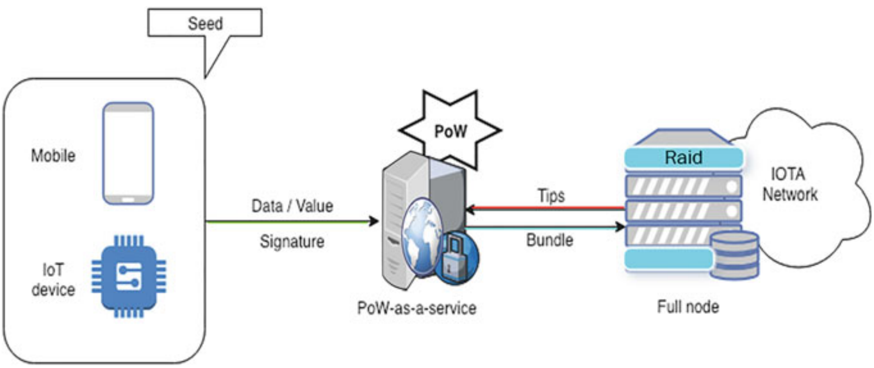

Fig. 4 Generic proof of work activity in IoTA

their cryptographic hash function called Curl to perform the PoW. After calculating a nonce, the modified bundles are broadcast all over the Tangle network.

5 New Proposed Scheme and Algorithm

IOTA tangle builds on the DAG framework concept as a substitute for Blockchain. For creating a transaction, a Bundle Construction Algorithm 1. is used, and the Tip Selection Algorithm 2. is used by the new transaction to select two-parent transactions to approve.

We have developed an IOTA-based Ledger Technology model. In Fig. 2, vehicles are connected and share their data [29] from vehicle to vehicle. Vehicles use a wide range of technology [30] to perceive their surroundings, including radar, sonar, GPS, lidar, and odometry. Our new model uses IOTA Tangle technology to secure and manage vehicular data [31], [32], microtransactions, and ride-sharing transactions in the IoV scenario.

We present a bundle construction algorithm (see Algorithm 1 and Table 2) to make a transaction among vehicles to vehicle-based on IOTA, and Tangle will be available for a bundle when a PoW operation has successfully verified all transactions. A seed is needed for address generation when a vehicle wants to communicate with another vehicle, and Tangle will validate this address. If the address is validated, they can create a transaction for further processing. The algorithm signs all transactions using a private key and bundle hash to gain a more secure transportation system.

Table 2 The notations are used in the algorithms

Symbol	Description
α	Random Data Execution Rate
λ	Data Arrival Rate
PB	Proposed Bundle
PT	Proposed Transaction
RNDEX	Random Data Execution
RgeApp	Return get Approvers
RNDEXM	Random Data Execution Module
RNDEXMS	Random Data Execution Module Scheduler
S	Key Balance Address Value (Seed)
TSA	Tip Selection Algorithm

Algorithm 1: Bundle Construction Algorithm

Input: Seed, Tag, Address value, Key, Proposed Transaction (PT), Proposed Bundle (PB)
Output: Bundle Construction from Seed S, Tag T, Address value A, PT and PB

```
foreach Transactions T append in Process Bundle sequence PB do
    Step 1: Actor: IoTA System Execution IoTASE
        Get input ← Seed S
        Balance Key Generation BG to appear in T ← Address A AND Tag t
        if S is Verified from valid A and t
        Balance Key input B ← index I AND Security Key K
        Proposed Transaction PT is Verified then
            PT ← true
            Security Range SR ← PB Compress in T AND
            PT Verification ← A, T, BG
            Crypt Signing Key is Verified ← Finalize PB AND PT
        else
            PT Not Verified ← Stop PT AND
            Check Verified S
        else
            Proposed Bundle Generator PBG ← true
            Compile Address Key of PBG AND Security Level SL of PBG
            Crypt Signing Key ← import From Signature Fragment
            Generator SFG Private Key Address PKA AND Security Level
            Transaction Hash SLTH import To ← SFG
            Compiled SFG ← PBG AND SLTH
    if PBG is Verified then
        Step 2: Actor: PBG Execution Layer PBGEL
            Execution Range ER ← PKA AND SL
            Newly Created PBG PBGNC ← SFG, PBG AND SL
            PBGNC ← Compiled Hash Trunk Generation HTG
            From tryte String St AND Tip tt
            Transaction Hash String HStr AND St import To ← HTG
    else
        Step 4: Actor: PBG tag Compilation PBGtC
            HTG Not Verified From ← T, PT, St
            PBGtC ← PBG Obsolete tag PBGOt
            Continue to PBGtC Verification
            Get Verified PBG From PBGEL AND Finalize PB, PT
```

After signing all transactions, we can consider them as a bundle. This bundle is validated by selecting tips from Tangle using a Tip Selection Algorithm (see Algorithm 2 and Table 2). The Proof of Work (PoW) validates this bundle again and broadcasts it to the Tangle environment.

Algorithm 2: Tip Selection Algorithm

Input: Number of Node Execution, Arrival Rate (λ), Random Data Execution Rate (α)
Output: Find out the tips from Tangle

foreach *Tangle Generation GENTan AND Call Function CF From Tangle Tan* **do**
  Step 1: Actor: *Tip Selection Primary*
    Generate Tangle GENTan ← *genesis node declaration* GENnodec
    GENnodec ← *Tip Selection Call* TSeC AND
    Return Links Node RLN
    if *GENTan is Verified From valid RLN*
    GENTan ← GENnodec, TSeC AND return Candidates rC
    then
      import Random Data Exec RNDEX To ← *Return*
      get Approvers RgeApp
      Generated RgeApp From ← RNDEX AND rC
      Generate Tangle Call GenTaC ← Finalize
      RNDEX Module RNDEXM
    else
      Step 2: Actor: *Tip Selection Secondary*
        RgeApp AND RNDEX *Not Verified* From ← RNDEXM
        Compile Tip Select Link Node TSLN
        Stop RNDEXM To *Verify* TSLN
        Reallocate Scheduler RNDEXM ← RNDEXMS
    else
      Step 3: Actor: *Tip Selection Tertiary*
        TSLN ← true
        Compile RNDEXM AND RNDEXMS
        Compress RNDEXMS ← *Get Return Ancestor Set*
        GetRAS AND RNDEX
        Complete RNDEXM AND RNDEXMS From ← *Verified*
        GENTan AND *Not Tip Select* NTSel
        Get *Verified* GENTan From ← *Verified* RgeApp,
        RNDEX, RNDEXM AND RNDEXMS

6 Simulation and Results

The core of the simulation is in ReactJs, a JavaScript library for building the Tangle for the tip selection while constructing the bundles. Furthermore, we used IoTA visualizer to visualize the comparison of different Tip Selection Algorithms and also compared the confirmation probability and confirmation delay with respect to the arrival rate (λ), random data execution rate (α), and vehicle node execution.

In the simulation, we designed three scenarios to track the algorithm's behavior and observe their performances concerning efficient data executions. Each scenario reveals necessary information for the analysis considering arrival rate, random data execution rate, and vehicle node execution. We define and identify three main considerable parameters throughout experiments that match our defined research objectives.

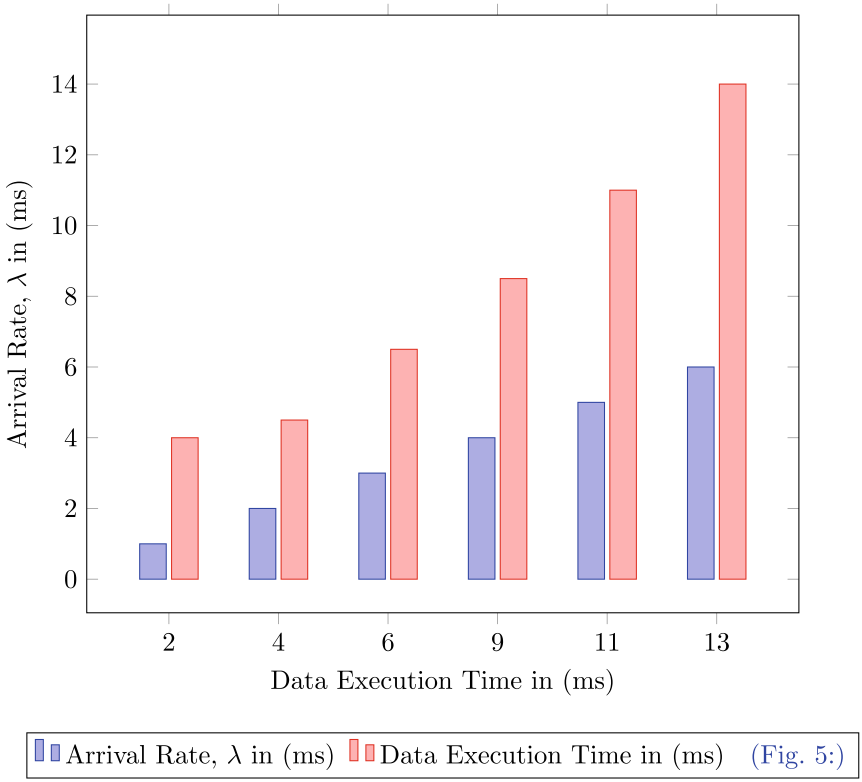

Fig. 5 Arrival rate (λ) vs. data execution time (Dt) in our proposed IoTA mechanism

In Fig. 5, we can see that the data execution time relies on the arrival rate. When the arrival rate increases, the data execution time goes double in accumulation. This means our procedure delivers the existing process (i.e., task) blocks while maintaining and considering newly created process stacks within algorithmic recursion. In 2 ms of process arrival rate, we get 4 ms of data execution time, and in 6 ms arrival rate, we get the data execution time of 14 ms. This result considerably supports our primary research objective of an efficient data delivery scheme where the existing processes are compiled with the new processes leaving no leftovers of process stacks or data offloads.

In Fig. 6, we can see that the random data execution rate relies on the data execution time. When the random data execution rate increases, the data execution time also increases in cumulative order. This means our procedure delivers the existing data handoff process (i.e., task offloads) blocks, inter-arrival process blocks, and existing processed data blocks. The random data execution rate considers and verifies the newly created or incoming process stack throughout the algorithmic recursive strategy. This recursive policy of the algorithm approach supports the reliability of our proposed scheme. In 50 ms of random data execution rate, we get 60 ms of data

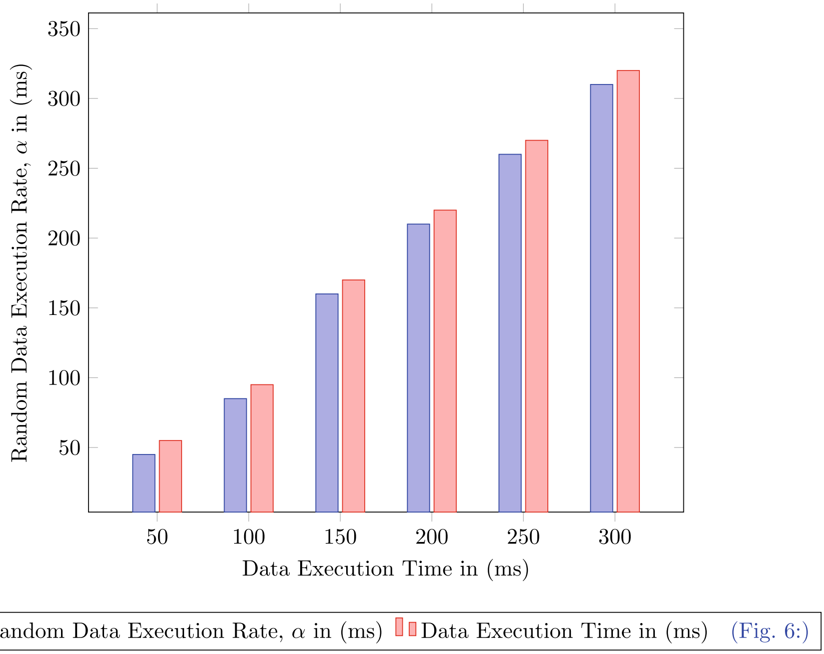

Fig. 6 Random data execution rate (α) vs. data execution time (Dt) in our proposed IoTA mechanism

execution time, and in 300 ms random data execution rate, we get the data execution time of 330 ms. This result considerably supports our primary research objective of an efficient and reliable data delivery scheme where the existing processes are compiled with the new processes providing fewer data offloads toward IoTA network occupied (i.e., task deliverable) nodes.

In Fig. 7, we can see that the vehicle node execution relies on the packet delivery time. When the vehicle node execution increases, the packet delivery time also increases in an augmenting order. This means our scheme delivers the existing and newly generated data packets (i.e., task-dependent stacks) toward the occupied vehicular nodes within the IoTA network. The inter-arrival task process blocks and existing task processed data blocks are accumulated while delivering to end-to-end IoTA network hops. The vehicle node execution considers and verifies newly created or incoming packet data throughout our developed scheme. This algorithmic approach supports the efficiency of 80% node execution rate within the IoTA scenario. In 20 ms of vehicle node execution, we get 50 ms of packet delivery time, and in 125 ms node execution rate, we get the packet delivery time of 150 ms. This result considerably supports our primary research objective of a reliable and low latency-based data delivery scheme. Moreover, the existing processes are compiled with the new processes delivering less delay over hop-to-hop data distribution toward the network occupied (i.e., task deliverable) nodes of the IoTA scenario.

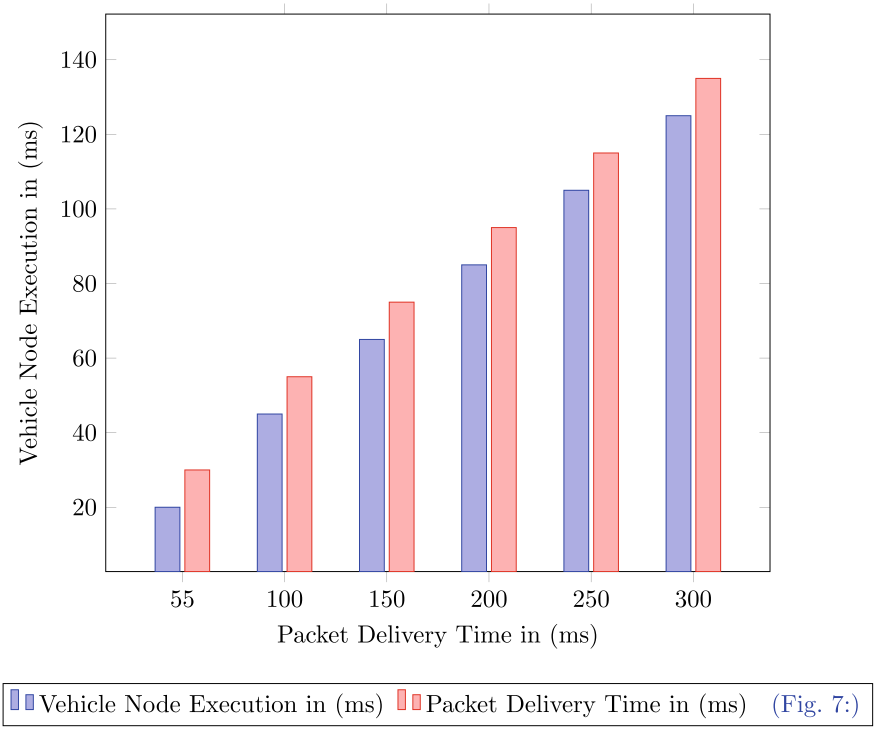

Fig. 7 Vehicle node execution (Vn) vs. packet delivery time (PDt) in our proposed IoTA mechanism

6.1 Research Objectives

In this section, we justify and establish our research objectives stated in this paper.

RO1: To propose an IOTA-based IoV scheme incorporating an algorithmic approach for fee-less transactions.

We answer the first objective by discussing the implementation overview algorithmic design and implementation based on practical scenarios. The fee-less distributed transaction property enhances the secured policies through a fast execution pattern. However, blockchain needs bidding and allocated transaction fees to every bit of block generation and distributed toward the intended users. The PoW allocated bidding process and transaction fee generation for each block, minimizing this extra latency; blockchain needs a congestion control strategy over moving vehicles, which is challenging. The IoTA successfully eliminates the network node congestion control problem (see Fig. 5). Since IoTA needs no transaction fee for each block generation, it distributes data via a secured channel toward the intended users in no time. The IoTA mechanism itself is aware of node congestion analogy and useful for high-speed moving entities (see Fig. 3). The vehicles within an IoV (i.e., Internet of vehicles) control area usually are not free from congestion awareness because of maintaining large network data execution. Partially or fully, data handoff occurs now and then in an IoV area since moving vehicles employ location awareness and RSU or BST allocation attribute problems. An additional delay mechanism (i.e., PoW-based sequential bidding for the transaction) may hamper the configured delay (i.e., optimized scheduled process to avoid extra delay) allocation toward the intended nodes as well as users within an IoV equipped area (see Figs. 6 and 2). For this reason, IoTA-based secured data transaction and distribution is effective in an IoV accumulated area.

RO2: To establish efficient data transfer for IOTA in heterogeneous active vehicles within IoV network.

We answer our second objective by experiment results and further discussion. In IoTA, the decentralized fashion of data distribution increases ends user activity, authenticity, and availability in a secured motion (see Fig. 3). Blockchain works as a sequential data distribution hierarchy, distribution, and transaction formulation across the network in a one-to-one pattern as a sequential order block. This causes extra network traffic and data execution delays which are not feasible for the frequent moving vehicle within the IoV network (see Fig. 2). For heterogeneous data delivery and execution toward the independent vehicle, we need a decentralized architecture of data execution and accession to minimize network congestion and data handoff delays (see Fig. 6). The IoTA property successfully alleviates the data accession (see Fig. 7) and verification and validation latencies (see Fig. 5) by deploying demand-based data transferring across IoV controlled area. Considering the data execution (i.e., cluster node data deliveries) around IoV (see Fig. 7), the IoTA architecture employs promising results. Thus, our proposed IoTA-based scheme is beneficial for efficient data transfer in the IoV network.

7 Conclusion

In this research, we investigated the possibility of IoTA technology, including Tangles in the IoV environment. We demonstrated the tip selection strategy to modify the data distribution structure module and node accession behavior across an IOTA tangle within IoV. Our newly configured algorithmic approach uses a modified tip selection and bundles construction of data block that deploys scheduled packet stacks efficiently toward the intended IoTA nodes. The implemented tip strategy scales the tangle module in an efficient data deliverable property toward the occupied IoTA nodes. The experimental result showed that our proposed scheme supports maximum data delivery, providing a low latency within higher inter-arrival rates. In the 6 ms arrival rate and 50 ms of random data execution rate (α), we get the data execution time of 14 and 60 ms, respectively. However, in the 125 ms node execution rate, we get the packet delivery time of 150 ms while supporting the efficiency of 80% node execution within the IoTA-occupied network. The overall result predominantly expressed our primary research objective of building a reliable and efficient low latency-based data delivery scheme within the IoV use case scenario.

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