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Research Article

Leveraging AI and Blockchain in MANETs to enhance Smart City Infrastructure and Autonomous Vehicular Networks

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ABSTRACT

The incorporation or combination of Artificial Intelligence (AI) and blockchain technology into Mobile Ad Hoc Networks (MANETs) shows important factor for modern and advance smart city infrastructure and autonomous vehicular networks. This paper describes the complementary potential of the technologies to help the built-in difficulties of MANETs includes flexibility, protection, and data integrity. AI techniques such as machine learning and reinforcement learning, are emphasized to improve routing protocols to optimize data transmission rates, and decrease latency. Blockchain technology using Practical Byzantine Fault Tolerance (PBFT) and other consensus mechanisms, gives a tight and decentralized architecture for data handling assuring trust and integrity amidst network nodes. The appeal of these incorpoarted technologies is especially related for smart cities which depand on collection of data and evaluation for effective handling of urban operations such as flow of traffic, environmental observing, and consumption of energy. Autonomous vehicular networks needing rigd and strong communication and data transfer between vehicles and infrastructure, also help from the enhanced network functions and security provided by AI and blockchain incorpoaration. Experimental evaluation denotes improvements in crucial performance metrics. Sensor 2 persists the highest data transmission rate of 12 Mbps. Sensor 4 had the decreased at 9 Mbps. Latency measurements observed that Sensor 2 recorded the lowest latency at 45 ms, with Sensor 3 having the highest at 55 ms.

1. INTRODUCTION

The quick urbanization and technological development of this century have driven the emergence of smart cities where the fusion of technologies is mandatory to handle resources effectively, assure public safety, and enhance the quality of life. This transformation plays primary role in deployment of rigid communication networks competent of managing large amounts of data produced by various related devices and systems [1]. MANETs have evolved as the solution in this context because of their elasticity, automated-configuration, and capability to function lacking a constant infrastructure [2]. MANETs faces difficulties including problems like security, and data integrity. To solve these difficulties, incorporating AI and blockchain technology into MANETs gives a suitable solution. AI techniques like machine learning and reinforcement learning helps to enhance the functions of network by forecasting and adjusting to fluctuating environments and challenges where blockchain technology gives a protective and decentralized architecture for data handling and transaction evaluation [3]. This combination is especially important in improving smart city infrastructure and autonomous vehicular networks [4]. Smart cities depend on real-time data collection and evaluate to handle urban functions, from traffic management and environmental observation for consumption of energy and public safety [5]. Autonomous vehicular networks need reliable communication and data transfer amidst vehicles and infrastructure to

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assure safe and effective transportation [6]. Investigating the mutual possibility of AI and blockchain in MANETs addresses the complicated requirements [7]. By using AI's ability in increasing routing protocols and blockchain's potency in obtaining data exchanges, a more strong, efficient, and flexible network architecture could be created [8]. The experimental evaluation gives findings into main performance metrics such as data transmission rates, latency, and air quality observation indicating the interests and areas for future enhancement in installing these technologies in real-world scenarios. The objectives are:

- Implement AI algorithms, such as machine learning and reinforcement learning, to optimize routing protocols and improve data transmission rates and latency.
- Evaluate the effectiveness of PSO and other AI techniques in dynamically adjusting network parameters based on real-time conditions.
- Integrate blockchain technology into MANETs to provide a secure, decentralized framework for data management.
- Employ PBFT and other consensus mechanisms to ensure data integrity and trust among network nodes.
- Deploy MANETs augmented with AI and blockchain technologies to enhance the efficiency and reliability of smart city applications, such as environment monitoring, traffic management, and energy consumption.

2. LITERATURE REVIEW

The incorporation of AI and blockchain technology in MANETs is a faster emerging area that could transforming smart city infrastructure and autonomous vehicular networks [9]. MANETs are automatic-configuring, active networks which have mobile nodes that propagate lacking consistent infrastructure [10]. They are important for applications needing quicker installment and scalability such as disaster recovery, military operations, smart cities and autonomous vehicular networks [11]. MANETs face challenges associated to elasticity, dependability, and integrity because of decentralized type and dynamic topology. AI techniques such as machine learning and reinforcement learning are used to label different issues in MANETs [12]. AI can improve routing protocols by forecasting network conditions and adapting routes. PSO and RL algorithms are increasing routing efficiency and network operations. PSO aids in enhancing path selection depend on different categories where RL can adjust to fluctuating network conditions and enhance decision-making processes [13]. Blockchain technology with its decentralized and protective nature, are highly being used to bring out security and trust problems in MANETs. Blockchain can give a full proof ledger for noting transactions and interactions amidst nodes improving trust and decreases the threat of malicious pursuits [14]. PBFT is has been incorporated into MANETs to assure data security and consensus amidst nodes [15]. The fusion of AI and blockchain in MANETs targets to use the positives of both technologies to build a more rigid and effective network. AI can improve the decision-making abilities and adjustments of MANETs, while blockchain gives a secure and dependable architecture for exchange of data and transaction documentation.

Research has displayed that such incorporation can enhance network function , security, and dependability, making it ideal for complicated applications. Smart cities depend on a diverse network of related devices and systems to handle resources, services, and framework efficiently. MANETs, multiplied with AI and blockchain, can aid different smart city applications such as environmental observation, traffic management, and public safety [16]. Wireless sensor networks (WSNs) installed in MANETs can gather real-time data on air quality, traffic flow, and energy consumption, while AI algorithms evaluate this data to enhance city functions. Autonomous vehicular networks need dependable communication and data transfer amid vehicles and infrastructure. MANETs give the needed scalability and exposure for such networks, and the incorporation of AI and blockchain can impriove their abilities. AI algorithms can enhance routing and traffic management while blockchain makes sure secure data exchanging and collaboration among autonomous vehicles.. Scalability and energy efficiency are important challenge in MANETs especially with the improved computational demands of AI and blockchain. Future research can concentrate on evolving lightweight protocols and energy-efficient algorithms. Real-world testing and deployment are important to estimate the efficiency of these technologies in vast urban pursuits. The incorporation of AI and blockchain in MANETs shows adjusting approach to improve smart city infrastructure. By solving existing challenges and using the positives of these technologies, future research can pay the way for more efficient, secure, and flexible urban systems.

3. PROPOSED WORK

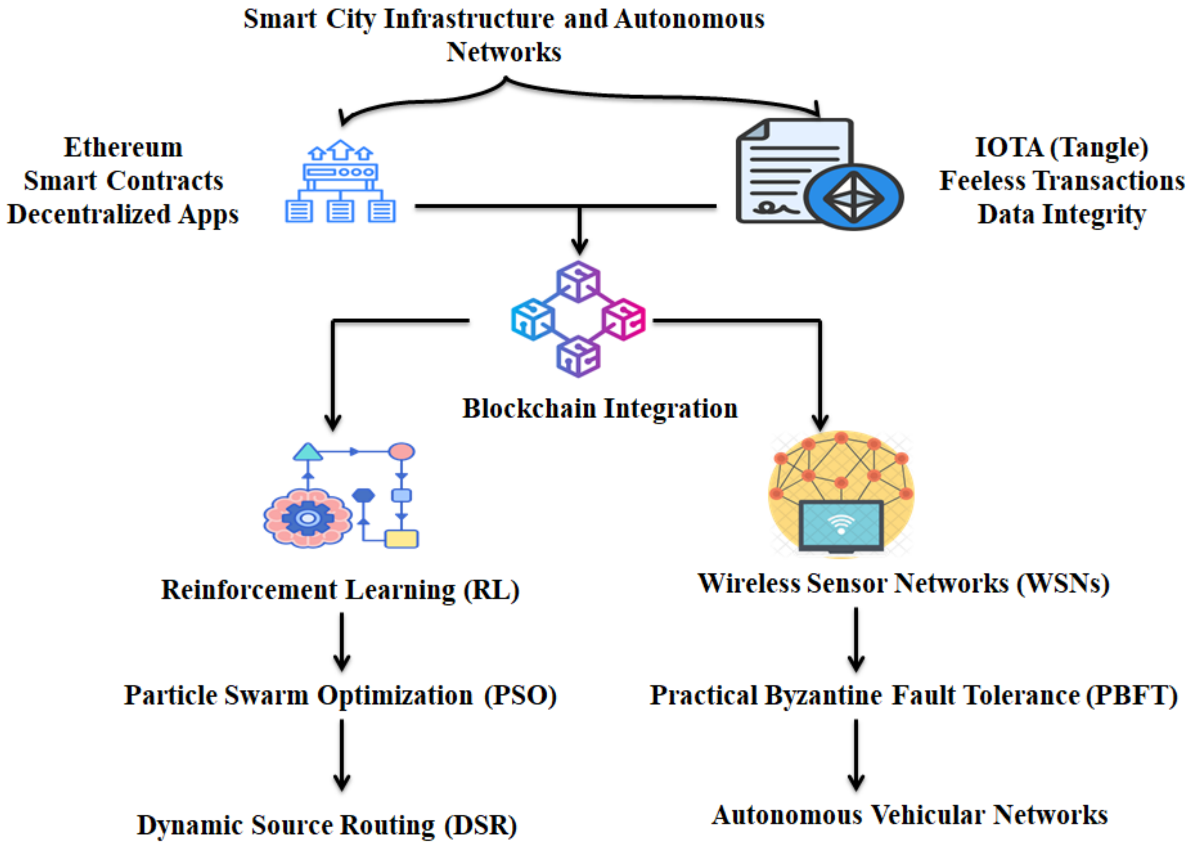

Fig.1 Integrated Framework for AI and Blockchain in MANETs

3.1 Practical Byzantine Fault Tolerance

PBFT is essential for protecting and enhancing scattered networks like MANETs, primary in smart city infrastructure and autonomous vehicle networks. It helps consensus even between Byzantine faults in which nodes act viciously assuring the network passes understanding on transaction setups. PBFT majorly functions in three stages that are pre-prepare, prepare, and commit. Nodes offer, evaluate and validate transaction arrays, needing understanding from a most of non-faulty nodes for consensus. This process assures the incorruptibility of the ledger essential for safe and stable applications in smart grids, water management, and public safety. PBFT assures authentic communication, protecting against interruptions and harmful attacks that can balance traffic systems and independent vehicle collaboration. It encourages data integrity across IoT devices, important for correct decision-making in management of traffic and emergency reaction. In autonomous vehicles, PBFT enables reliable data exchange, primary for real-time navigation and collision avoidance. PBFT's capability in consensus makes sure that low-latency refining suitable for real-time applications in autonomous driving and smart city functions. The decentralized techniques aid flexibility, reducing sole points of collapse and improving network persistence. This flexibility enlarges to vehicular networks, allowing rigid communication and cooperation without centralized control which allows entire network dependability. Incorporating PBFT in MANETs allows security, dependability and effectiveness across smart city infrastructure and autonomous vehicle networks using AI and blockchain technologies for modern, scalable systems.

3.2 Particle Swarm Optimization

PSO gives innovation from combined behavior in type which includes bird flocking, to enhance essential for MANET. PSO establishes a swarm of particles indicating a likely key that adapts its spot grounded on individual and combined occurrences. It estimates toughness via an intent function and continuously process key till meeting stopping categories. PSO enhances routing protocols to improve distribution of data effectively amidst IoT devices, sensors, and central systems. This increases real-time applications such as traffic monitoring and energy management. PSO enhances vehicular routing to decrease put off and bottleneck, important for dependable communication of autonomous vehicle. It assigns resources effortlessly over smart city services, corresponding network load and computational tasks in edge computing pursuits, improving entire system functions. PSO adjusts network configurations in MANETs to differing conditions assuring the persistence and speedy performance among commuting traffic and environmental element. It enhances communication connection amidst vehicles aiding autonomous driving. PSO is flexible as it manages diverse deployments applications, adjusting to robust vehicular network pursuits efficiently. Incorporating PSO in MANETs increases performance, efficiency, and adaptability. It enhances routing, resource allocation, and network configurations to produce stable, flexible systems that are according to the demands of modern urban environments and autonomous driving.

Algorithm 1: PSO Algorithm for Enhancing Smart City Infrastructure and Autonomous Vehicular Networks in MANETs

1. Define the problem and the objective function f(x) to be optimized.
2. Initialize a swarm of nnn particles with random positions X_i and velocities V_i in the solution space.
3. Set the maximum number of iterations T and the stopping criteria.
4. Calculate the fitness value $f(X_i)$ for each particle iii based on the objective function.
5. Identify the particle's best-known position P_{best}
6. Identify the swarm's best-known position g_{best}.
7. Update the velocity $V_{i,t+1}$ for each particle i using the formula
8. $V_{i,t+1} = \omega V_{i,t} + c_1 r_1 (P_{i,t} - X_{i,t}) + c_2 r_2 (g_t - X_{i,t})$
9. Repeat the evaluation and update steps until the stopping criterion is met (e.g., a maximum number of iterations TTT or a satisfactory fitness level is achieved).
10. Return the best solution found g_{best} and the corresponding fitness value.

The PSO algorithm gives an efficient technique for enhancing different factors in MANETs, assisting to improve smart city infrastructure and autonomous vehicular networks. By repeatedly adapting particle placements depend on collective pursuits, PSO accomplishes equilibrium between exploration and exploitation, steering to effective solutions for robust and segregated network environments.

3.3 Dynamic Source Routing

DSR is a routing protocol built for MANETs, improving smart city infrastructure and autonomous vehicular networks by allowing effective communication between mobile nodes lacking stable framework. Its required routing analysis adjusts d to fluctuating topologies of network, important for the rigid environments. DSR works with route discovery and maintenance mechanisms. If a source node transfers a packet to an isolated terminal, it begins a route discovery by transmitting a Route Request (RREQ). Intermediate nodes promote the RREQ till it achieves the destination or a node with route data, which reacts with a Route Reply (RREP). The source node observes status of route and begins new route discovery through Route Error (RERR) as it is wanted because of connection interruption, assuring constant communication. DSR routes data among IoT devices, sensors, and central systems, improving resource of network like traffic management and crisis assistance. DSR makes sure dependable communication by adjusting routes to replacing vehicular network topologies, acute for applications like navigation and collision shunning. DSR's versatility is ideal for urban environments, assuring constant communication regardless of regular topology fluctuations from node mobility or environmental conditions. Rapid adjustment improves communication paths, decreasing latency for autonomous vehicle systems in vehicular networks. DSR measures for huge smart city installments, handling various devices without central dominance improving network persistence. It aids flexible vehicular networks by effectively managing communication between vehicles assuring functional continuity even with node collapse. Incorporation with blockchain improves DSR's security, protecting routing data with resilient ledgers to avoid attacks like route contrivances. This combination makes sure data legitimacy and security, critical for secure autonomous vehicular functions. DSR improves performance, reliability, and adaptability in MANETs. It enhances routing, adjusts to robust environments, aids flexibility, decentralization, and improves protection via possible blockchain incorporation. This generates DSR important in using AI and blockchain for rigid urban network keys and modern autonomous driving.

3.4 Implementation

Ethereum and IOTA (Tangle) works as base for blockchain architecture, each providing different benefits. Ethereum uses smart contracts to ease firm, automated agreements between nodes, mandatory for handling data. IOTA's cost effective and flexible Tangle technology aids high-frequency minute transactions mandatory for data transferring between autonomous vehicles assuring effective and rigid communication in urban environments. RL evolves as a important AI technology improves process of decision-making. RL algorithms adjusts traffic management systems by actively suiting signal timings depend on real-time traffic information to decrease any traffic and improving flow of traffic. RL allows vehicles to study from their environments, enhancing route maximization, energy efficiency, and safety via constant learning and adjusting. WSNs play a primary role by giving collection of data and propagation abilities in smart city pursuits. These networks install sensors everywhere in urban areas to observe factors such as air quality, temperature, and traffic conditions. WSNs accelerate data aggregation for decision-making processes which maximizes urban planning, resource allocation, and environmental governance. PBFT assures the dependability and protection of MANETs by allowing consensus between distributed nodes in the existence of malicious or faulty techniques. PBFT protects data integrity by obtaining communications between WSN nodes and central servers making sure that the validity and integrity of collected data. PBFT increases network security by calculating transactions and preserving compatible network outlook amidst vehicles for secure autonomous driving. PSO maximizes network functions by actively adapting factors such as routing protocols and resource allocations in MANETs. PSO allows the positioning of WSN nodes and maximizes data routing avenue, increasing scope. PSO helps route planning and traffic management dropping traffic and vehicle collaboration via adjusted optimization plans for autonomous vehicular networks. DSR improves communication dependability in MANETs by helping nodes to actively find and assert effective communication routes. DSR aids smart city operations by assuring transmission of data amidst WSN nodes and central systems, even while changing network conditions. DSR helps vehicles to actively adapt routes depend on real-time traffic and environmental pursuits, assuring constant and certain communication important for safe autonomous driving.

$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha[R_{t+1} + \gamma max_a Q(s_{t+1}, a) - Q(s_t, a_t)] \quad (1)$$

The equation represents the Q-learning update rule in reinforcement learning. Here, $Q(s_t, a_t)$ is updated based on the observed reward R_{t+1} received after taking action a_t in state s_t, adjusted by the learning rate α\alphaα and the discounted future rewards $\gamma max_a Q(s_{t+1}, a)$. This iterative process allows the agent to learn the optimal policy by updating its estimates of action values according to the experienced rewards and future expected rewards in subsequent states.

$$V_{i,t+1} = \omega V_{i,t} + c_1 r_1 \left(P_{i,t} - X_{i,t}\right) + c_2 r_2 (g_t - X_{i,t}) \quad (2)$$

The equation represents the velocity update rule in PSO. Here, $V_{i,t}$ denotes the velocity of particle i at iteration t, ω is the inertia weight maintaining particle momentum, c_1 and c_2 are acceleration coefficients governing particle movements towards its personal best $P_{i,t}$ and the global best g_t, respectively. The random variables r_1 and r_2 adjust the influence of personal and global bests, ensuring exploration and exploitation to optimize the search space effectively in PSO algorithms.

3. RESULTS

The devices are setup to communicate wirelessly via MANET protocols such as DSR making sure that active and adjusting routing abilities. Communication modules and onboard processing units which accomplish AI algorithms are furnished with autonomous vehicles and communicating safely with blockchain networks such as Ethereum and IOTA. The incorporation of Ethereum and IOTA includes installing blockchain nodes and smart contracts to handle and obtain transactions and exchanges of data inside the MANETs. Smart contracts are built to mechanize and impose agreements between smart city services and vehicles assuring data securing and clearness. PBFT mechanisms are executed to protect against harmful attacks and assure consensus between distributed nodes. Collection of data from WSNs and vehicle-to-vehicle (V2V) communication data are assumed to evaluate the functions of AI-driven algorithms like RL and PSO. RL algorithms improve flow of traffic and resource allotment and PSO enhances network factors such as routing and utilization of energy.

Table.1 Performance Metrics of Sensor

Sensor ID	Temperature (°C)	Humidity (%)	Traffic Flow (vehicles/hour)	Energy Consumption (kWh)
1	25.3	65	1200	35.2
2	23.8	70	1100	31.5
3	27.1	62	1150	33.8
4	24.5	68	1250	34.6
5	26.0	67	1180	32.9

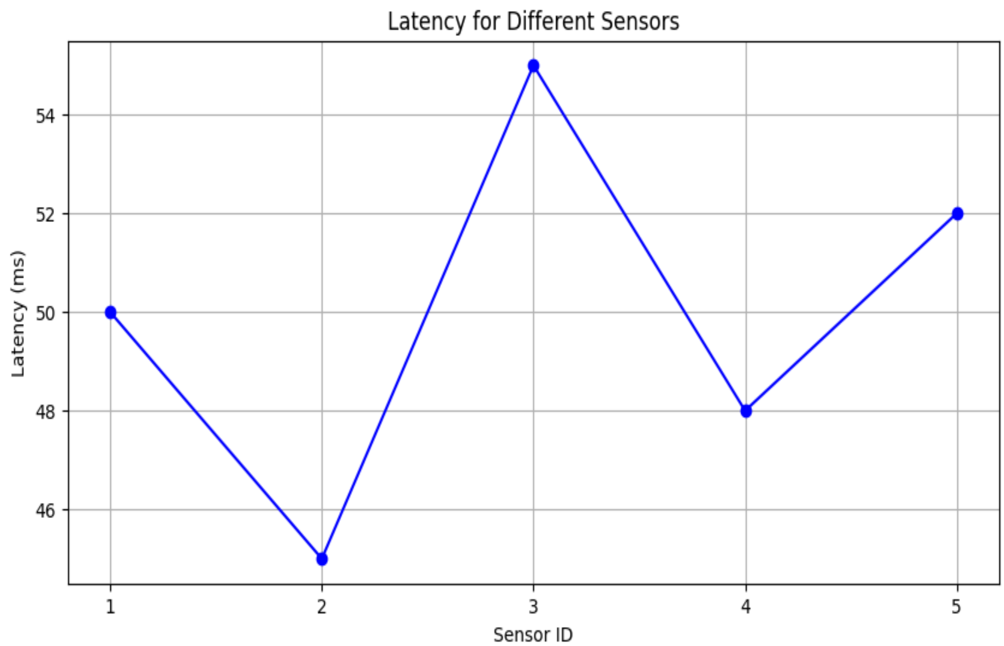

Fig.2 Latency of different Sensors

Figure 2 shows the latency in milliseconds (ms). Sensor 3 shows the peak latency of 55 ms, referring the great delay over the sensor. Sensors 1 and 4 both show decreased latencies of 50 ms and 48 ms, indicating abrupt transmission of data and response times contrast to Sensor 3. Sensor 2 has the lowest latency at 45 ms, showing the most reactive performance of network amidst the sensors. Sensor 5 has latency between 52 ms. These differing latency among sensors mirror differences in conditions of network, traffic loads, and communication effectiveness. The decreased latencies show quicker transfer of data and enhanced network reactiveness important for real-time applications and accordance. Figure 2 elaborates a standpoint of latency metrics among multiple sensors, showing in terms of data transmission speed and network reactiveness. Observing and enhancing degree of latency are mandatory for improving entire system effectiveness, assuring dependable communication, and aiding the efficient installment of smart city components.

Fig.3 Data Transmission Rate of different Sensors

Figure 3 depicts the rate of data transmission in megabits per second (Mbps). This shows a contrastive view of how effectively each sensor transmits the data inside the network pursuits. Sensor 2 shows the increased data transmission rate of 12 Mbps showing suitable transmission of data abilities contrast to the further sensors. Sensors 1 and 5 both display a data transmission rate of 10 Mbps showing constant functions in transfer of data. Sensor 3 displays a rate of 11 Mbps, Sensor 4 has the decreased transmission rate of 9 Mbps. These differences in data transmission rates over sensors tell contrast in network conditions such as bandwidth accessibility, or functional effectiveness inside the smart city infrastructure. Sensor 2 is well structured in transmission of data and sensors 4 and 1 specify decreased rates, possibly affected by network traffic or resource allotment. Figure 3 gives findings into the data management abilities sensor, important for improving functions of network and assuring trustworthy data communication. Observing and examining these transmission rates assist in evaluate network health, detecting possible hindrance, and optimizes entire system for better service transportation and decision-making.

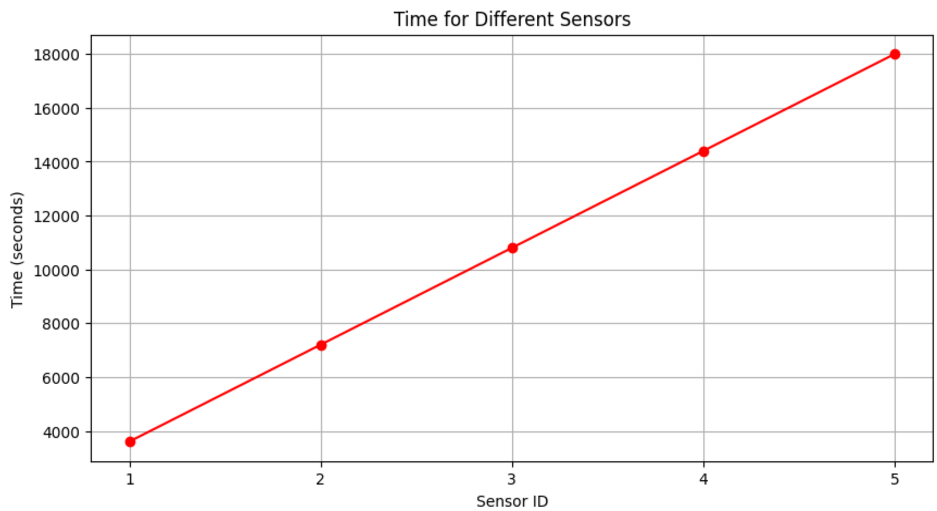

Fig.4 Time of different Sensors

Figure 4 shows the time in seconds noted by multiple sensors. Sensor 1 displays a time calculation of roughly 3600 seconds this is the minimal amid entire sensors. Sensor 2 displays 7200 seconds showing an extended time in comparison to Sensor 1. Sensor 3 scales of 10800 seconds extending the trend of enhancing time durations. Sensor 4 and Sensor 5 shows 14400 and 18000 seconds, respectively, making it as the peak time period amidst the sensors. The slow and steady enhancement in time calculations from sensor 1 to sensor 5 tells likely contrast in functional cycles or periods of pursuit. This can mirror differing patterns in transmission of data, energy consumption series, or frequent response intervals. Figure 5 gives a required view of time measurements over multiple sensors indicating the individual functional or periods over the mentioned period. These findings are mandatory for observing and handling sensor installation assuring constant collection of data and system function enhancement.

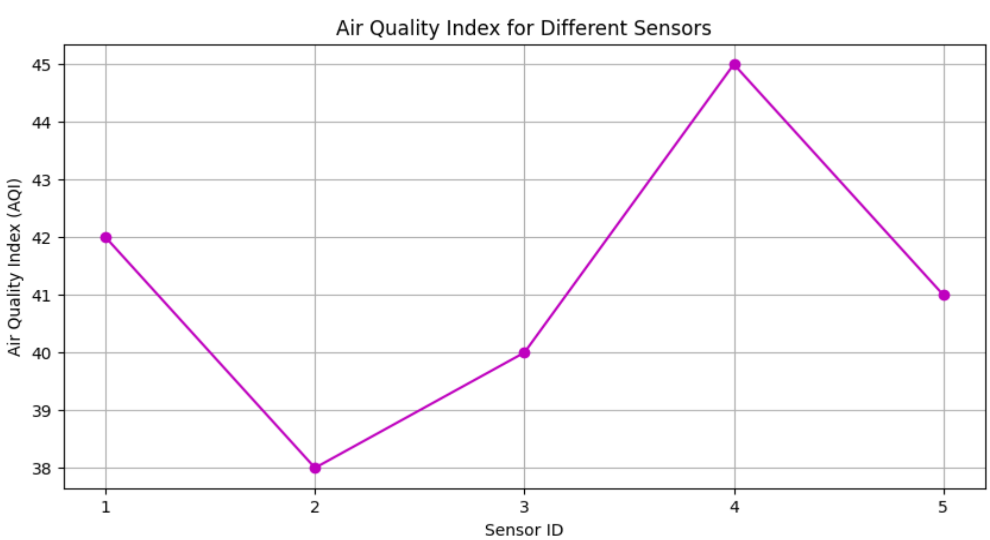

Fig.5 Air Quality Index of different Sensors

Figure 5 depicts the Air Quality Index (AQI) observed by different sensors. The AQI values confines from 38 to 45, shows differing stages of air pollution and quality. Sensor 4 noted the peak AQI of 45 which has low air quality in contrast to the other sensors. Sensors 1, 3, and 5 displays moderate AQI values around 40 to 42 showing faintly better air quality in the areas. Sensor 2 has the least AQI of 38 representing the best air quality amidst the locations. This data mirror positive environmental requirements throughout multiple areas of the city, authorized by elements such as vehicular traffic, industrial activities, and weather patterns. Observing AQI using IoT sensors assist in recognizing air pollution levels by accelerating enlightened decision-making for urban planning, public health measures, and environmental policies purposed at increasing entire air quality.

4. CONCLUSION

The combination of AI and blockchain in MANETs shows noteworthy possibility for improving smart city infrastructure and autonomous vehicular networks. Sensor 2 displayed the increased data transmission rate with 12 Mbps exhibiting transfer of suitable data competence that are mandatory for communication and functions of network. Sensor 4 has the decreased value of data transmission rate of 9 Mbps shows that there are areas for likely enhancements to assure stable network performance for entire nodes. Calculation of latency is a main pointer of responsiveness of network, differed over sensors. Sensor 2 displays the minimal latency of 45 ms indicating its higher performance in assuring quick data transmission. Sensor 3 had the peak latency of 55 ms displaying likely delays that can influence time-sensitive applications. The AQI values also supplied environmental insights with sensor 4 has the maximum AQI of 45 showing poorer air quality contrast to the other locations. This environmental observation is important for health of public assuring that smart city schemes can react actively to fluctuating conditions. These findings emphasize the significance of using modern and recent technologies like AI and blockchain in MANETs to improve data transmission efficiency, minimize latency, and supplies real-time environmental observation. By calling out the mutability in network functions and environmental conditions, smart city infrastructure can be improved to assist more trustworthy autonomous vehicular networks. Future research should intent to build and execute advanced algorithms that can manage the elasticity issues of MANETs as the number of nodes reaches peak. This involves enhancing transmission of data rates and decreasing latency across a wider network. Machine learning techniques can be emphasized to foretell network traffic and adapt routing protocols. Blockchain technology supplies built-in security properties further work is required to show possible susceptibility in MANETs. Building feathery cryptographic methods acceptable for resource-constrained nodes and improving privacy-preserving mechanisms are mandatory for protecting data.

Conflicts Of Interest

No competing financial interests are reported in the author's paper.

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