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Performance optimization of greedy and FIFO algorithm in vehicle to vehicle (V2V) communication

M. Raditya Aisy Dharmawan[1], M. Satrio Dwi Cahaya[1], Raffie Ilham Winata[1],
Linda Meylani[1], Vinsensius Sighit Widhi Prabowo
[1]Department of Telecommunication Engineering, School of Electrical Engineering, Telkom University, Indonesia

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ABSTRACT

In the era of autonomous vehicles, Vehicle-to-Vehicle (V2V) communication is crucial for enhancing traffic efficiency. This study adheres to the standards of 3GPP TS 22.185, TS 22.186, TS 22.885, and TS 22.886 to support V2X communication in 5G networks. We evaluated the resource allocation algorithms FIFO and Greedy, using both clustering and non-clustering approaches. The test results indicate that the Greedy algorithm with clustering outperforms FIFO. In the first scenario, Greedy with clustering improves the Total Data Rate by 8.97%, the Average Data Rate by 10.08%, and the Spectral Efficiency by 9.09%. In the second scenario, there is an increase in the Total Data Rate by 11.07%, the Average Data Rate by 7.91%, and the Spectral Efficiency by 10.57%. This study recommends using the Greedy algorithm with clustering for optimizing radio resource allocation performance in V2V communication, as it demonstrates higher values and performance improvements compared to the FIFO algorithm with clustering.

Corresponding Author:

Muhammad Satrio Dwi Cahaya
Department of Telecommuncation Engineering
School of Electrical Engineering, Telkom University
Bandung, Indonesia
muhammadsatrio@telkomuniversity.ac.id

1. INTRODUCTION

The rapid growth in the number of vehicles on the road has demanded the development of smarter and more efficient transportation systems. In this context, Vehicle-to-Vehicle (V2V) communication plays a crucial role. V2V communication allows vehicles to exchange information in real-time, which not only enhances traffic efficiency but also improves the driving experience. With increasingly complex traffic environments and the rising demand for better transportation systems, the need for adaptive and efficient radio resource allocation becomes more urgent. The advent of 5G cellular network technology has opened new opportunities in V2V communication by offering higher data speeds, lower latency, and more reliable connectivity. However, achieving optimal performance requires radio resource allocation algorithms that can adapt to dynamic network conditions [1] or [2].

V2V communication has significant potential to enhance the efficiency and reliability of transportation systems. However, several major challenges must be addressed to ensure the smooth and effective operation of this communication. These challenges include optimal resource allocation, increased data rates, spectral efficiency, and fairness in resource distribution. Improving data rates is crucial for supporting fast and reliable data transmission, while good spectral efficiency allows for maximum use of available frequency spectrum, thereby increasing overall network capacity. Additionally, fairness in resource allocation must be ensured to prevent unequal distribution among different vehicles. Based on their simplicity and computational efficiency, this research chooses the Greedy and FIFO algorithms over more complex algorithms like genetic algorithms for testing when combined with clustering algorithms [3] or [4].

This research aims to optimize the performance of radio resource allocation algorithms in V2V communication. By adhering to the standards set by 3GPP, the study implements and evaluates several resource allocation algorithms, namely FIFO (First In First Out) and Greedy. The increasing number of vehicles adopting V2V technology demands more complex and efficient developments, particularly in resource allocation algorithms in the 5G era. Through this research, we hope to make a significant contribution to the advancement of V2V technology, specifically in the development of radio resource allocation algorithms. The evaluation is conducted through two scenarios: first, varying the number of users with a fixed trajectory distance; second, keeping the number of users constant while varying the trajectory distance. This paper is organized into four main sections: the introduction, which outlines the background and objectives; the method, which details the experimental setup and algorithms used; the results and discussion, which present and analyze the findings; and the conclusion, which summarizes the key outcomes and suggests directions for future research [5] or [6] or [7].

2. METHOD

The design of the proposed solution starts from the initial stage with the creation of a system model that includes two main parameters: Signal-to-Noise Ratio (SNR) from BTS to vehicle and battery level of each vehicle. These parameters are used to determine the resource block (RB) allocation in the Vehicle-to-Vehicle (V2V) communication network. Furthermore, this system model is broken down into two main approaches: Non-Clustering and Clustering. In the Non-Clustering approach, the [Vehicle x RB] allocation matrix is directly generated which describes the resource block allocation for each vehicle without clustering. Meanwhile, the Clustering approach involves grouping vehicles based on certain parameters before allocating resource blocks.

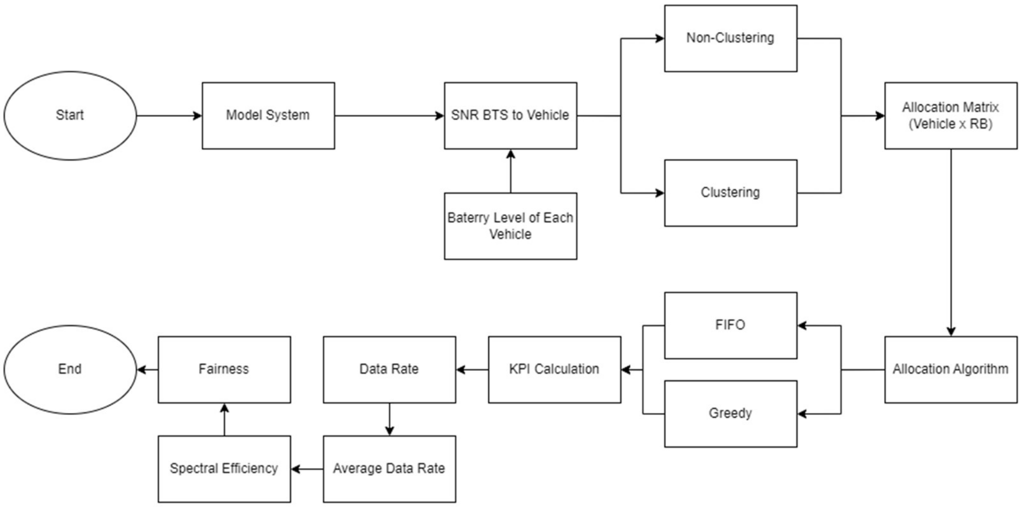

Figure 1. Flowchart Method

After clustering or directly from the Non Clustering model, resource block allocation is determined using various allocation algorithms such as First-In, First-Out (FIFO) which allocates RBs based on the order of arrival of requests, Greedy algorithm which selects the best allocation at each step without considering long-term consequences, and Genetic algorithm which mimics natural selection to find the optimal solution through selection, crossover, and mutation processes. The results of these various algorithms are then evaluated based on several performance metrics such as fairness, data rate, spectral efficiency, average data rate.[8]

2.1. Technical Specification

Technical specifications and industry standards play a crucial role in ensuring the interoperability and performance of global telecommunication systems. The 3GPP TS 22.185, TS 22.186, TS 22.885, and TS 22.886 standards set the service requirements to support Vehicle-to-Everything (V2X) communication scenarios in 5G networks [9]-[12].

Table 1. V2V Technical Specification Parameters

5G V2V Requirements	KPIs	Target Values
Data Rate	Minimum Data Rate	≥ 10 Mbps for standard V2V applications, ≥50 Mbps for advanced V2V applications
Spectral Efficiency	Spectral Efficiency (bps/Hz)	≥3 bps/Hz for downlin; ≥1.5 bps/Hz for uplink
Interference	SINR (Signal-to-Interference-plus-Noise-Ratio)	≥ 9 dB for V2V communication under normal operating conditions
Power Efficiency	Power Throughput Maximum	Max 35 dBm EIRP
Fairness	Resource Allocation Fairness	Inter-user throughput variation < 0.5 (Gini coefficient)
Frequency	Frequencies Standard for V2V Communication System	1900 MHz
Bandwidth	Bandwidth Use for Resource Block	10 MHz
Resource Block(RB)	Number of Resource Block (RB)	50 RB

2.2. Platooning

The system model employs a platooning scheme. The concept of vehicle platooning in a Vehicle-to-Vehicle (V2V) network involves a group of vehicles traveling together at a close, safe distance, with the capability to communicate with each other. In a platoon, one vehicle acts as the leader. Other vehicles can join or leave the platoon as needed. Platooning in V2V allows vehicles to move in a coordinated manner. Vehicles within the platoon use communication technology to interact, enabling rapid responses to changes in road conditions and the behavior of other vehicles [13].

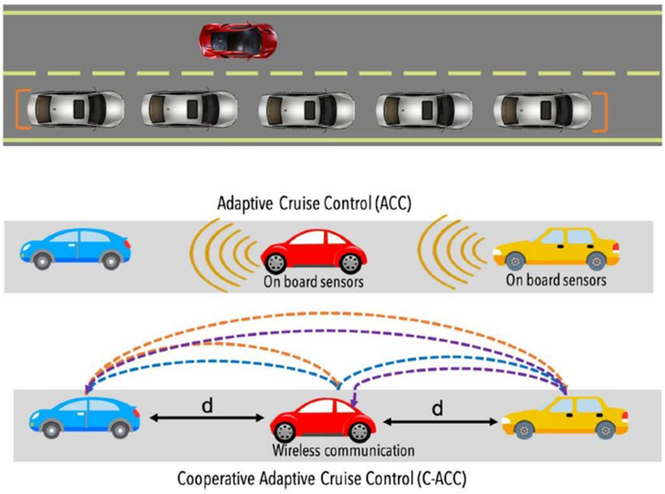

Figure 2. Platooning System Model

2.3. Clustering

In the Vehicle-to-Vehicle (V2V) platooning scheme on a straight highway, vehicles are positioned randomly and connected to a base transceiver station (BTS). Each vehicle group has a leader or medoid responsible for the allocation of resource blocks (RB). This study employs the K-Medoid Clustering algorithm, where the platoon leader is chosen, and vehicles are grouped based on their Euclidean distance to the platoon leader. The performance of K-Medoids Clustering is compared to the non-clustering concept in the implementation of each radio resource allocation algorithm. In the non-clustering concept, vehicles are grouped based on predetermined distance segmentation, and within this range, a leader or medoid is selected to allocate resources to each vehicle [14].

Figure 3. V2V Cluster Scenario

2.4. Pathloss

Pathloss COST 231 Rural

Pathloss COST 231 Rural is a development of the COST 231-Hata model used to estimate signal losses in rural environments, with frequencies between 1500 MHz and 2000 MHz and distances between 1 and 20 km. The model considers both transmitter (30-200 meters) and receiver (1-10 meters) antenna heights and uses a basic equation that includes correction factors for receiver antenna height and environment. In planning cellular networks in rural areas, the model is particularly useful for determining optimal antenna locations and heights, estimating signal coverage, and optimizing resource usage. Pathloss COST 231 Rural helps ensure effective and efficient communications, supporting reliable connectivity for residents in the area.

$$Pathloss_{cost231} = 46.3 + 33.9\, log_{10}(f) - 13.82\, log_{10}(h_{tx}) - dt + (44.9 - 6.55\, log_{10}(h_{tx}))\, log_{10}(d) \tag{1}$$

In (1), the model extends the Hata model for higher frequencies and diverse propagation conditions. The variable frequency (f) is measured in MHz, antenna height h_{tx} in meters, and the distance (d) between the transmitter and receiver in kilometers [15].

3GPP Pathloss V2V

The 3GPP Pathloss V2V propagation model is a model used to estimate signal losses (pathloss) between vehicles in Vehicle-to-Vehicle (V2V) communications. The model is specifically designed for inter-vehicle communication environments, where dynamic and rapidly changing conditions such as vehicle movements and distance variations greatly affect signal quality. The model considers various factors including operating frequency, antenna height, distance between vehicles, and highway or urban environmental conditions. 3GPP Pathloss V2V helps in the planning and optimization of inter-vehicle communication networks, ensuring reliable and efficient data transmission for applications such as advanced driver assistance systems (ADAS), traffic management and road safety. This model is critical to support consistent and responsive connectivity in the smart transportation ecosystem.

$$Pathloss_{3GPP\ Pathloss\ V2V} = 38.77 + 16.7\, log_{10}(d) + 18.2\, log_{10}(f) \tag{2}$$

In (2), the model estimates pathloss specific to vehicle-to-vehicle communication. The variable frequency (f) is measured in MHz, antenna height h_{tx} in meters, and the distance (d) between the transmitter and receiver in kilometers [16].

2.5 Channel State Information (CSI)

Channel State Information (CSI) is a critical component in wireless communication systems, providing detailed information about the state of the communication channel between the transmitter and the receiver. CSI includes parameters such as the channel's gain, phase, and impulse response, which describe the propagation conditions of the channel at a given time. Accurate CSI allows the transmitter to adapt its signaling strategies to optimize performance, enhancing data rates, reliability, and overall system efficiency. In vehicular communication systems, CSI is particularly important due to the rapidly changing environments and mobility of the vehicles, necessitating frequent updates and precise adjustments to maintain robust and efficient communication links.

$$P_{rx}(dBm) = P_t(dBm) + G_t(dBi) + G_r(dBi) - PL(dB) \tag{3}$$

$$Prx_{mW} = 10^{(\frac{Prx_{dB}}{10})} \tag{4}$$

In (3) and (4), transmission power (Pt) is measured in decibels relative to one milliwatt (dBm) and indicates the power level at which a signal is transmitted. The sending antenna gain (Gt) and the receiver antenna gain (Gr) are measured in decibels relative to an isotropic antenna (dBi), reflecting the antenna's ability to direct radio waves in a particular direction. Pathloss (PL), measured in decibels (dB), quantifies the reduction in signal strength as it propagates through space. Together, these parameters are critical in determining the effective communication range and signal quality in a wireless communication system.

The bandwidth of the communication channel, typically measured in Hertz (Hz), is a crucial parameter in telecommunications as it is said in (5). Signal-to-Noise Ratio (SNR_i) for the i-th Resource Block (RB) is another essential factor, representing the strength of the received signal relative to the background noise. To determine the channel capacity, the base-2 logarithm function (log2) is employed, allowing the calculation of the capacity in bits per second per Hertz (bps/Hz). This capacity indicates the maximum rate at which data can be transmitted over the channel while maintaining reliable communication.

$$\text{Total Data Rate} = \sum_{i=1}^{n} B \log_2(1 + SNR_i) \tag{5}$$

$$\text{Spectral Efficiency} = \frac{\text{Total Data Rate}}{Bandwidth} \tag{6}$$

In (6), the total data rate is calculated using the aforementioned formula, which takes into account various parameters such as transmission power, antenna gains, pathloss, and signal-to-noise ratio. This rate represents the maximum amount of data that can be transmitted over the communication channel per unit of time. Meanwhile, the total bandwidth refers to the entire frequency range utilized for data transmission, crucial for determining the overall capacity and efficiency of the communication system.

$$\text{Jain's Fairness Idx} = \frac{(\sum_{i=1}^{n} x_i)2}{n \sum_{i=1}^{n} x_i^2} \tag{7}$$

The total data rate is calculated using the aforementioned formula, which takes into account various parameters such as transmission power, antenna gains, pathloss, and signal-to-noise ratio. In (7), this rate represents the maximum amount of data that can be transmitted over the communication channel per unit of time. Meanwhile, the total bandwidth refers to the entire frequency range utilized for data transmission, crucial for determining the overall capacity and efficiency of the communication system.

2.6 System Model

In Scenario One, as illustrated in Figure 4, the simulation of the Vehicle-to-Vehicle (V2V) communication system features two Base Transceiver Stations (BTS) positioned at 750 meters (BTS 1) and 2250 meters (BTS 2) along a 3000-meter stretch of roadway. Vehicles travel in three parallel lanes, organized into several platoons. Within each platoon, vehicles communicate directly to maintain safe distances and synchronize speeds, ensuring cohesion and safety. Each platoon also interacts with the nearest BTS for broader information exchange, facilitating the dissemination of critical data such as traffic conditions and road hazards. This simulation progressively increases the number of vehicles from 60 to 100 users to evaluate the V2V communication system's performance under varying traffic densities, providing a robust assessment of its capabilities in managing communication and coordination among an increasing number of vehicles.

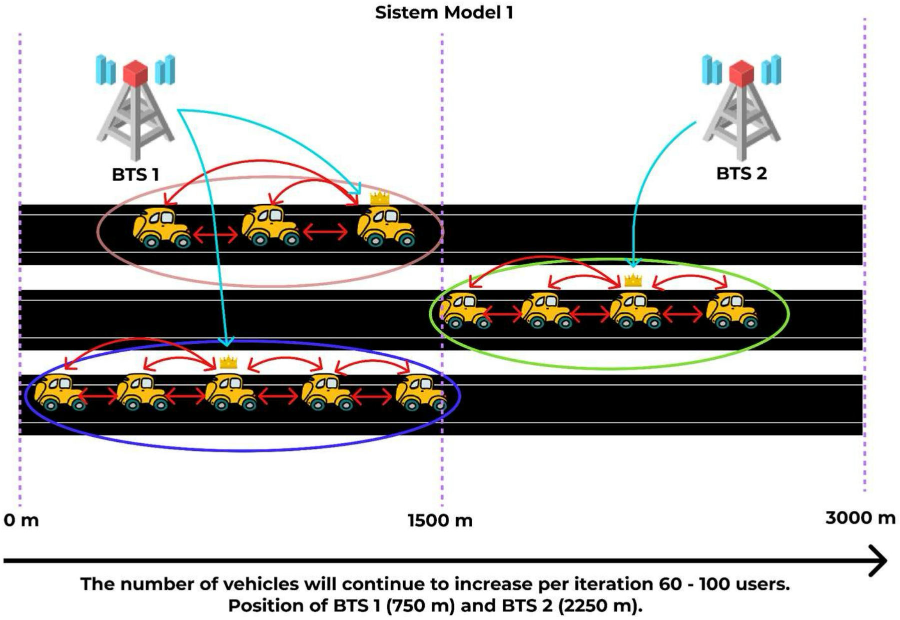

Figure 4. Scenario 1 Simulation

As detailed in Table 2, the simulation includes a varying number of vehicles, ranging from 60 to 100 users, each with a communication range of 50 meters, operating in a 10 MHz bandwidth and using a 1900 MHz frequency with a transmission power of 15 dBm. The setup also features 50 Resource Blocks (RB), with BTS and car antenna gains of 3 dBi, and utilizes the Cost 231 Rural and 3GPP-based Pathloss models for BTS and car communications, respectively. This setup evaluates the performance of V2V communication under different traffic conditions, providing valuable insights into resource allocation and system efficiency.

Table 2. Scenario 1 Parameters

Variable	Value
Road Length	3000 Meters
Maximum Distance V2V	50 Meters
Lane Roads	3 Lane Roads
Number of Vehicles	60, 70, 80, 90, 100 Users
Bandwidth RB	10 MHz
TRx Power	1900 MHz
Frequency	15 dBm
Number of Resource Block	50 RB
BTS Gain Antenna	3 dBi
Car Antenna Gain	3 dBi
BTS Pathloss Model	Cost 231 Rural
Car Pathloss Model	Pathloss V2V Based on 3GPP

In Scenario Two, illustrated in Figure 5, the Vehicle-to-Vehicle (V2V) communication simulation involves two Base Transceiver Stations (BTS) positioned at 750 meters (BTS 1) and 2250 meters (BTS 2) from the starting point. Vehicles travel in three parallel lanes over varying distances of 1000, 1500, 2000, 2500, and 3000 meters, organized into several platoons. Within each platoon, vehicles communicate directly to maintain safe distances and coordinate speeds, ensuring cohesion and safety. Additionally, each platoon interacts with the nearest BTS for broader information exchange, facilitating the dissemination of critical data such as traffic conditions and road hazards. Unlike Scenario One, the number of vehicles in this simulation remains constant at 100 users. This setup is designed to evaluate the performance of V2V communication under different trajectory conditions, providing valuable insights into how varying distances impact resource allocation and system efficiency.

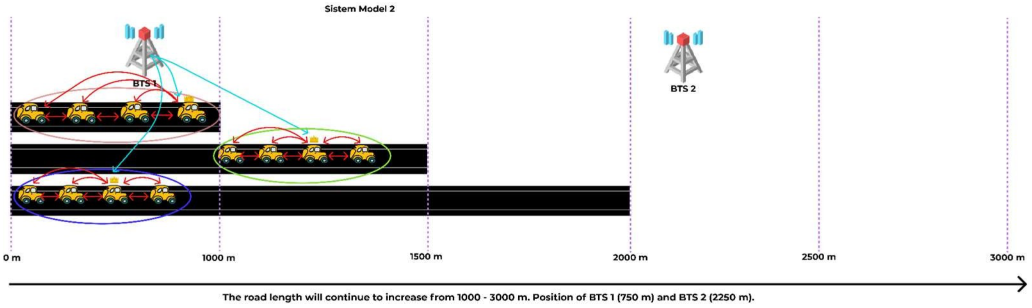

Figure 5. Scenario 2 Simulation

As detailed in Table 3, the setup includes 100 vehicles, each with a communication range of 50 meters, operating in a 10 MHz bandwidth and using a 1900 MHz frequency with a transmission power of 15 dBm. The configuration also features 50 Resource Blocks (RB), with both BTS and car antenna gains of 3 dBi, and utilizes the Cost 231 Rural and 3GPP-based Pathloss models for BTS and car communications, respectively. This simulation evaluates the performance of V2V communication under various trajectory conditions, providing valuable insights into effective resource allocation and system reliability.

Table 3. Scenario 2 Parameters

Variable	Value
Road Length	1000, 1500, 2000, 25000, 3000 Meters
Maximum Distance V2V	50 Meters
Lane Roads	3 Lane Roads
Number of Vehicles	100 Users
Bandwidth RB	10 MHz
TRx Power	1900 MHz
Frequency	15 dBm
Number of Resource Block	50 RB
BTS Gain Antenna	3 dBi
Car Antenna Gain	3 dBi
BTS Pathloss Model	Cost 231 Rural
Car Pathloss Model	Pathloss V2V Based on 3GPP

2.7 Resource Allocation Algorithm

FIFO Algorithm

The FIFO algorithm used in the matrix model above is a process of allocating Resource Blocks (RB) to users based on their order of arrival. Each user is allocated RBs sequentially, starting from the first arrival to the last. After an RB is allocated to a user, the corresponding row and column values are set to zero to prevent other users from receiving already allocated RBs. This process continues until all RBs are allocated or all users have been processed. Consequently, users arriving last may not receive any allocation if all RBs are already used

Pseudo Code 1 : FIFO Algorithm

```
//Classes for vehicles
class Vehicle: id, position, speed, cluster_id, is_leader

// Creating clusters
function create_clusters(vehicles, radius):
  clusters = []
  for v in vehicles:
    if v.cluster_id is None:
      cluster = [u for u in vehicles if abs(v.position - u.position) <= radius]
      for u in cluster: u.cluster_id = v.id
      clusters.append((v, cluster))
  return clusters

// FIFO Communication
function platoon_communication(platoons):
    for leader, members in platoons:
      queue = members[:]
      while queue:
          v = queue.pop(0)
          print(f"{v.id} -> {leader.id}")
          if not v.is_leader and queue:
            print(f"{v.id} -> {queue[0].id}")
```

Greedy Algorithm

The Greedy algorithm in the above matrix model selects the highest value of the RB matrix, allocates it to the corresponding user, and then sets all values in the same row and column to zero. This process continues until all RBs are allocated or all users have been processed. As a result, the user with the smallest value may not receive any allocation if all RBs have been used. This algorithm prioritizes allocation efficiency by prioritizing the highest value, but it may cause unfairness in resource distribution, especially for users with low priority or minimal needs [8].

Pseudo Code 2 : Greedy Algorithm

```
function greedyPlatooning(graph, leaderID, followerCount):
  leader = findNode(graph, leaderID)
  platoon = {ID: leaderID, Leader: leader, Followers: []}
  remaining = [n for n in graph.Nodes if n != leader]
  while len(platoon.Followers) < followerCount:
    nearest = findNearest(leader, remaining)
    platoon.Followers.append(nearest)
    remaining.remove(nearest)
  return platoon

function findNearest(leader, nodes):
  nearest, minDist = None, infinity
  for node in nodes:
    dist = calculateDistance(leader, node)
    if dist < minDist:
      nearest, minDist = node, dist
  return nearest
```

3. RESULTS AND DISCUSSION

This section will present the simulation results of both scenarios, focusing on total data rate, average data rate, spectral efficiency, and fairness. Additionally, we will discuss the comparative analysis of these four parameters across the two scenarios to identify the optimal configuration. The comparison will evaluate the performance of clustering versus non-clustering combined with FIFO and Greedy algorithms to determine the best approach.

3.1. Result Scenario 1

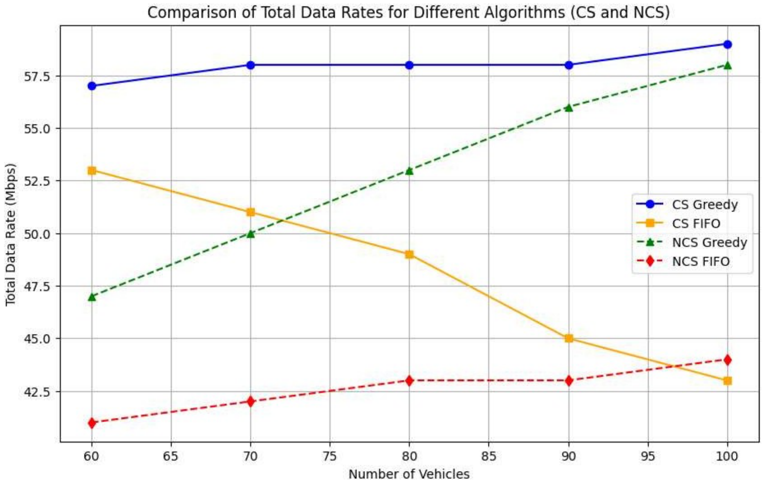

Figure 6. Total Data Rate Scenario 1

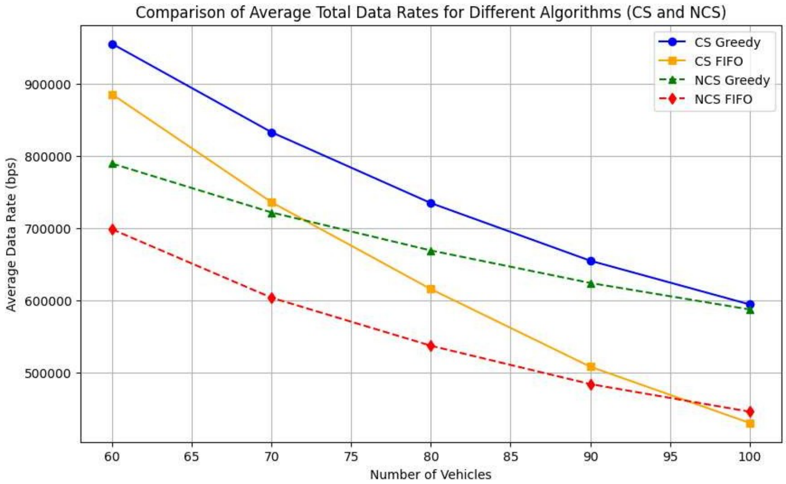

Figure 7. Average Data Rate Scenario 1

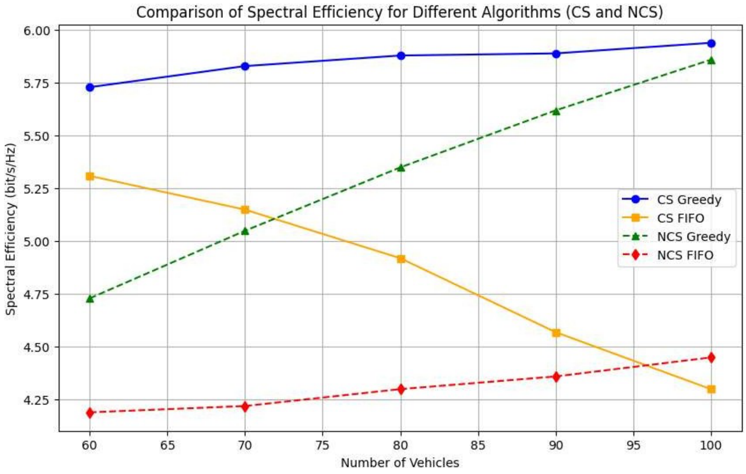

Figure 8. Spectral Efficiency Scenario 1

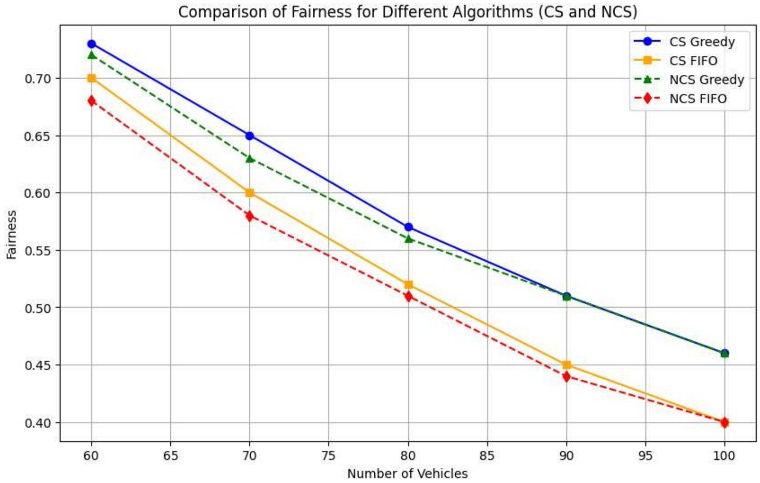

Figure 9. Fairness Scenario 1

3.2 Result Scenario 2

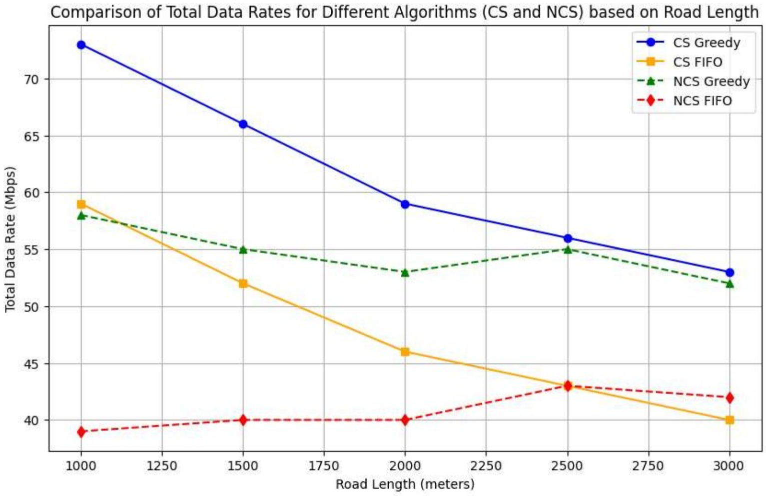

Figure 10. Total Data Rate Scenario 2

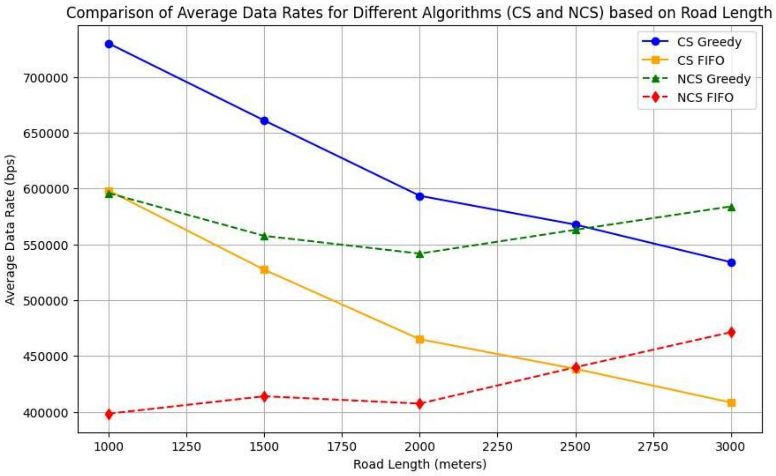

Figure 11. Average Data Rate Scenario 2

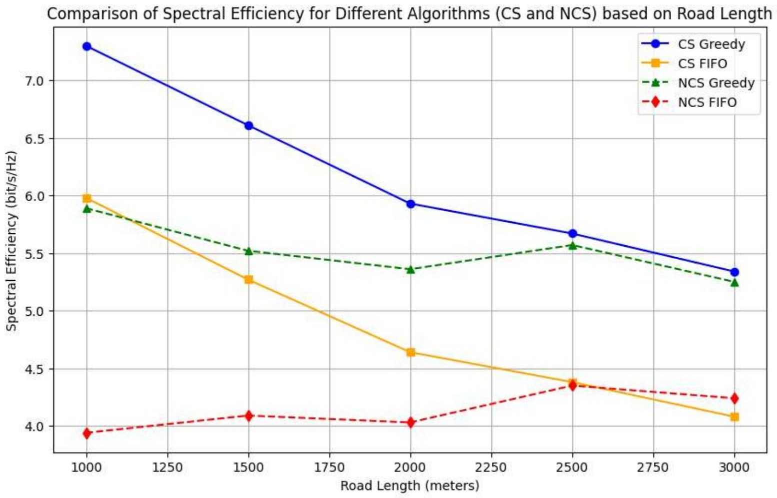

Figure 12. Spectral Efficiency Scenario 2

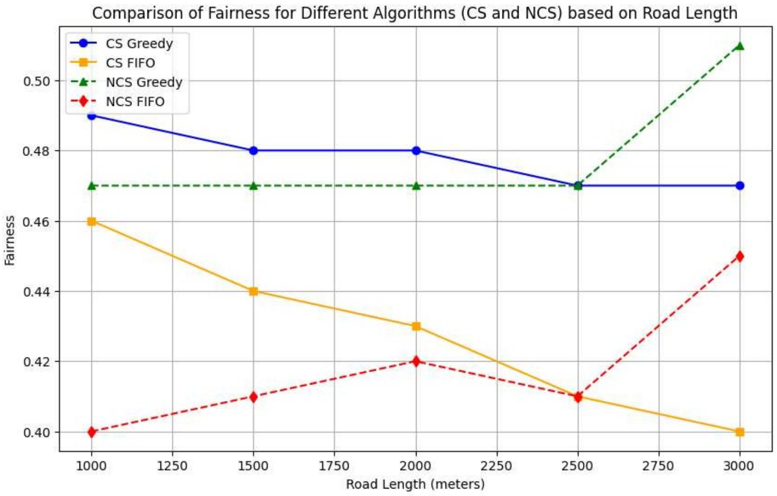

Figure 13. Fairness Scenario 2

3.2. Discussion

Table 4. Comparison of Clustering and Non-Clustering Algorithms

Scenario 1

Algorithm	Total Data Rate (Mbps)	Average Total Data Rate (bps)	Spectral Efficiency (bps/Hz)	Fairness
CS Greedy	58	754953,2	5,854	0,58
CS FIFO	48,2	635526,4	4,85	0,53
NCS Greedy	52,8	678847,6	5,322	0,58
NCS FIFO	42,6	554286,2	4,304	0,52

Scenario 2

Algorithm	Total Data Rate (Mbps)	Average Total Data Rate (bps)	Spectral Efficiency (bps/Hz)	Fairness
CS Greedy	61,4	617266,8	6,17	0,48
CS FIFO	48	487436	4,87	0,43
NCS Greedy	54,6	568437,2	5,518	0,48
NCS FIFO	40,8	426100,8	4,13	0,42

Table 5. Performance Comparison of Performance of each Algorithm with Clustering

Scenario 1

Algorithm	Total Data Rate (%)	Average Total Data Rate (%)	Spectral Efficiency (%)	Fairness (%)
CS Greedy vs CS FIFO	16,90	15,82	17,15	9,24
CS vs NCS in Greedy	8,97	10,08	9,09	1,47
CS vs NCS in FIFO	11,62	12,78	11,26	1,77

Scenario 2

Algorithm	Total Data Rate (%)	Average Total Data Rate (%)	Spectral Efficiency (%)	Fairness (%)
CS Greedy vs CS FIFO	21,82	21,03	21,07	10,44
CS vs NCS in Greedy	11,07	7,91	10,57	-0,84
CS vs NCS in FIFO	15,00	12,58	15,20	2,43

In the first scenario, when comparing CS Greedy with CS FIFO, it is evident that CS Greedy performs better with a Total Data Rate increase of 16.90%, Average Data Rate of 15.82%, Spectral Efficiency of 17.15%, and Fairness of 9.24%. This demonstrates that CS Greedy is more effective than CS FIFO in this context. Furthermore, when comparing CS (Clustering Scheme) and NCS (Non-Clustering Scheme) in the first scenario, the results show that CS FIFO offers a more significant improvement with a Total Data Rate increase of 11.62%, Average Data Rate of 12.78%, Spectral Efficiency of 11.26%, and Fairness of 1.77% compared to CS in the Greedy algorithm. This confirms that while CS FIFO provides better performance, the values produced are not higher than those of the Greedy algorithm in this scenario.

Furthermore, the highest spectral efficiency value is obtained with the largest number of users, specifically 100 users. As the number of users increases, the distance between users decreases. Consequently, the path loss value decreases, which in turn increases the Signal-to-Noise Ratio (SNR). This increase in SNR directly enhances the system's spectral efficiency. However, the most significant comparison between clustering and non-clustering methods occurs with 60 users. At this point, the clustering algorithm shows more optimal performance compared to other user numbers. This is due to the clustering algorithm's ability to efficiently group users.

In the second scenario, when comparing CS Greedy with CS FIFO, it is evident that CS Greedy performs better with a Total Data Rate increase of 21.82%, Average Data Rate of 21.03%, Spectral Efficiency of 21.07%, and Fairness of 10.44%. This demonstrates that CS Greedy is more effective than CS FIFO in this context. Furthermore, when comparing CS (Clustering Scheme) and NCS (Non-Clustering Scheme) in the first scenario, the results show that CS FIFO offers a more significant improvement with a Total Data Rate increase of 15.00%, Average Data Rate of 12.58%, Spectral Efficiency of 15.20%, and Fairness of 2.43% compared to CS in the Greedy algorithm. This confirms that while CS FIFO provides better performance, the values produced are not higher than those of the Greedy algorithm in this scenario.

Furthermore, the highest spectral efficiency value is obtained at the largest user distance, specifically 1000 meters. This indicates that when the distance between users is increased, while keeping the number of users constant, the distance between individual users becomes shorter. Consequently, the path loss value decreases, which in turn increases the Signal-to-Noise Ratio (SNR). This increase in SNR directly correlates with an improvement in the system's spectral efficiency. Specifically, the most significant spectral efficiency comparison between clustering and non-clustering methods is achieved with a user distance of 1000 meters and a constant number of users. Under these conditions, the clustering algorithm shows more optimal performance. The clustering algorithm works more efficiently due to its ability to group vehicles based on distance. This is due to the significant reduction in path loss and the consequent increase in SNR, which allows the clustering algorithm to utilize the spectrum more efficiently compared to the non-clustering method.

4. CONCLUSION

The research on V2V communication within 5G networks reveals that the CS (Clustering Strategy) Greedy algorithm excels in resource allocation compared to the CS FIFO algorithm. The CS Greedy algorithm consistently achieves higher data rates, better spectral efficiency, and greater fairness in resource distribution across various scenarios. Clustering significantly enhances the performance of both Greedy and FIFO algorithms, with the CS Greedy algorithm proving to be the most effective in dynamically managing resource blocks among vehicles. This ensures optimal spectrum utilization and reliable communication, making the CS Greedy algorithm the recommended choice for V2V communication on highways.

Furthermore, the comparison between clustered and non-clustered versions of the algorithms highlights the critical role of clustering in improving resource management. The CS FIFO algorithm, while not as efficient as CS Greedy, still outperforms its non-clustered counterpart, NCS FIFO, demonstrating the benefits of clustering in V2V communication. These findings suggest that clustering should be an integral part of resource allocation strategies to maximize the advantages of 5G technology in vehicular networks. Future research could enhance these strategies by incorporating real-time mobility models and handover processes, further refining V2V communication systems for increased efficiency and reliability.

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