Chews First Delaunay Triangulation refinement
Scheme-Based Positioning of RSUs for Optimal
Network Coverage in VANETs

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Chews First Delaunay Triangulation refinement Scheme-based positioning of RSUs for optimal network coverage in VANETs

Abstract: The temporal network fragmentation and uncertain vehicle mobility are considered to impact the communication connectivity among the vehicular nodes of the network. In this context, Road Side Units (RSUs) play an anchor role in enhancing the vehicle-to-vehicle (V2V) communication connectivity and support Vehicle-to-Infrastructure (V2I) communication. In the current scenario, deploying a huge number of RSUs in the vehicular networks at an initial stage is completely impossible as it incurs high installation cost and authority restriction. Moreover, the optimal placement of RSUs in the vehicular network needs to be enforced for attaining maximized network coverage. In this paper, Chews First Delaunay Triangulation Refinement Scheme (CFDTRS) is proposed for optimal positioning of RSUs in order to attain optimal network coverage in the vehicular network with minimized cost. This CFDTRS considered the factors of vehicular density, number of obstacles in the map, intersection popularity and global coverage into account during the placement of RSUs. It is proposed with the objective of deploying required number of RSUs within the range of data transmission in order to achieve maximal coverage in the convex map, such that each area of the convex map is completely covered with at least a single RSU in the existence of multiple number of obstacles. The simulation results of the proposed CFDTRS attained from the real time situations of simplex, moderate and complex maps confirmed improved packet delivery rate of 9.32%, throughput by 10.74% with minimized packet loss of 9.14% and reduced end-to-end delay of 19.31$, compared to the benchmarked schemes considered for investigation.

Keywords: Network Coverage, Road Side Units (RSUs), Chews First Delaunay Triangulation Refinement, Convex Maps, Optimal RSUs Placement, Intersection Popularity

1. Introduction

From the recent decade, Vehicular ad-hoc network (VANET) is considered to be the emerging technology that has invited huge amount of attention in the field of academics and industry [1]. The inclusion of VANETs in the Intelligent Transportation System (ITS) is determined to wide opened the way for predominant enhancement of the road safety and guaranteed reliable real time services with efficient through vehicle-to-vehicle (V2V) communications and vehicle-to-infrastructure (V2I) communications [2]. The V2V communications is facilitated by incorporating on-board units (OBUs) over the vehicles, while V2I communications is attained by deploying roadside infrastructure such as LTE base stations or road side units (RSUs) with the comprehensive support of wireless technology such as cellular networks or Dedicated Short Range Communication (DSRC) [3]. In this context, the cellular networks refers to the potential future 5G developments, both LTE and advanced LTE-Advanced. The diverse communication requirements associated with different applications cannot be satisfied, even when the complete communications solely relies on V2V and V2I as they possesses a highly dynamic characteritics of VANETs [4]. Hence, the communications of V2V and V2I need to coexist in order to improve the performance
of the network. Moreover, RSUs as a critical entity of V2I communications that plays an anchor role in improving the quality of service (QoS) facilitated to the users by preventing the degradation of services that are introduced by areas of congestion, non line of sight problems and security issues, etc [5]. In specific, RSUs acts as a gateways to the Internet and other systems infrastructure (for instance, ITS) and enhances the degree of traffic information dissemination that extends the level of message coverage in the network [6]. But, the deployment of RSUs in order to attain complete network coverage is definitely not possible during the initial stage of VANETs as they incur a high cost during the their placement and further maintenance [7].

In the urban area, RSUs need to potentially deployed for handling the influence introduced by the maximum number of obstacles present in the vehicular environment [8]. The process of identifying the possible regions of RSUs deployment is determined to be highly challenging due to the hinderance introduced by the tall buildings, tall trees, constructions and water bodies [9]. The regions considered for deploying RSUs may not exits in the rectangle or square geometric shape [10]. Moreover, the regions considered for RSUs deployment may be complex and has the possibility of introducing potential challenges that incurs high communication delay in the process of V2I communication [11]. At this juncture, the concept of Constrained Delaunay Triangulation (CDT) is considered to be indispensible for optimal RSUs deployment in order to reduce deployment cost and network coverage [12]. This concept of CDT relies on the core principle that emphasises that the deployment of RSUs need to be attained only along its vertices [13]. This CDT aids in handling the issue of RSU deployment cost and network coverage based on the estimation of transmission range and distance between the RSUs. Further, the challenge of transmission delay is handled through the potential properties of CDT as they are always updated regularly. In this context, the method of triangulation is determined to the suitable and reliable candidate for covering the convex region that need to be covered through the optimal deployment of RSUs [14]. This method of triangulation plays a vital role in the construction of triangular meshes that aids in estimating the significant position at which the RSUs can be deployed for maximized coverage and minimized deployment cost. Furthermore, location for RSUs deployment need to be estimated based on the strategy of optimization that concentrates on cost incurred in deploying RSUs and end-to-end delay essential for interacting with the neighbourhood RSUs that lies with a close proximity [15]. Moreover, the delay incurred in V2I communication can be potentially minimized based on the selection of ideal number of RSUs with their best position that exists within the communication range. At this juncture, Chew First Delaunay Triangulation Refinement Scheme is considered as the first predominant CDT technique that can be potentially used in the process of optimal RSUs placement.

In this paper, Chews First Delaunay Triangulation Refinement Scheme (CFDTRS) is proposed for identifying the optimal number of RSUs that could be significantly placed during V2I communication with the objective of covering maximum area with minimized deployment cost. This CFDTRS is proposed by inheriting the factors of vehicle density, different number of obstacles, intersection popularity and global coverage into account for attaining optimal RSUs
placement in the convex map. It was proposed with the characteristic merits of CDT that focusses on deploying required number of RSUs with necessitated transmission range for achieving maximized coverage in the convex map, such that each and every region of the map can be suitably covered by at least one RSU, independent to the number of obstacles present in the map. The comparative investigation of the proposed CFDTRS and the benchmarked schemes are achieved based on the simulation experiments conducted over the complex, moderate and simple maps that portrays real time road traffic scenarios. The simulation results confirmed that the proposed CFDTRS is capable enough in improving the packet delivery rate by 9.16%, reduced packet loss by 8.62% and minimized end-to-end delay by 18.42%, superior than the baseline schemes used for comparison and investigation.

The remaining sections of the paper is organized as follows. Section 2 depicts the literature review of the existing RSU optimal placement strategies proposed for V2I communication over the recent years with their pros and cons. Section 3 describes the complete details of the proposed CFDTRS scheme and their significant triangular mesh construction process with the strategy included for optimal RSUs selection that minimizes the cost of RSUs placement. Section 4 demonstrates the simulation results of the proposed CFDTRS scheme and the baseline approaches evaluated in terms of packet delivery ratio, throughput, packet loss, network coverage, end-to-end delay and RSUs placement cost under different number of RSUs, transmission range and vehicular densities. Section 5 concludes the paper with major contributions with the future scope of research.

2. Related Work

In this section, the review of the existing works of the literature proposed for optimal placement of RSUs in the vehicular network is presented with their pros and cons.

A constrained Delaunay triangulation (CDT) method named new spanner was proposed for optimal placement of RSUs with the view to improve network area coverage with minimized end-to-end delay [19]. This new spanner method attained the objective of RSUs placement based on the requirements of network and geometric properties. This method of CDT construction minimized the hops count between the network graph nodes by including a small collection of edges into the local Delaunay triangulation process. The simulation results of new spanner confirmed its potential in reducing the hops count from the source to the destination. It was determined to minimize jitter, delay and improve the throughput on par with the baseline planarized local Delaunay triangulation, local Delaunay triangulation, relative neighborhood graph and Gabriel graph-based triangulation approaches. A partial mobility information-based optimal RSUs placement scheme was proposed for targeting on the process of road network partition that aids in better RSUs deployment [20]. This RSUs deployment policy included the merits of migration ratios that are estimated between the neighboring urban cells for determining the optimal location of RSUs placement. It targeted on the identification of some specific number of locations that maximizes the degree of V2I contact opportunity. This partial mobility information-based
optimal RSUs placement scheme was determined to be better than the full mobility information and no mobility information-based optimal placement scheme.

A RSU deployment strategy was proposed for addressing the issue of computational demand and network coverage during placement [21]. This RSUs deployment framework was proposed for generating different number of placement models through the characteristics of area targeted for installation. It was utilized the infrastructure providers who played a vital role in the design of smart city. The results confirmed its significance by improving the packet delivery rate by 12.21%, minimized end-to-end delay by 10.38% and reduced RSUs cost of 8.74%, better than the existing approaches. Then, a realistic coverage scheme named Geocover was proposed for handling the challenges of resource constraints, mobility patterns and different service area that are common during RSU deployment in vehicular networks [22]. It was proposed geometry-based sparse coverage protocol that incorporated the geometrical attributes of networks and facilitates a buffering operation that gets adapted with respect to different kinds of road topology. This Geocover was proposed with the capability of discovering hotspots and predicted mobility patterns to an acceptable level. It included the merits of quality constraints and budget constraints into account for resolving the problem of resource constraints. It further used greedy and genetic algorithm for handling the problem of coverage.

Further, a Constrained Delaunay Triangulation (CDT) method of RSUs placement was proposed for assigning transmission range in the convex map, such that every individual map position can be perfectly covered by any one of the deployed RSUs independent to the number of obstacles [23]. This CDT approach initially determined the RSUs position for optimal deployment of RSUs in the obstacle free region. Then, an optimization method was included for determining the more potential location on which the RSUs deployment can be facilitated for attaining minimized end-to-end delay and RSUs cost. It also achieved a RSU selection strategy based on the merits of a multi-criteria decision making that aided in superior communication between I2V and V2I communication. The experimentation conducted with the simple, moderate and complex maps of Manhattan, Erlangen and Rome confirmed improvement in packet delivery rate of 7.7%, minimized packet loss of 9% and reduced end-to-end delay of 22%, compared to the existing CDT schemes.

3. Proposed Chews First Delaunay Triangulation Refinement Scheme (CFDTRS) for optimal RSUs placement

The proposed Chews First Delaunay Triangulation Refinement Scheme (CFDTRS) is proposed as a potential CDT approach that focuses on the optimal placement of RSUs with the view to achieve maximized global coverage with minimized deployment costs during reliable data dissemination. This CFDTRS scheme derives the merits of Chews First Delaunay Triangulation Refinement technique [25] and determines the optimal number of RSUs that can be significantly placed during V2I communication for reducing cost and maximizing network coverage within a given range of data transmission. It is developed with Chews First Delaunay Triangulation
Refinement strategy for ensuring better network coverage, which is considered as a significant approach over the constrained Delaunay triangulation based RSUs deployment strategy implemented by Ghorai and Banerjee [23]. The first objective of this proposed CFDTRS targets on the placement of RSUs in an urban area in which possible number of obstacles such as trees, water bodies, buildings and other constructions portraying a concave or convex polygon exists in the specified region. In this situation, the RSUs placement is completely impractical within such kind of polygons, even when there exists a possibility of placing RSUs on its sides. The primary goal of this CFDTRS scheme aims in placing the RSUs in an urban region for attaining complete network coverage, even when the area is completely obstructed by the existence of obstacles. It is also a reliable computational geometry approach of RSUs placement with an optimization strategy of Complex Proportional Assessment of alternatives (COPRAS) adoped for estimating the more potential RSUs position of deployment [24]. The secondary objective concentrated on the minimization of communication delay during V2I communication based on the utilization of multiple metric RSUs selection strategy, which plays an anchor role in selecting the best RSUs among the number of RSUs available in the range of data communication.

This proposed CFDTRS scheme of CDT construction achieved a larger minimized angle threshold of 28.32 degrees, which is estimated as a significant improvement over the CDT constructed by the baseline CDT scheme [23]. It is proposed with the potentiality of constructing uniform CDTs that are considered as the ideal candidate for modeling real time practical scenarios. This uniform density CDTs construction is also necessary for minimizing the number of RSUs that are deployed with the view to reduce their deployment cost and improve the coverage area of the network to a maximized degree. Moreover, the proposed CFDTRS scheme is considered to construct non uniform triangular meshes with the minimum and maximized angle of 27.92° and 122.64°, respectively. The proposed CFDTRS scheme consists of two significant parts such as, i) Initial RSUs position estimation based on CFDTR triangulation with optimization and ii) COPRAS-based multicriteria decision making strategy for RSU selection.

3.1 Initial RSUs position estimation based on CFDTR triangulation

The detailed view of the proposed CFDTR triangulation scheme that concentrated on the placement of optimal RSUs is described as follows. This RSUs optimal placement policy is explained based on Figure 1, which considered three RSUs such as A, B and C deployed in the vehicular network area.
In the process of this CDT construction, the transmission range associated with the RSUs are assumed to be unequal contributing towards the generation of non-uniform triangular meshes that maximizes network coverage with minimized RSUs deployment. The significance of the proposed CFDTRS scheme and its indispensable role of CDT construction for optimal RSU placement is explained based on the following lemmas.

**Lemma 1:** If the transmission range of the RSUs are $r_t = 1.44t$ and $r_t = 1.11t$, with the minimum angle between the CDT sides is 27.92°, [25], then the maximized global network area coverage achieved during the implementation of the proposed CFDTRS scheme is always 3 times better than the total area enveloped by the constructed CDT.

**Proof:** Let $TC_{A(G)}$, $TC_{B(G)}$ and $TC_{C(G)}$ represents the circles at the points A, B and C representing the network coverage area associated with each RSUs as illustrated in Figure 2. The network area covered by the RSUs-A, B and C in the constructed CFDTR triangle is m(Aed), m(Bfg) and (Cih), respectively, then the total area covered by the RSUs represented by m(ABC) can be computed based on the addition of three areas- m(Aed), m(Bfg) and (Cih). The maximum network coverage area of RSUs is considered to be achieved, if the total area covered by the RSUs is at least 3 times of the complete area covered by the CDT as the total area is partitioned into a number of CDTs. Thus, the total network area coverage facilitated by the three deployed RSUs are determined based on Equation (1)

$$TNA_{Coverage} = A(RSU_{Coverage}) + B(RSU_{Coverage}) + C(RSU_{Coverage})$$ (1)
\[\frac{\angle A}{2\pi} \pi NT_R^2 + \frac{\angle C}{2\pi} \pi NT_R^2 + \frac{\angle B}{2\pi} \pi NT_R^2 \]

\[= \frac{NT_R^2}{2} (\angle A + \angle C + \angle B)\]

The total angle enveloped by a CFDTR riangularization method is 180 degrees, thus the total network area coverage facilitated by the three deployed RSUs is estimated based on Equation (2)

\[\frac{\pi NT_R^2}{2}\]

Similarly,

\[\Delta ABC = \frac{1}{2} \times AC \times AB \times \sin \angle A\]

\[= \frac{1}{2} \times 1.44 NT_R \times 1.11 NTR \times \sin 27.92^\circ\]

\[= 0.3742 NT_R^2\]

Thus, the network area completely covered by the utilized RSUs as per the strategy of RDTRS scheme is confirmed to be 2.5 times \(TNA_{Coverage} > 3 \times \Delta ABC\) better than the area covered by a CDT constructed using CFDTRM and ICDT schemes. Moreover, the benchmarked CFDTRM and ICDT schemes were potent to cover only a total area of 2 times better than the area enveloped by the single constructed CDT.

**Lemma 2:** If the transmission range of the RSUs are 1.44\(r\) and 1.11\(r\), with the minimum angle between the CDT sides is 122.64\(^\circ\), [25], then the maximized global network area coverage achieved during the implementation of the proposed CFDTRS scheme is always 3 times better than the total area enveloped by the constructed CDT.

**Proof:** Let \(TC_{A(G)}\), \(TC_{A(G)}\) and \(TC_{A(G)}\) represents the circles at the points A, B and C representing the network coverage area associated with each RSUs as illustrated in Figure 2. The network area covered by the RSUs-A, B and C in the constructed CFDTR triangle is \(m(Aed)\), \(m(Bfg)\) and \(m(Cih)\), respectively, then the total area covered by the RSUs represented by \(m(ABC)\) can be computed based on the addition of three areas- \(m(Aed)\), \(m(Bfg)\) and \(m(Cih)\). The maximum network coverage area of RSUs is considered to be achieved, if the total area covered by the RSUs is at least 3 times of the complete area covered by the CDT as the total area is partitioned into a number of CDTs. Thus, the total network area coverage facilitated by the three deployed RSUs are determined based on Equation (1)

\[TNA_{Coverage} = A(\text{RSU}_{\text{(Coverage)}}) + B(\text{RSU}_{\text{(Coverage)}}) + C(\text{RSU}_{\text{(Coverage)}})\]

\[= \frac{\angle A}{2\pi} \pi NT_R^2 + \frac{\angle C}{2\pi} \pi NT_R^2 + \frac{\angle B}{2\pi} \pi NT_R^2\]
\[ = \frac{N_T^2 R^2}{2} (\angle A + \angle C + \angle B) \]

The total angle enveloped by a CFDTR riangularization method is 180 degrees, thus the total network area coverage facilitated by the three deployed RSUs is estimated based on Equation (2)

\[ = \pi \frac{N_T^2 R^2}{2} \quad \text{(4)} \]

Similarly,

\[ \Delta ABC = \frac{1}{2} \times AC \times AB \times \sin \angle A \]

\[ = \frac{1}{2} \times 1.44 N_T R \times 1.11 N_T R \times \sin 122.64^\circ \]

\[ = 0.3742 N_T^2 R^2 \]

Thus, the network area completely covered by the utilized RSUs as per the strategy of RDTRS scheme is confirmed to be 3 times \((TNA_{Coverage} > 3 \times \Delta ABC) \) better than the area covered by a CDT constructed using CFDTRM and ICDT schemes. Moreover, the benchmarked CFDTRM and ICDT schemes were potent to cover only a total area of 2 times better than the area enveloped by the single constructed CDT.

**Lemma 3:** The RSUs covers the maximum network coverage area with the transmission range of during the construction of CDT using CFDTRS, when the constructed CDT has a minimum angle of 27.92° with the sides of the length \(l\), \(2l\) and \(3l\) respectively.

**Proof:** The network area completely enclosed by the constructed CDT is calculated based on

\[ \Delta ABC = \frac{1}{2} \times AC \times AB \times \sin 27.92^\circ \]

\[ = \frac{1}{2} \times 2l \times 3l \times \sin 27.92^\circ \quad \text{(Where, } AC = 2l \text{ and } AB = 3l ) \]

\[ = 1.892l^2 \]

At this juncture, If the complete area covered by the considered three RSUs is identified to be times enveloped by the CFDTRS-based constructed CDT (According to lemma 1), then RSUs has the possibility of maximizing the network area coverage with the specified range of transmission determined based on

\[ \frac{\pi N_T^2 R^2}{2} = 4 \times 1.892l^2 \quad \text{(Where, } AC = 2l \text{ and } AB = 3l ) \]

\[ N_T R = 1.821l^2 \quad \text{(The total area is equal to 2 times the area covered by } \Delta ABC \text{)} \]
Lemma 4: The RSUs covers the maximum network coverage area with the transmission range of during the construction of CDT using CFDTRS, when the constructed CDT has a maximum angle of 121.36° with the sides of the length \( l, 2l \) and \( 3l \) respectively.

Proof: The network area completely enclosed by the constructed CDT is calculated based on

\[
\Delta ABC = \frac{1}{2} \times AC \times AB \times \sin 122.64° \]

\[
= \frac{1}{2} \times 2l \times 3l \times \sin 122.64° \quad \text{(Where, } AC = 2l \text{ and } AB = 3l \text{)}
\]

\[
= 3.218l^2
\]

At this juncture, If the complete area covered by the considered three RSUs is identified to be times enveloped by the CFDTRS-based constructed CDT (According to lemma 2), then RSUs has the possibility of maximizing the network area coverage with the specified range of transmission determined based on

\[
\frac{\pi}{2} R_t^2 = 4 \times 2.561l^2 \quad \text{(Where, } AC = 2l \text{ and } AB = 3l \text{)}
\]

\[
R_t = 3.274l
\]

Thus, the total area covered by the RSUs is equal to 2 times of the area enclosed by \( \Delta ABC \) during the implementation of CFDTRS-based constructed CDT

The aforementioned lemma 3 and 4 transparently proved that the implementation of RDTRS-based constructed CDT with the RSUs transmission range of \( R_t = 1.904l \) and \( R = 2.554l \) with the minimum and maximum angle ranging from 27.922° and 122.64°, confirmed that the complete area covered by the three RSUs is identified to guarantee 100% of the coverage.

3.2 Position estimation of significant RSUs

In this position estimation process of RSUs, the initial location of the RSUs are identified first based on the CFDTR triangularization method as described in Section 3.1. Then, an optimization method is incorporated for estimating the suitable position based on the initial position identified for each individual RSUs initially deployed in the vehicular network. If a number of RSUs, say \( RSU(i) = (RSU(1), RSU(2), RSU(3), \ldots, RSU(n)) \) are deployed in the network with their initial position \( (Pos_{RSU(1)}, Pos_{RSU(2)}, Pos_{RSU(3)}, \ldots, Pos_{RSU(n)}) \), then the weight function \( WF_{RSU(Select)} \) is estimated based on four vital constraints that includes transmission range, RSUs cost, delay and the number of obstacles based on Equation (5)

\[
WF_{RSU(Select)} = wf_1 \times NT_R + wf_2 \times RSU_{Cost} + wf_3 \times D_{Network} + wf_4 \times Obs_{Count} \quad (5)
\]
Where, \( w_f^1 \), \( w_f^2 \), \( w_f^3 \) and \( w_f^4 \) refers to the weight considered for the parameters of transmission range \( (NT_R) \), RSUs cost \( (RSU\text{Cost}) \), delay\( (D_{Network}) \) and the number of obstacles \( (Obs_{Count}) \). In this context, the values of \( w_f^1 \), \( w_f^2 \), \( w_f^3 \) and \( w_f^4 \) are assigned equally to 0.25 in order to emphasize their equal priority during the process of estimating the position of significant RSUs. At this juncture, the delay\( (D_{Network}) \) is computed based on Equation (6)

\[
D_{Network} = \min \sum_{i=1}^{n} D_{Cost(i)}
\]  

Where, \( D_{Cost(i)} \) highlights the minimum cost function calculated based on the lowest cost delay determined from the complete and feasible cost incurred during and every individual session.

### 3.3 RSU selection based on COPRAS

In this final step, the method of COPRAS is utilized as the multicriteria decision making process that aids in determining the process of RSU selection during V2I communication in order to reduce the transmission cost with maximized coverage and reduced delay. The method of COPRAS is included for selecting the suitable and ideal RSUs for effective routing of packets from the source to the destination vehicles for attaining reliable data communication in the network. This RSU selection process considered the collection of RSUs, criterions considered for RSU selection and their associated weights (already explained in Section 3.2). The steps involved in the process of RSU selection achieved through COPRAS is detailed as follows.

**Step 1**: Select the potential parameters (influencing criterions-say transmission range, RSU cost, delay and number of obstacles, etc.) that impact the selection of RSUs during V2I communication.

**Step 2**: Construct a decision making matrix \( (M_{DM}) \) based on the aforementioned constraints using Equation (7)

\[
M_{DM} = \begin{bmatrix}
RSU(C_{11}) & RSU(C_{12}) & \ldots & RSU(C_{1k}) \\
RSU(C_{21}) & RSU(C_{22}) & \ldots & RSU(C_{2k}) \\
\ldots & \ldots & \ldots & \ldots \\
RSU(C_{m1}) & RSU(C_{m2}) & \ldots & RSU(C_{mk})
\end{bmatrix}
\]

Where, ‘\( m \)’ and ‘\( n \)’ refers to the number of RSUs and the number of criterions considered for evaluating each of the RSUs deployed in the vehicular network.

**Step 3**: Determine the weight \( (W_i) \) associated with the criterions (factors of selection indexes used for RSUs selection) for attaining the goal of optimal RSUs selection process.
Step 4: Construct the Normalized Decision Matrix (\( M_{NDM} \)) (presented in Equation (9)) based on Equation (7) with the normalization process depicted through Equation (8).

\[
\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i} x_{ij}} ; \quad 1 \leq i \leq m \text{ and } 1 \leq j \leq k
\]  
\[
M_{DM} = \begin{bmatrix}
RSU(C_{11-N}) & RSU(C_{12-N}) & \ldots & RSU(C_{1k-N}) \\
RSU(C_{21-N}) & RSU(C_{22-N}) & \ldots & RSU(C_{2k-N}) \\
\vdots & \vdots & \ddots & \vdots \\
RSU(C_{m1-N}) & RSU(C_{m2-N}) & \ldots & RSU(C_{mk-N})
\end{bmatrix}
\]  

Step 5: Construct the Weight Normalized Decision Matrix (\( M_{WN_{DM}} \)) (presented in Equation (11)) based on Equation (9) with the normalization process depicted through Equation (10).

\[
\hat{x}_{ij} = \bar{x}_{ij} * W_j ; \quad 1 \leq i \leq m \text{ and } 1 \leq j \leq k
\]  
\[
M_{DM} = \begin{bmatrix}
RSU(C_{11-WN}) & RSU(C_{12-WN}) & \ldots & RSU(C_{1k-WN}) \\
RSU(C_{21-WN}) & RSU(C_{22-WN}) & \ldots & RSU(C_{2k-WN}) \\
\vdots & \vdots & \ddots & \vdots \\
RSU(C_{m1-WN}) & RSU(C_{m2-WN}) & \ldots & RSU(C_{mk-WN})
\end{bmatrix}
\]  

Step 6: The weighted normalized values of the RSUs are determined based on the most preferable maximization parameters such as network coverage and throughput considered for optimization are added together as depicted in Equation (12)

\[
M_{P_{Max,Fn}(i)} = \sum_{j=1}^{k} \hat{x}_{ij}
\]  

In the above mentioned Equation, ‘\( k \)’ refers to the maximum and complete number of criterions considered for maximization or minimization. Moreover, the evaluation criterions that possesses the maximal optimal possibility are used identified before confirming the criterions that possess minimal optimal possibility in the matrix columns.

Step 7: Then, the weighted normalized values of the RSUs are also determined based on the most preferable minimization parameters such as RSUs cost, delay, number of obstacles and network transmission range considered for optimization are integrated together as specified in Equation (13)

\[
M_{P_{Min,Fn}(i)} = \sum_{j=k+1}^{q} \hat{x}_{ij}
\]
Step 8: Determine the minimized value associated with the most preferable minimization parameters-based weighted normalized values \((MP_{Min\_Fn(i)})\) depending on Equation (14)

\[
Select(MP_{Min\_Fn(i)}) = \min_i MP_{Min\_Fn(i)}; \quad 1 \leq i \leq m
\]  

(14)

Step 9: Calculate the relative weight of each RSU ‘i’ based on Equation (15)

\[
RW_{(RSU-i)} = MP_{Max\_Fn(i)} + \frac{\text{Select}(MP_{Min\_Fn(i)}) \sum_r Select(MP_{Min\_Fn(i)})}{MP_{Min\_Fn(i)} \sum_i Select(MP_{Min\_Fn(i)})}
\]  

(15)

Step 10: Select the optimality criteria \((OC_k)\) based on Equation (16)

\[
OC_k = \max_i RW_{(RSU-i)}
\]  

(16)

Step 11: Identify the priority of RSUs that possesses a greater weight \((RW_{(RSU-i)})\) among ‘m’ RSUs deployed in the network in order to select them as the fittest RSUs that has the possibility of selection during V2I communication. Moreover, a degree of satisfaction with respect to each RSUs complies with the indices of selection that are either maximized or minimized during optimization process.

Step 12: Finally, the RSUs selection degree \((RSU_{Select(i)})\) is computed based on Equation (17)

\[
MN_{DU(i)} = \left( \frac{RW_{(RSU-i)}}{RW_{Max-RSU-i}} \right) \times 100\%
\]  

(17)

Where, \(RW_{(RSU-i)}\) and \(RW_{Max-RSU-i}\) represents the weights of the RSUs estimated based on Equation (15).

Hence, the RSUs with maximized RSUs selection degree \((RSU_{Select(i)})\) are selected during V2I communication in order to achieve reliable data dissemination with low cost of deployment.

4. Simulation Results and Discussion

The simulation experiments of the proposed CFDTRS scheme and the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes are conducted based on EXataCyber-5.4 Network Simulator [25]. The simulation experiments of the proposed CFDTRS scheme and the baseline schemes are conducted based on the scenario that comprises of 100 vehicular nodes with the maximum and minimum velocity of vehicles set to 20 meters per second and 10 meters per second. In the implementation environment, the number of RSUs deployed in the network are varied from
10-100 in order to investigate their significance with respect to their increase and increase in the network with reference to network area coverage and deployment costs. The simulation experiments are attained with the protocols of MobileIP, AODV and UDP that corresponds to the network layer, transport layer and application layer based on the data traffic that satisfies the characteristics of Constant Bit Rate (CBR). data traffic. In addition, Table 1 depicts the simulation parameters considered for implementation of the proposed CFDTRS scheme.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulator Used</td>
<td>EXataCyber-5.4</td>
</tr>
<tr>
<td>Topology considered for implementation</td>
<td>Urban area with obstacles</td>
</tr>
<tr>
<td>Number of vehicles</td>
<td>100</td>
</tr>
<tr>
<td>Minimum velocity of vehicular nodes</td>
<td>20 meters per second</td>
</tr>
<tr>
<td>Maximum velocity of vehicular nodes</td>
<td>40 meters per second</td>
</tr>
<tr>
<td>Network terrain area</td>
<td>2500 x2500 square meters</td>
</tr>
<tr>
<td>Simulation time</td>
<td>500 seconds</td>
</tr>
<tr>
<td>Protocol considered for routing packets</td>
<td>AODV</td>
</tr>
<tr>
<td>Transport protocol</td>
<td>UDP</td>
</tr>
<tr>
<td>Size of the packet</td>
<td>120 bytes</td>
</tr>
<tr>
<td>Traffic type</td>
<td>Constant Bit Rate (CBR)</td>
</tr>
<tr>
<td>Number of packets disseminated per second</td>
<td>50 packets</td>
</tr>
<tr>
<td>Network protocol</td>
<td>MobileIPv4</td>
</tr>
<tr>
<td>Physical layer radio</td>
<td>IEEE 802.11p</td>
</tr>
<tr>
<td>Antenna model</td>
<td>Omnidirectional</td>
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<tr>
<td>Path Loss model</td>
<td>Two ray</td>
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<tr>
<td>Shadowing model</td>
<td>Log normal</td>
</tr>
<tr>
<td>Fading model</td>
<td>Ricean</td>
</tr>
<tr>
<td>SNR threshold</td>
<td>4 dBm</td>
</tr>
</tbody>
</table>

In the first of investigation, the proposed CFDTRS scheme and the baseline CRCCDT, PMIRSUP and NFDRSUP schemes are investigated based on network area coverage, mean throughput and average end-to-end delay with simple (Manhattan) and complex maps (Rome) and RSUs count varied from 10 to 100. Figure 2 and 3 presents the network area coverage and mean throughput of the proposed CFDTRS scheme and the baseline CRCCDT, PMIRSUP and NFDRSUP schemes with with simple (Manhattan) and RSUs count varied from 10 to 100. The network area coverage of the proposed CFDTRS scheme with systematic increase in the number of RSUs is considered to be significant on par with the baseline schemes, since the network area enveloped by the constructed triangular CDT is maximized. Moreover the mean throughput of the proposed CFDTRS scheme is also improved as the selection of optimal RSUs is attained through the inclusion of COPRAS multicriteria decision making strategy. Thus, the proposed CFDTRS
scheme is confirmed to improve the network area coverage by 5.42%, 7.18% and 9.64%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes. Moreover, the mean throughput of the proposed CFDTRS scheme is determined to be enhanced by 6.14%, 8.52% and 9.18%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes.

Figure 2: Proposed CFDTRS: Network Area Coverage with different RSUs (Simple Map-Manhattan)
Figure 4 demonstrates the average end-to-end delay of the proposed CFDTRS scheme and the baseline CRCCDT, PMIRSUP and NFDRSUP schemes with simple (Manhattan) and RSUs count varied from 10 to 100. The average end-to-end delay of the proposed CFDTRS scheme is visualized to be minimized on par with the benchmarked schemes, since optimal number of RSUs are deterministically selected based on the application of equal weights to each of the parameters considered for optimizing the placement of RSUs in the network. On the other hand, the proposed CFDTRS scheme is reliable in handling the impact of obstacles that completely hinders the communication between the source and destination vehicular nodes. Hence, the average end-to-end delay incurred by the proposed CFDTRS scheme is proved be presominantly reduced by 7.21%, 8.28% and 9.02%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes.

Further, Figure 5 and 6 demonstrate the network area coverage and mean throughput of the proposed CFDTRS scheme and the baseline CRCCDT, PMIRSUP and NFDRSUP schemes with complex map (Rome) and RSUs count varied from 10 to 100. The network coverage area enveloped by the proposed CFDTRS scheme is determined to cover atleast three time the area coverage by a single CDT. Furthermore, maximized throughput is guaranteed in the network through the selection of RSUs that compulsorily prevents the drop of packets in the network. Thus, the network area coverage of the proposed CFDTRS scheme under complex map is confirmed to
be improved by 5.32%, 7.64% and 8.929%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes. Moreover, the mean throughput of the proposed CFDTRS scheme is also visualized to be enhanced by 6.02%, 7.94% and 9.51%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes.

Figure 5: Proposed CFDTRS: Network Area Coverage with different RSUs (Complex Map-Rome)
Figure 6: Proposed CFDTRS: Mean Throughput with different RSUs (Complex Map-Rome)

Figure 7: Proposed CFDTRS: Average End-to-end delay with different RSUs (Complex Map-Rome)

Figure 7 demonstrates the average end-to-end delay of the proposed CFDTRS scheme and the baseline CRCCDT, PMIRSUP and NFDRSUP schemes with complex map (Rome) and RSUs.
count varied from 10 to 100. With respect to complex map, the average end-to-end delay of the proposed CFDTRS scheme with different number of obstacles is confirmed to be minimized compared to the benchmarked schemes, since the included triangulation process is efficient and effective enough in determining minimal number of RSUs with maximized network coverage. This proposed scheme is effective in preventing the delay by selecting only the RSUs that considerably minimizes the drop of packets during V2I communication process. Thus, the average end-to-end delay incurred by the proposed CFDTRS scheme is proved be predominantly reduced by 5.18%, 7.92% and 9.14%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes.

In the second part of investigation, the proposed CFDTRS scheme and the baseline CRCCDT, PMIRSUP and NFDRSUP schemes are investigated based on network area coverage, mean rate of packet delivery, mean packet loss and average end-to-end delay with complex map (Rome) and density of vehicles varied from 10 to 100. Figure 8 and 9 depicts the network area coverage and mean rate of packet delivery achieved by the proposed CFDTRS scheme and the baseline schemes evaluated with respect to different vehicular densities. The network area coverage of the proposed CFDTRS scheme with different vehicle densities is identified to be improved by 7.21%, 9.42% and 11.68%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes. Moreover, the mean rate of packet delivery of the proposed CFDTRS scheme with different vehicle densities is identified to be improved by 7.21%, 9.42% and 11.68%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes.

![Figure 8: Proposed CFDTRS : Network Area Coverage with different density of vehicles](image-url)
Figure 9: Proposed CFDTRS: Mean Rate of Packet Delivery with different density of vehicles

Figure 10: Proposed RDTRS: Mean Packet Loss with different density of vehicles
Figure 10 and 11 demonstrates the mean packet loss and average end-to-end delay of the proposed CFDTRS scheme and the baseline schemes evaluated with respect to different vehicular densities. The proposed CFDTRS scheme with different vehicle densities is determined to reduce the mean packet loss by 6.54%, 8.56% and 10.72%, superior to the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes. In addition, the proposed CFDTRS scheme with different vehicle densities is identified to minimize the average end-to-end delay by 6.92%, 8.64% and 10.88%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes.

5. Conclusions

In this paper, CFDTRS scheme is proposed for better triangulation method that aids in better construction of CDT that focuses on minimizing deployment cost of RSUs with maximized network coverage in V2I communication. This proposed CFDTRS scheme was proposed for handling huge number of obstacles that hinders the network performance in urban environments. It was proposed with the merits of COPRAS for better multi-attribute decision making process that concentrated on the optimal RSUs selection that maximizes the network area coverage. This CFDTRS is proposed by inheriting the factors of vehicle density, different number of obstacles, intersection popularity and global coverage into account for attaining optimal RSUs placement in the convex map. The simulation results of this proposed CFDTRS scheme with different RSUs is confirmed to improve the network area coverage and mean throughput, on an average by 8.36% and 8.92%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes. With respect to different vehicle densities, the proposed CFDTRS scheme improved the...
mean network area coverage, mean rate of packet delivery by 8.64% and 8.42% with minimized packet loss and average end-to-end delay by 9.12% and 9.54%, superior to the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes. In addition, the proposed CFDTRS scheme with different vehicle densities is identified to minimize the average end-to-end delay by 6.92%, 8.64% and 10.88%, better than the benchmarked CRCCDT, PMIRSUP and NFDRSUP schemes. As the part of the future scope, it is decided to formulate a Ruppert CDT-based triangulation method and compare it with the proposed CFDTRS scheme.

Data Availability Statement

Data sharing not applicable – no new data generated. Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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The authors declare that there is no competing interest

References


Figures

Figure 1
Optimal RSUs placement based on the proposed CFDTRS scheme

Figure 2
Proposed CFDTRS: Network Area Coverage with different RSUs (Simple Map-Manhattan)
Figure 3

Proposed CFDTRS: Mean Throughput with different RSUs (Simple Map-Manhattan)

Figure 4

Proposed CFDTRS: Average End-to-end delay with different RSUs (Simple Map-Manhattan)
Figure 5

Proposed CFDTRS: Network Area Coverage with different RSUs (Complex Map-Rome)

Figure 6

Proposed CFDTRS: Mean Throughput with different RSUs (Complex Map-Rome)
Figure 7

Proposed CFDTRS: Average End-to-end delay with different RSUs (Complex Map-Rome)

Figure 8

Proposed CFDTRS: Network Area Coverage with different density of vehicles
**Figure 9**

Proposed CFDTRS: Mean Rate of Packet Delivery with different density of vehicles

**Figure 10**

Proposed RDTRS: Mean Packet Loss with different density of vehicles
Figure 11

Proposed RDTRS: Average end-to-end delay with different density of vehicles