A Cluster-based Mechanism for Vehicular Networks in the Scale-Free ICN Core Network

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Abstract**—** The repetition of content requests happens frequently in the vehicular networks, and it is increasing depending on the vehicular density in a certain area. On the other hand, information-centric networking (ICN) is being used in the vehicular networks to fulfill the faster content communication requirements, reduce latency, and enhance the network capacity. Although, the ICN-based vehicular networks have many benefits, it has several drawbacks, e.g., interest packet flooding, inefficient content caching, and so on. Moreover, the network scalability is related to the drawbacks of the existing ICN-based vehicular networks. It is also important that the current Internet architecture is considered as a scale-free network. Therefore, the solution of the existing drawbacks can be solved using the concept of the scale-free ICN network. In this paper, we propose a cluster-based mechanism for vehicular networks in the scale-free ICN core networks. We also simulate the various scenarios of a scale-free network and show the comparative analysis of different scenarios in terms of the total number of clusters vs the number of nodes in a cluster. Our simulation result ensures the solution to the interest flooding problem and the efficiency of the content caching mechanism.

Keywords—Vehicular Network; scale-free network; cluster; ICN; CCN

I. INTRODUCTION

The existing Internet architecture is becoming complex and the content delivery in the current Internet architecture based on the position-dependent IP addresses becoming challenging because of the limited number of IP addresses. The demand for fast content transfer is also increasing day by day. In the current Internet architecture, the end-to-end communication latency is very high compared to the expected future end-to-end communication latency. Considering this situation, a new communication paradigm called has emerged. Content-centric networking (CCN) [1] is one of the types of ICN which has also attracted the research communities because of its new communication mechanism where the content location is not required to retrieve any content. CCN has been being used as an emerging solution in various areas, e.g., faster content retrieval in vehicular networks and content delivery networks.

ICN-based vehicular communication was already proposed in our previous work [2] where we used CCN as a type of ICN. CCN can solve the existing problems of the IP-based architecture by using the naming of the content and it is already familiar for faster content retrieval. In ICN-based vehicular communication, the content queries and data packets are routed based on the content name [3] instead of the content location information. Although ICN-based vehicular networks are promising with their various characteristics, its operation still floods the network when the network size is very large. Moreover, the content is cached inefficiently at all the traversing nodes in the ICN core network.

The current ICN-based Internet core architecture is considered a scale-free network [4, 5]. Therefore, we propose a cluster-based mechanism for vehicular networks in the scale-free ICN core networks to solve the existing drawbacks of ICN-based vehicular communication. The rest of the paper is organized as follows. Section II describes the related work of this paper. Our proposed cluster-based scale-free network is described in Section III. Section IV presents simulation results, and Section V concludes our paper.

II. RELATED WORKS

Although, there are some other clustering-based approaches for mobility support [6, 7] in ICN, where they do not consider the maximum drawbacks of ICN. Therefore, we considered most of the drawbacks of ICN and tried to incorporate all of the probable solutions to each drawback into 987 our proposal.

In-networking caching is one of the most important characteristics of ICN. A framework for vehicular networks has been proposed to provide multimedia services [8]. They mainly concentrated on increasing the capacity, improving QoE, and supporting mobility services. Another cooperative gap-based caching [9] mechanism was proposed in the vehicular networks without exchanging extra cache management information. A cluster-based in-networking caching mechanism [10] was proposed to improve the cache hit ratio and reduce caching redundancy for CCN. This cluster-based in-networking caching mechanism can improve the cache hit ratio and reduce the link load of networks, but they do not provide the detailed mechanism to reduce the Interest flooding in the CCN. They worked mainly on the caching-related issues, but our work has integrated multiple solutions to the ICN problems, e.g., the solution to the Interest flooding problem as well as efficient cache management mechanism.

III. CLUSTER-BASED SCALE-FREE NETWORK

In this section, we describe our proposed cluster-based mechanism in detail. We describe the clustering mechanism from a scale-free network perspective and then the cluster head selection mechanism for each cluster.

A. Scale-free ICN Core Networks

The scale-free network follows a power-law degree distribution to create the network. We created our scale-free network for the variable number of nodes and α values by following equation number 1.

$$p(k) = k^{-\alpha} \;\dots\dots\dots\; (1)$$

For each α value, the network structure of the CCN core network is different. Figure 1 shows a scale-free network for 30 nodes when α = 2.

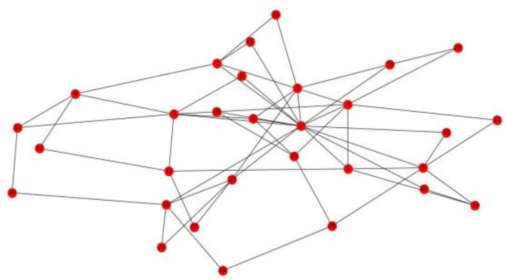


Figure 1: A scale-free network for 30 nodes

B. A clustering mechanism in a scale-free network

We applied the clustering algorithm in the created scale-free network to make the clusters for a given network. The following algorithm 1 is used to make the cluster. After applying this algorithm in any scale-free network, we get the set of clusters and their members in each cluster based on the degree of centrality of each node.

Algorithm 1: To make the Clusters

Definition: Node is defined as λ_i, cluster is defined as ξ_j, visited node is defined as $\pounds_k$, neighbor node is defined as ς_m

Initialization: $\pounds_{k = \{0\}}$

1. Select a random node, λ_i while $\pounds_{k\, != \{0\}}$
2. If λ_i is not in $\pounds_k$
3. Calculate the degree of λ_i
4. Calculate ς_m degree of λ_i if $\pounds_k$ is 0
5. If (degree of $\varsigma_m > \lambda_i$)
6. Cluster found;
7. Append (ς_m and λ_i)
8. End if
9. Continue
10. Continue
11. End if
12. End while

Figure 2 shows the clusters in different colors. Each color in a different position indicates the clusters and the total number of similar colors indicates the total number of cluster members at each cluster. Figure 2 indicates the clusters from the previously created scale-free network.

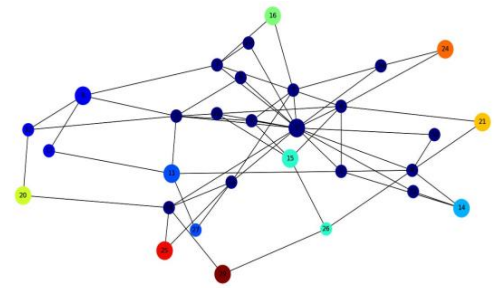


Figure 2: A clustered scale-free network for 30 nodes

C. Cluster head selection in each cluster

To select the cluster head for each cluster, we applied another algorithm. After applying the following algorithm 2, we get the cluster head for each cluster. This algorithm gives us the set of cluster heads for a given clustered algorithm. The larger node of each color represents the cluster head of each cluster.

Algorithm 2: To make the Cluster head

Definition: Cluster is defined as ξ_j, neighbor node is defined as ς_m, visited cluster is defined as δ_v, cluster head is defined as $¥_q$

Initialization: $\delta_{v = \{0\}}$

1. Select a random cluster, ξ_j while $\delta_{v\, != \{0\}}$
2. If ξ_j is not in δ_v
3. For each node in ξ_j, calculate the degree of ς_m
4. Find the maximum degree from ξ_j and ς_m
5. Maximum degree node became cluster head;
6. Add in list of $¥_q$
7. End for
8. End if
9. End while

D. Responsibility of the cluster node and the cluster head node to solve the Interest flooding problem

The vehicles are either connected with the ICN core network via a cluster node or a cluster head node. When any vehicle sends an Interest packet to the ICN core network, the Interest is received by the cluster node or cluster head node. If any cluster node receives the Interest packet, then that cluster node tries to serve the request if the requested content is already available in the directory. Otherwise, that cluster node forwards the Interest packet to the cluster head. The cluster head already knows the information of available content in the cluster and also knows the neighbors' cluster head information. After receiving the Interest packet in the cluster head, the cluster head tries to serve that Interest Packet. Otherwise, if the content is available in his own or other cluster nodes, then forward the Interest packet to that cluster node member. That cluster node serves the incoming Interest Packet. If the content is not available in that cluster, then the cluster heads forward that incoming Interest packet towards the neighboring cluster head. The neighboring cluster head follows the similar mechanism as the previous cluster head did until reaching that Interest packet to the final content provider. By following this mechanism, the Interest flooding problem can be solved easily.

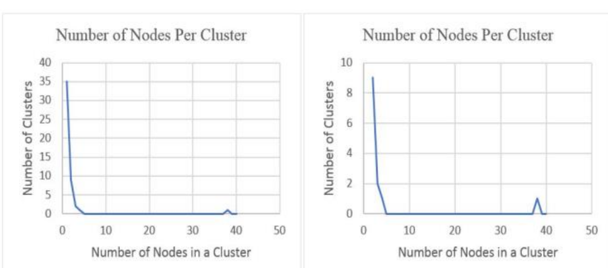
E. *Efficient content handling and caching mechanism*

The node members in a cluster and the cluster head have their own caching capabilities. As the cluster head knows the available free cache size and also the available contents in each cluster node member, the cluster head can manage the duplicate contents from his own cluster member and one-hop cluster heads node. Therefore, the cache is efficiently handled in our cluster-based ICN core network. Following a similar mechanism, the overall network caching efficiency is increased. As the cluster head knows the available free cache size of each cluster node member, so the cluster head can also decide on the content store during the unavailability of cache for a certain node in a cluster. Based on the content short-term and long-term content popularity, the cluster head can distribute the popular content within the cluster nodes based on the availability of cache in the respective nodes. This mechanism increases the availability of the content in the network. By following these two mechanisms, our cluster-based vehicular networks in ICN can handle the content and cache efficiently.

IV. SIMULATION RESULTS

We used a Python-based simulation environment to create the scale-free network for different α values and a variable number of nodes in the network.

Figures 3 shows the number of clusters comparison for an α value in a constant size of the network for 100 nodes. In Figure 3 (a), we can see that when the α value is 2.0 then the total number of single-node clusters is 35 and the double node cluster is 9. But Figure 3 (b) shows that if the single node cluster is merged into the nearest cluster, then the total number of clusters is reduced significantly. Therefore, the network communication overhead is also reduced greatly. Figure 3 (a) also shows the number of nodes in a cluster for 100 nodes when the α value is 2.0. The total number of nodes in a cluster for this network is also reasonable, and a cluster head easily can maintain all of its cluster members but only one cluster contains a large number of cluster members that is a little bit difficult to maintain that cluster. We can also control this situation depending on the α value. When the α value is increased, the number of multiple node clusters is decreased, and the size of the networks seems smaller in terms of hop-by-hop communication.



(a) (b)

Figure 3: Number of Nodes Per Clusters for 100 nodes when α = 2.0, (a) With single node cluster, (b) without single node cluster

The above analysis ensures that the cluster-based scale-free vehicular networks make the network very small compared to the non-clustered network. Moreover, the Interest forwarding mechanism is different from the regular Interest forwarding mechanism. Therefore, the Interest packet has not flooded the network. Similarly, the caching mechanism is also handled as discussed before.

V. CONCLUSION

In this paper, we applied the clustering concept in the ICN-based vehicular core network that is considered as the scale-free network. Our proposed clustering mechanism works well in the scale-free vehicular network. We also described the mechanism of Interest handling and caching in the cluster-based scale-free vehicular networks. We have simulated in the Python-based simulation environment and showed that our proposed cluster-based mechanism can handle the Interest flooding and content caching efficiently.

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