Chapter 3

Data dissemination in Vehicular Networks

3.1 Data dissemination models

One of the key design aspects of vehicular communication systems is data dissemination, which is the process of distributing and pushing data to network nodes [64]. The source data or message can be distributed in one-to-one, one-to-any, or one-to-all modes. In the networking aspect, these three schemes are defined as unicast, anycast, and broadcast modes of communication [28] [38].

3.1.1 Unicast

In unicast mode, data transmission occurs from a single source to a single destination node. This kind of communication is a dedicated point-to-point connection between nodes and is usually used in non-safety applications. It is less efficient if data needs to be shared with multiple nodes. Figure 3.1 shows the unicast mode for data dissemination. As shown, the message from the source (S) traverses a multi-hop path through multiple relay nodes (R) to reach its destination (D).

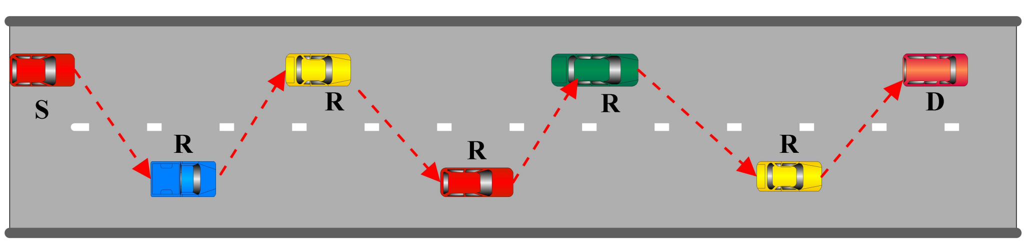

Figure 3.1: Multi-hop Unicast Communcation

3.1.2 Anycast

Anycast is a one-to-any kind of transmission in which data is sent to any nodes in the area of interest (AoI). Certain traffic efficiency applications require this mode of communication to alert vehicles in a specific region. Figure 3.2 represents the anycast communication model for data dissemination. As shown, the anycast message from the source (S) traverses a multi-hop path through multiple relay nodes (R) until it reaches one of the nodes (D) in the area of interest (AoI).

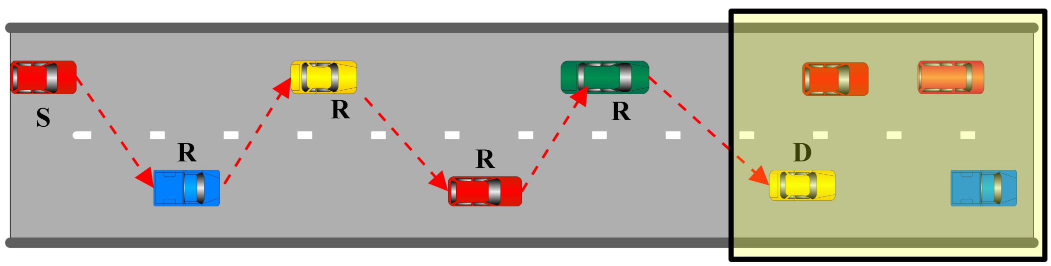

Figure 3.2: Multi-hop Anycast Communcation

3.1.3 Broadcast

Broadcast is a very native data dissemination scheme in which the source node sends the data to all surrounding nodes. Here the same message is sent to all the nodes, so the spreading of the message is very efficient and fast. Multi-hop forwarding of data is used in a unicast, anycast, or broadcast scheme to convey data over a longer distance (beyond the transmission range of the source). Figure 3.3 represents the broadcast communication model for data dissemination. In this mode of communication, every node within the sender's transmission range receives the message. If multi-hop broadcasting is employed, the message will be rebroadcast by favorable nodes in order to cover the entire network[37].

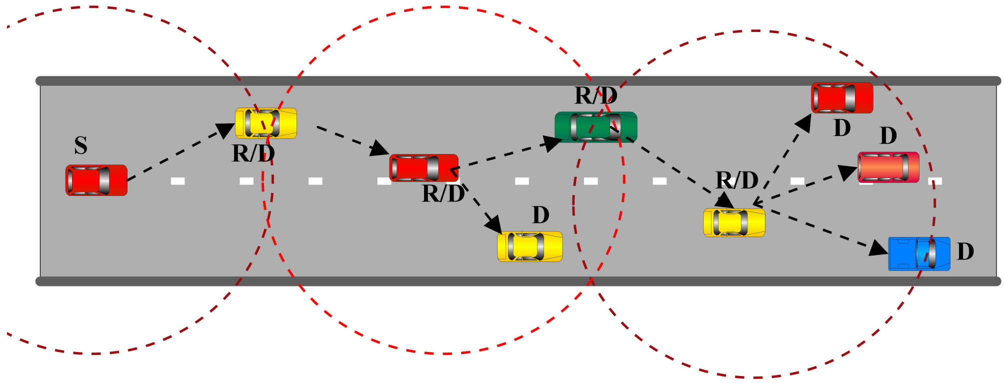

Figure 3.3: Multi-hop Broadcast Communcation

3.2 Flooding

The easiest method of covering every node in vehicular networks is simple flooding, often known as blind flooding. It is the simplest method for performing multihop broadcasting [48]. In flooding, when a vehicle receives a message, it checks to see if it is the first time it has received this message. It rebroadcasts the message if the answer is "yes", otherwise, it is discarded. However, excessive redundancy and packet collisions are the main drawbacks of blind flooding [47] [55][15].

Redundancy: The primary reason for redundancy is that the transmission ranges of different vehicles overlap with each other. In such a scenario, even if all of the neighbors have already received the message, a vehicle could broadcast the message to its neighbors. Redundancy will also increase with the rise in vehicle densities. The radio range of DSRC communication may reach up to 1000 m. In a high-density scenario, there may be 50 to 100 vehicles per kilometer. As a result, 50 to 100 message receptions will occur as a result of simple flooding [20].

Packet Collisions: Vehicle communication based on 802.11p uses the CSMA/CA channel access strategy, where idle channels are identified via clear channel assessment (CCA). A back-off process is utilized to avoid collisions. If a vehicle has to send a frame, it first scans the channel for Distributed Inter-Frame Space (DIFS). If the medium is idle, the vehicle initiates frame transmission. If the medium is already in use, the vehicle will perform a random back-off to wait before transmitting. Here, collisions occur for three primary reasons: (i) All nearby vehicles may begin rebroadcasting at around the same time after having completed their back-off procedures; (ii) broadcast is a handshake-less communication, so collisions will result due to the hidden node problem. (iii) IEEE 802.11p does not support collision detection (CD). Without collision detection (CD), a vehicle will continue to broadcast messages even if its previous messages are lost, resulting in additional collisions.

The issue of an excessive rise in broadcast packets is known as the "broadcast storm" problem. A broadcast storm will cause significant packet loss and bandwidth exhaustion [66]. Repeated forwarding of the same message will also increase the delay. To mitigate the issue of blind flooding, controlled-flooding-based broadcast systems are chosen, which allow only a subset of vehicles to rebroadcast the message. Controlled-flooding relies on selecting a subset of surrounding vehicles, known as "forwarders", which relay the received message to the next hop of vehicles. A message is transmitted from the source node to vehicles in the area of interest (AoI) through the forwarders. Controlled-flooding Select forwarders carefully in order to meet application requirements for reliability, latency, and bandwidth efficiency. Figure 3.4 shows the steps in the process of controlled flooding. The performance of controlled flooding will heavily depend on the next forwarding node selection method [55].

3.3 Safety Message Broadcast approaches

Broadcast is the preferred communication mode for safety-related vehicular applications. Safety applications broadcast alerts to vehicles in a risk zone. Due to the limited range of DSRC-based vehicle communication, multi-hop broadcast is the most prevalent method for message dissemination. Infotainment applications also necessitate multi-hop communication, but it is largely demand-driven and follows a unicast method. This study focuses on the multi-hop broadcast method for disseminating safety-related data. In vehicle networks, flooding appears to be the best method for multi-hop broadcasting. However, it is not employed be-

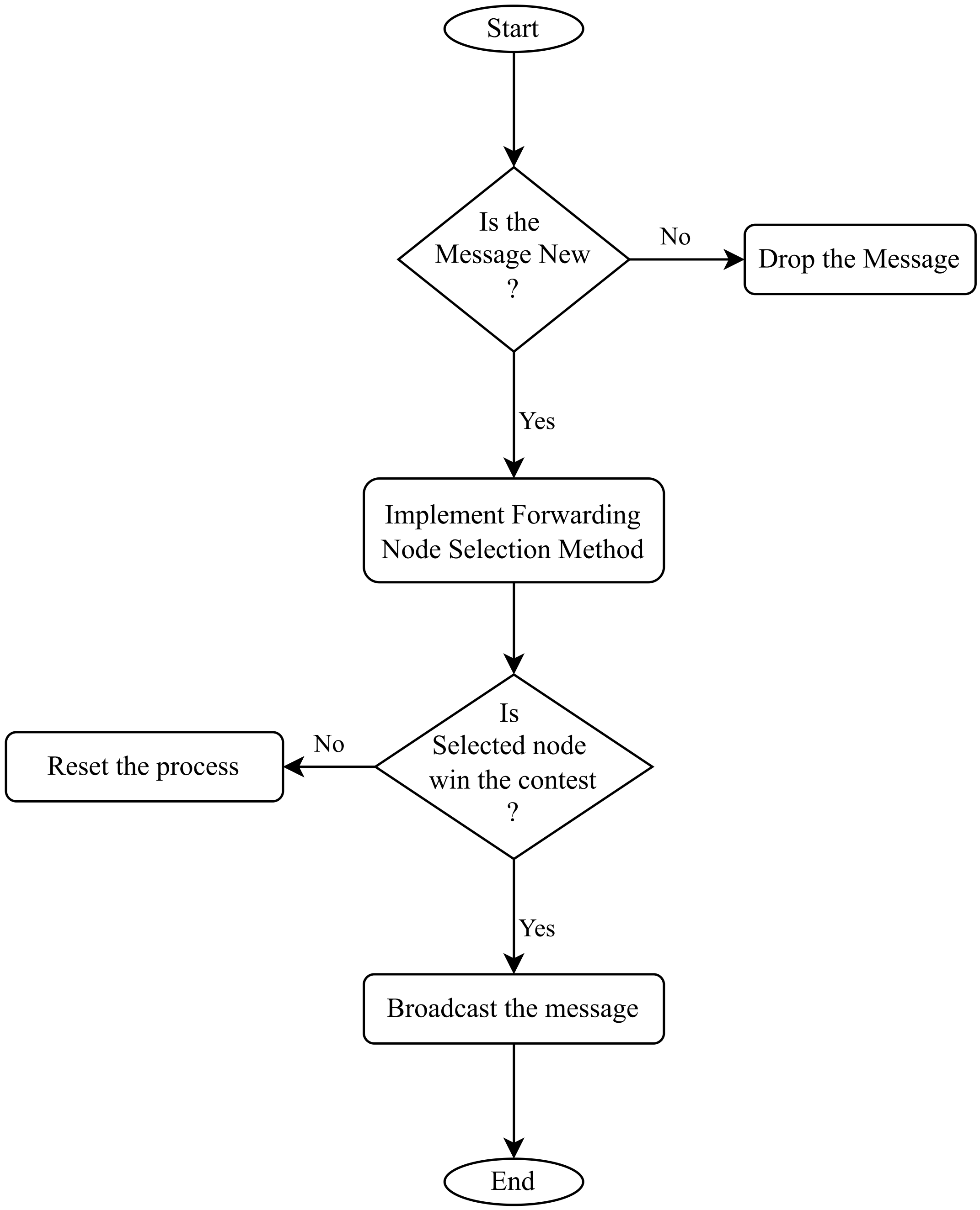

Figure 3.4: Controlled-flooding method

cause the performance of safety applications decreases drastically at high network densities. Controlled-flooding techniques are a preferable choice for implementing safety applications; however, these approaches have many challenges. This section represents different multi-hop safety message broadcast schemes that are designed to avoid the broadcast storm problem and establish reliable and efficient safety message dissemination in vehicular environments. These schemes are classified into Five categories: probabilistic schemes, delay-based schemes, counter-based schemes, repetition-based schemes, and cluster-based schemes.

3.3.1 Probabilistic schemes

The probabilistic broadcast method assigns each forwarder candidate a unique forwarding probability. These potential forwarders then retransmit the message in accordance with their given probability. Therefore, a candidate with a higher probability of being rebroadcast is likely to be selected for broadcasting. In its simplest form, the probabilistic scheme assigns a predetermined probability for rebroadcast. An advanced scheme may calculate the rebroadcast probability based on distance, node density, speed of the vehicle, etc. Determining the best probability assignment is a significant challenge in the probabilistic approach. Several protocols, such as weighted p-persistence [54], Optimized Adaptive Probabilistic Broadcast (OAPB) [3], and Auto-Cast [52], use a stochastic-based forwarding strategy.

Wisitpongphan et al.[54] suggested slotted 1-persistence, slotted p-persistence, and weighted p-persistence schemes. Each vehicle determines its own broadcast probability using only local information. On receiving a packet from a neighboring node i node j rebroadcasts the packet with probability P_{ij} if the packet is received first time; otherwise, it discards the packet. In the weighted p-persistence strategy, vehicles at a higher distance from the sender are assigned a higher probability to speed up the data dissemination. The slotted 1-persistence method grants each vehicle a forwarding probability of 1 for retransmitting the message only during its specified time slot. S_{ij}. The equation-3.1, shows that S_{ij} is function of intervehicle seperation (D_i).

$$S_{ij} = S_T \times \tau \left(1 - \frac{D_i}{Range}\right) \tag{3.1}$$

Some probabilistic protocols, such as [3],[52],[36] and [21] used the traffic intensity to calculate the probabilty of broadcast. Recently [32],[10] proposed Speed adaptive probabilistic protocols, which determine probability of broadcast based on vehicle speeds.

The main problem with these methods is that more than one forwarder might be chosen to send the same message, resulting in network flooding, collisions, and inefficient channel utilization. added to this, these techniques do not consider challenges encountered in high-density urban areas, such as severe multi-path fading and shadowing, lossy channels, etc, making them unsuitable for driving safely in congested urban environments.

3.3.2 Delay-based schemes

A delay-based technique assigns different waiting delays to each forwarder candidate before rebroadcasting the message. The vehicle with the least waiting delay is allowed to rebroadcast the message, whereas the other vehicles abort their broadcasts upon finding that the message has already been rebroadcast. In delay-based techniques, a node delays the broadcast for a specific amount of time. The delay time is calculated based on different parameters, such as distance, node density, vehicle speed, etc.

Figure-3.5 shows the pictorial presentation of the furthest node-based relay selection process. The source node(S) initiates the message, and F_1 and F_2 are the two possible relay nodes to broadcast the message further toward the receiver (R). As can be seen, the F_2 node is further away from the source node than the F_1. So, more coverage will be offered if the message is relayed through F_2. Using F_2 as a relay node, messages reach the receiver in two hops, whereas F_1 requires three hops.

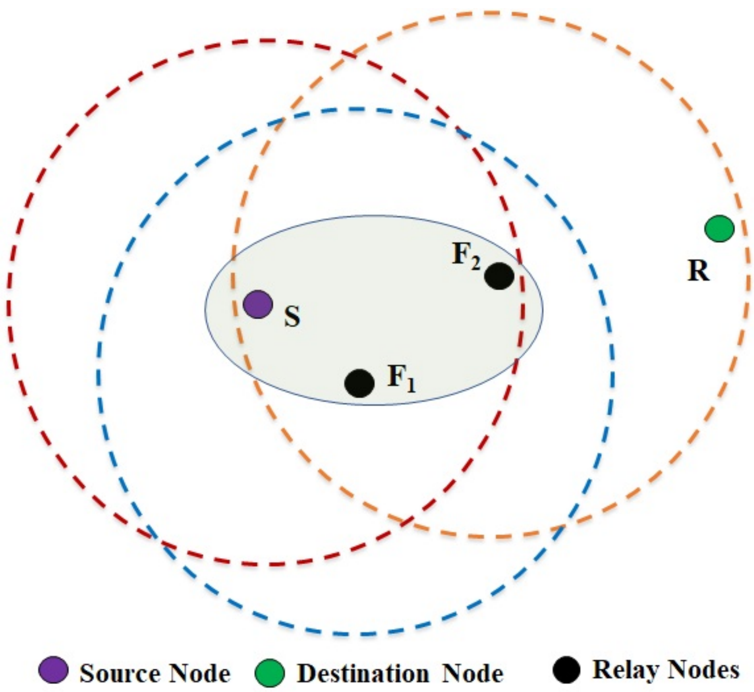

Figure 3.5: Furthest node based relay selection

$$Delay(t) = MaxT\left(1 - \frac{d_i}{Range}\right) \tag{3.2}$$

The distance-based delay calculation mechanism is shown in equation 3.2, where d_i is the distance between the sender and receiver vehicles. Several delay-based protocols as per equation-**??** is presented in [6], [58], [49].

According to PAB [57], each node that receives a packet calculates its distance from the sender. It then chooses a waiting period that is inversely correlated with the distance between the transmitter and the receiver. The node whose timer expires first is the one that is farthest away.

UMB is presented in [25] to overcome the hidden node problem, and reliability issues in multihop broadcasting. In UMB, the sender's transmission range was divided into several segments, and the forwarder candidates from the furthest segment were assigned the highest rebroadcast priority. To prevent collisions and resolve the hidden node problem, handshaking procedures based on Request-to-Broadcast (RTB) and Clear-to-Broadcast (CTB) are used prior rebroadcasting the safety message. In order to guarantee message transmission, the forwarder additionally sends the sender an acknowledgement (ACK). In a dense network, however, collisions will still occur due to multiple vehicles in same segments. UMB assigns the longest waiting time to the farthest segment, increasing delay in broadcast.

3P3B [44] solves the problem of concurrent transmission within the same segments. It gradually divides the communication range into tiny fragments. The partitioning mechanism lets the vehicle in the sector farthest from the sender node do the forwarding. This speeds up the dissemination of data by reducing the number of hops.

In order to decrease collisions and long wait periods, RObust and Fast Forwarding (ROFF) [61] has been developed. Using shared empty space distribution (ESD) bitmaps, ROFF enables each node to select its own forwarding priority. However ROFF result into very high overhead.

3.3.3 Counter-based schemes

The number of times a packet is received on any node has an inverse relationship with the possibility of additional coverage if that node re-broadcasts. The counter-based method uses this simplest analogy in the forwarding node selection process. On receiving any packet for the first time, the node initiates a counter to count the number of receptions of the same message within a time value of T_{max}. The counter value increases by one every time the message is received within T_{max} time. The packet is rebroadcast if the counter is lower than a threshold value (C_{th}) when the timer expires. If not, it is merely abandoned [34].

Oh et al. in [36] describe the Distance-based Backoff with Counter-based Suppression (DBCG) hybrid scheme, which chooses a backoff timer based on location information. DBCG has a delay function based on the distance to the last forwarder, which uses different statistical means for different distances.

A constant counter value is not suitable for all densities. Performance can be enhanced by varying the counter value in relation to the neighbor density. Protocols utilizing counter-based techniques can adjust the counter values dependent on the surrounding population density to achieve a balance between transmission repetition and aditional coverage.

3.3.4 Repetition-based schemes

The objective of a repetition-based scheme is to increase the probability of reception [56]. In this scheme, every possible relay vehicle is assigned a frame with N time slots. The vehicle is allowed to repeat the transmission of the message within the allotted frame. The pattern of repetition can be random or structured. In random repetition, the selection of time slot is random. In [56], vehicles transmit with probability p in every time slot and avoid with probability $1-p$. In [60], the protocol selects k time slots at random from a total of N slots. In FREMD [27], surrounding vehicle density is used to identify the appropriate repetition rate.

3.3.5 Cluster-based schemes

Cluster-based information dissemination is a advanced dissemination strategy. Nodes with similar characteristics are joined together into clusters[63]. Each cluster has a cluster head who assumes administrative responsibilities and manages the other cluster members. Nodes that can communicate to other clusters act as a gateways and responsible for information exchange btween different clusters[31]. Vehicles with similar velocity, direction, and position are grouped together to form a cluster because such vehicles will stay in the cluster for a longer time[42].

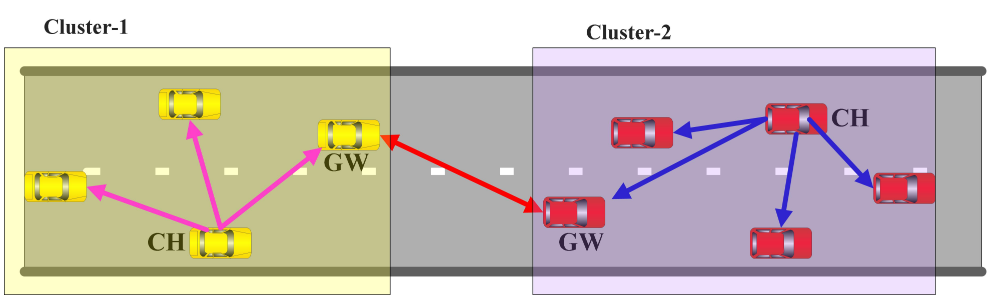

Figure 3.6: Cluster-based Communcation

There are mainly two types of communication that take place in cluster-based data dissemination.

(i) *intra-cluster communication:*

Within the cluster, communication take place between cluster head (CH) and members (CM). Cluster head will use multicast to convey messages toward members. Cluster memebers use unicast communication model to direct message toward cluster head.

(ii) *inter-cluster communication:*

To disseminate message beyond cluster size, inter-cluster communication take place. Usually the nodes at the boarder of cluster act as a gateway and connect with gateway of neighbor cluster. two cluster heads of different clusters exchange information through this gayway nodes and also broadcast the received information with cluster members. unicast and broadcast schemes are used for inter-cluster communication. Figure 3.6 shows the cluster based-communication. Cluster 1 and Cluster 2 are connected through their gateway nodes for data exchange.