An Efficient Emergency Messages Dissemination for Hybrid Sensor and Vehicular Networks

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***Abstract*— Hybrid Sensor and Vehicular Network (HSVN) is a combination of Vehicular Ad hoc Network (VANET) and Wireless Sensor Network (WSN). The main objective of HSVN is to provide real-time detection of road conditions and to solve the disconnection problem in VANET. In HSVN, the major challenge is to find an efficient scheme ensuring fast and reliable emergency messages dissemination. In this paper, firstly, we have proposed a new one-hop weight-based clustering algorithm for vehicle-to-vehicle communication, where only beacon messages are used for information exchange, to reduce the broadcast storm problem and to increase the stability of clusters. Secondly, we have presented a fast and reliable emergency messages dissemination protocol for HSVN to reduce the dissemination delay and to improve the reachability of emergency messages. Simulation results show that the cluster head lifetime and the awareness degree of vehicles are improved up to 87% and 40% respectively, and the dissemination delay is reduced up to 77%.**

Keywords—Hybrid Sensor and Vehicular Network (HSVN), Clustering, Cluster head election, Cluster stability, Emergency Messages Dissemination.

I. INTRODUCTION

With the rapid development of society and economic, the road networks become more and more congested and the increased risk of accidents is even greater. Several new technologies and various kinds of networks are used into Intelligent Transportation Systems (ITS) to improve road safety. Among them, the most prominent technology is Vehicular Ad hoc Network (VANET) [1].

VANET consists of vehicles that are highly mobile and roadside infrastructures that are sparsely deployed. VANET allows for the dissemination of safety-related information to drivers over vast distances. Nonetheless, real-time detection of road conditions may not be guaranteed by VANET. Thus, information can only be shared within the VANET if a vehicle or roadside infrastructure detects or is informed of certain road conditions. Moreover, the VANET may experience disconnection due to the sparsity of roadside infrastructure, low vehicle density, and high mobility of vehicles.

To overcome the VANET limitations, a network generation known as Hybrid Sensor and Vehicular Network (HSVN) has been created [2]. HSVN consists in making VANET and WSN work jointly to provide timely detection of road conditions and to help connect partitioned segments of the VANET by using a subgroup of sensor nodes as WSN-Gateways (WGs) between vehicles.

In HSVN, there are three distinct types of communication. The first is Sensor-to-Sensor (S2S) communication, which guarantees the coverage of road events and the transmission of detected events to the WSN-Gateway (WG). The second is WG-to-Vehicle (WG2V) communication, which enables the exchange of road information between the two networks. Finally, Vehicle-to-Vehicle (V2V) communication is used to disseminate road information gathered from the WSN to other vehicles on a large scale.

The approach used by researchers for message dissemination in HSVN is that the sensor node sends the captured event hop by hop to the WG that in turn transmits it to the Vehicles' cluster head. However, this technique causes additional delays especially in case of emergency messages that are time-critical and need to be sent to vehicles as soon as possible as the lives of drivers are dependent on them.

In this paper, we have proposed a new one-hop weight-based clustering algorithm for V2V communication, using a totally distributed approach where only beacon messages are used for information exchange. This clustering algorithm aims to reduce the broadcast storm problem by grouping together vehicles with parameters common, such as speed, destination, physical location, and direction of travel. In addition, cluster stability is strengthened to enhance the network lifetime. Moreover, we have proposed a fast and reliable emergency messages dissemination protocol for HSVN to reduce the dissemination delay and to improve the reachability of emergency messages.

II. RELATED WORK

In this section, we give an overview of the existing research on safety message dissemination in HSVN.

To minimize the end-to-end delay, reference [3] proposes to use directional antennas that extend the transmission range of sensor nodes and allows monitoring the events with less number of deployed sensor nodes, which leads to significant decrease of the transmission delay. Authors in [3, 4] have added the concept of relays vehicles in case the communication between the two group's cluster head of the both networks do not finish in success, which ensure that important road information will arrive at other vehicles in a reasonable delay. Moreover, in case of critical messages, the authors in [4] have proposed that the WG communicates with all vehicles to ensure a quick delivery of the messages. However, in case of Emergency Messages (EMs), these improvements are insufficient, because these messages need to be delivered upon detection of the emergency events. Authors in [5] have proposed a delivery messages protocol in HSVN. This protocol

ensures timely delivery of warning messages detected by the deployed sensor nodes (sensor nodes and roadside units) to the sink. In this protocol, each node (except the sink) which holds a warning message transmits it in priority to the nearest vehicle to the sink, which minimizes the transmission delay of the warning message because the vehicles have a long transmission range compared to sensor nodes. If there is no vehicle in the transmission range of the sensor node, this latter transmits the warning message to the closest sensor node to the sink. This process is repeated until the warning message successfully reaches the sink. The drawback of this approach is that in areas where the vehicles density is low, the alert message is likely to transfer through the majority of sensor nodes to reach the sink, which increases the transmission delay and the energy consumption of sensor nodes. Moreover, a vehicle that holds a warning message, it sends it in priority to the neighboring vehicle closest to the sink, but the vehicles that are between these two vehicles will not be informed of the detected event, which can compromise the safety of drivers especially in emergency situations. Authors in [6] have presented a destination based stable clustering algorithm and routing for V2V communication. The proposed algorithm calculates the Cluster Head Eligibility (CHE) of each vehicle based on several attributes such as vehicle velocity, location, destination, and direction, as well as a possible list of interests of the vehicle. Based on this CHE, it triggers the cluster head selection procedure. In addition, the authors have presented a routing protocol based on destination that selects as the next possible forwarding node the nearest one having the best Forward Eligibility (FE) metric. However, the proposed algorithm leads to global network overhead and large transmission delay when the vehicles' density becomes high.

III. PROPOSED PROTOCOL

In the literature, safety message dissemination was generally studied separately in HSVN, either in the WSN or in the VANET. In this work, we have proposed an emergency messages dissemination protocol for the all HSVN since the detection of emergency event by the source sensor node until its arrival to the target vehicle.

A. System model

In the proposed protocol, we used the deployment model of the WSN proposed in our previous work [7]. Each sensor node in this model is connected to two neighboring nodes on its left and two neighboring nodes on its right. Hence, in case of sensor node damage, another sensor node takes over to preserve the connectivity between nodes and ensure the successful transmission of the detected event to the WG.

To facilitate communication with both vehicles and other sensor nodes, each sensor node is equipped with a ZigBee interface. Additionally, each vehicle has two communication interfaces: a WAVE (IEEE802.11p) interface for communication with other vehicles, and a ZigBee (IEEE 802.15.4) interface for communication with sensor nodes. It is assumed that vehicles are equipped with GPS, which is used to identify similarities in destination and traveling direction.

B. Metrics for election of vehicles' cluster head

To select the optimal cluster head, each vehicle calculates a weight based on specific metrics, and the vehicle having the highest weight is chosen as the cluster head. The weight of vehicle *i*, denoted as W_i is determined by utilizing the following metrics:

1) Node degree ($Degree_i$): is the total number of vehicles that are directly connected to vehicle *i* at time *t*. A higher degree means that the vehicle is more suitable for being a CH.

2) Transmission range (Tr_i): is the maximum distance a vehicle can send its data to. A vehicle with high transmission range is suitable to be cluster head because it covers the maximum of neighbors.

3) Mean of Probability of Successful Transmissions ($MPST_i$): is the average probability of successful transmissions occurring between a vehicle, denoted as *i*, and its neighbors. Vehicles that have a high transmission probability can effectively and promptly distribute emergency messages (EMs). The probability of successful transmissions between sender vehicle *i* and receiver vehicle *j* is modeled using the Nakagami-m distribution [8] as follows:

$$Ps_{ij}^{f}(d_{ij}) = 1 - F_d(r_{TS}, \delta, \beta)$$

$$= e^{-\delta r_{TS}/\beta} \sum_{i=1}^{\delta} \frac{(\left(\frac{\delta}{\beta}\right) r_{TS})^{i-1}}{(i-1)!} \quad (1)$$

Where $F_d(r_{TS}, \delta, \beta)$ represents the cumulative distribution function of received signal strength, r_{TS} is the reception threshold of a signal, β indicates the average strength of the received signal at distance d_{ij}, δ is the finding parameter defined based on the distance d_{ij} between the vehicles *i* and *j* [9].

$$\delta = \begin{cases} 3, & d_{ij} < 50\ m \\ 1.5, & 50\ m \le d_{ij} < 150\ m \\ 1, & d_{ij} \ge 150\ m \end{cases} \quad (2)$$

Therefore, the $MPST_i$ of vehicle i is calculated as follows:

$$MPST_i = \frac{\sum_{j=1, j\neq i}^{Degree_i} Pr_{ij}^{f}(d_{ij})}{Degree_i} \quad (3)$$

4) Mean Distance (MD_i): is the mean distance that separates vehicle *i* from its neighbors. A vehicle with a shorter mean distance to its neighbors is suitable to serve as a cluster head, as it can help reduce communication delays. The mean distance MD_i of vehicle *i* is calculated using the Euclidean distance as follows:

$$MD_i = \frac{\sum_{j=1, j\neq i}^{Degree_i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{Degree_i} \quad (4)$$

Where *j* is any neighboring vehicle connected to vehicle *i*, and (x_i, y_i), (x_j, y_j) are the coordinates of the positions of vehicles *i* and *j* respectively.

5) Mean Velocity (MV_i): is the mean velocity between a vehicle *i* and its neighbors. A vehicle with a lower mean velocity is suitable to be cluster head because it is more stable compared to its neighbors. The velocity v_i of vehicle *i* traveled a distance Δd_i from position *P1* (x_1, y_1) at time T1 to position *P2* (x_2, y_2) at time *T2* is calculated as :

$$v_i = \frac{\triangle d_i}{\triangle t_i} \quad (5)$$

Where: $\Delta d_i = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$, $\Delta t_i = T2 - T1$

The mean velocity MV_i of vehicle *i* is expressed as:

$$MV_i = \frac{\sum_{j=1, j\neq i}^{Degree_i} |v_i - v_j|}{Degree_i} \quad (6)$$

Where *j* is any neighboring vehicle connected to vehicle *i*.

Therefore, the weight W_i of vehicle *i* is calculated based on the previous parameters as follows:

$$W_i = \frac{Degree_i * Tr_i * MPST_i}{MD_i * MV_i} \quad (7)$$

6) Mean Link Reliability Factor ($MLRF_i$): is the probability of a direct communication link between two vehicles will be available over a specified time period.

The assumption is that vehicles' velocity v follows the Gaussian distribution $N(\mu,\alpha^2)$ [10], having probability density function as :

$$f(v) = \frac{1}{\alpha.\sqrt{2\pi}} e^{-\frac{(v-\mu)^2}{2\alpha^2}} \quad (8)$$

Where α^2 and μ represent the variance and mean of velocity v respectively. The function that describes the probability density of the link duration T of v_i and v_j is given by [11] as:

$$f(T) = \frac{R_{ij}}{\alpha_{\Delta v_{ij}} \cdot \sqrt{2\pi} T^2} e^{-\frac{(\frac{R_{ij}}{T} - M_{\Delta v_{ij}})^2}{(2\alpha_{\Delta v_{ij}})}} \quad (9)$$

The parameter $M_{\Delta v_{ij}}$ is the anticipated mean of velocity v, R_{ij} is the relative transmission range, and $\alpha_{\Delta v_{ij}}$ is the deviation of both vehicles, i.e. $\alpha_{\Delta v_i} + \alpha_{\Delta v_j}$. The probability of a link *l* being available for a duration *D* is given by [11] as:

$$R_t(l) = \int_t^{t+D} f(T)dt \quad if \;\; D > 0 \quad (10)$$

Where $R_t(l)$ represents at time *t* the reliability of link *l*.

Therefore, the $MLRF_i$ of node *i* is calculated as follows:

$$MLRF_i = \frac{\sum_{j=1, j\neq i}^{Degree_i} R_t(l_j)}{Degree_i} \quad (11)$$

C. Cluster formation and cluster head election

Within clusters, vehicles can perform two different roles: cluster head (CH) or cluster member (CM). The CM sends messages to the CH, which subsequently broadcasts them to the other CMs.

In our proposition, to select a vehicles' cluster head, every vehicle gets information from disseminated beacon messages (BMs) and computes a weight W_i (7). The vehicle having the highest weight in its neighborhood declares itself as the CH.

Initially, all vehicles are in the Undefined State (US). Periodically, each vehicle *i* computes its W_i value and broadcasts it to all its neighboring vehicles *j* through beacon messages (BM_i). In addition to the W_i, the BM_i contains the vehicle's identifier, state, location (two-dimensional coordinates), direction, velocity, as well as the Mean Link Reliability Factor ($MLRF_i$).

Algorithm 1 – *Cluster head election*

Input
Vehicle ID, direction, location, transmission range and velocity of the vehicle *i*
Output
cluster formed

State = US;
Compute_Weight();
Broadcast (BM_i);
While (Receive(BM_j) = True) **do**
  Update Neighbor list
End While
If (W_i > MaxW()) **then** // *MaxW(): Returns the maximum weight value of neighboring nodes*
  $State_i$ ← CH;
  Broadcast(CHA_{msg});
Else
  DCH_i ← MaxWID(); // *MaxWID():Returns the id of the neighboring node that has the highest weight value*
  t ← Δt;
End
While (Receive(CHA_{msg}) = True) **and** (Δt > 0) **do**
  If (ID_j = DCHi) **Then**
    $State_i$ ← CM;
    ID_{CHi} ← ID_j
    Send(ACK_{msg}, ID_j);
  Else
    Save(ID_j); //*The vehicle records all the IDs of the CHs that have invited it to join their respective clusters*
  End
End While
If (Δt = 0) and ($State_i$ = US) **Then** // *The vehicle i does not receive a CHA_{msg} from its DCH*
  If MaxCHID() <> Null **Then** // *MaxCHID():Returns the id of the CH with the highest weight*
    $State_i$ ← CM;
    ID_{CHi} ← ID_j
    Send(ACK_{msg}, MaxCHID());
  Else If ∃ W_j < W_i **Then**
      $State_i$ ← CH;
      Broadcast(CHA_{msg});
    Else
      $State_i$ ← AS;
    End;
  End;
End.

When a vehicle *i* receives a BM_j from vehicle *j* it updates its neighbors list. After receiving the BMs from all its neighbors, a vehicle *i* checks if its weight is higher than all weights received from its neighbors of the same direction. In such case, the vehicle *i* declares itself as the CH and starts broadcasting a CH advertisement message (CHA_{msg}) to its single-hop neighbors. Else, the vehicle *i* elects the vehicle that has the highest weight value among its neighbors of the same direction, as its desired cluster head (DCH) and sets a timer to a predefined Δt. If there are two or more nodes that have the same highest weight, the node with the lowest identifier (ID) will be elected as CH.

When a vehicle *i* receives a CHA_{msg} from vehicle *j*, it checks if the message is sent from its DCH_i. In such case, a

vehicle *i* changes its status to CM, it updates the identifier of its CH (ID_{CH}) which is initially NULL and sends to it an acknowledge message (ACK_{msg}). Otherwise, it records all the IDs of the CHs that invite it to join their cluster and that are moving in the same direction as it, as well as their weight.

In the case the timer expires and the vehicle *i* is in the US (i.e. the vehicle *i* does not receive a CHA_{msg} from its DCH), it checks if it has received any CHA_{msg} from other CHs. In such case, it changes its status to CM, and updates the identifier value of its CH (ID_{CH}) to the identifier value of the CH having the highest weight and sends to it an ACK_{msg}. Otherwise, if a vehicle *i* does not receive any CHA_{msg} and it has neighbors with low weight, it declares itself as the CH and starts broadcasting a CHA_{msg}. However, when a vehicle *i* does not receive any CHA_{msg} and it has not a neighbor with low weight, it updates its state to alone (AS).

The cluster formation and the CH election are described in algorithm 1.

D. Cluster maintenance

When the clusters' formation is achieved, the vehicles continue to broadcast the BMs to all their neighbors each time period *T* with the aim to update the neighbors list. In order to maintain a stable cluster and reduce the cluster formation initialization each time period *T*, we introduce a new metric named MLRF (11) that is used to evaluate the reliability links of the CH. Thus, the cluster formation is initiated only when the CH's MLRF value is below than a CH Eligibility Threshold (CH_{ET}) (i.e. when a CH loses more than (1-CH_{ET}) of its connectivity links, it loses its CH eligibility). When the clusters formation is achieved, several vehicles in US and AS seek to join the network. These vehicles are either new vehicles or vehicles leaving other clusters. The vehicles in US and AS change their status to CM when they receive a beacon messages from the neighboring CHs. Thus, they update the identifier value of their CH (ID_{CH}) to the identifier value of the CH having the highest weight and send to it an ACK_{msg}.

When a CM moves out of the CH range, the CH detects this event and removes immediately this vehicle from its neighbors list. On the other hand, if a CM does not receive the periodic BM from its CH over a time period T, it changes its state to US.

E. Data dissemination

In our proposition, the sensor node sends the EM upon detection of the dangerous event to the vehicles' cluster heads and vehicles in AS locate inside its transmission range. This reduces the transmission delay of the EM because the vehicles have a long transmission range as compared to sensor nodes. Furthermore, the sensor node disseminates the EM to its neighboring sensor nodes in both directions until it reaches the WG in one side of the road segment and the border sensor (BS) on the other side. This allows saving the EM in the WSN to be used for notifying the vehicles that pass by later when no other vehicles are in reach, overcoming thus the disconnection problem of VANET.

Upon receiving an EM, a sensor node simply forwards it to the vehicles' CHs and vehicles in AS inside its transmission range in both directions. In addition, if the receiver sensor node is not a WG or BS, the EM is also forwarded to the neighboring sensor nodes until it reaches the WG or the BS.

Algorithm 2 – *EM dissemination protocol among the WSN*

```
Input
    Sensor : Current node
Output
    Message disseminated
If Detect() Then  // Detection of an event with high severity by
                  the sensor node
   m=Detect()   // Generation of the emergency message
End;
If Detect_V() Then   // Detection of CH or vehicle in AS
   Send(m);   // Send to CH or vehicle in AS for dissemination
              among the VANET
End
Send(m);  // Send to neighboring sensor nodes for dissemination
          among the WSN
While Receive (m)  do
   If Detect_V() Then  // Detection of CH or vehicle in AS
      Send(m);
   End
   If Sensor is not WG Or Sensor is not BS Then
      Relay(m);
   End
End.
```

When a vehicles' CH receives an EM, it sends it to all its CMs and to all neighboring vehicles' CHs (inside its transmission range) on the opposite direction. The use of the EM dissemination in the opposite direction rather than the backward direction reduces the dissemination delay and ensures fast spread of the EM towards vehicles.

Similarly, when a CM receives an EM, it sends it only to its CH without broadcasting it, avoiding consequently the broadcast storm problem. Finally, a vehicle in AS receiving an EM, it broadcasts it in order to reach the nearest CH or CM.

Algorithm 3 – *EM dissemination protocol among the VANET*

```
Input
    Vehicle: current node
Output
    Message disseminated
While Receive (msg)  Do
   If Vehicle is CH Then
      Send(msg); // Sending the message to CMs
      While Detect_CHO() Do // Detecting a CH on the
                               opposite side
         Send(msg);  // Sending the message to CH on the
                        opposite side
      End While
   Else If Vehicle is CM Then
         Send(msg); // Sending the message to CH for
                       dissemination
      Else If Vehicle is in AS Then
            Broadcast(msg);
         End if
      End if
   End if
End While
```

IV. SIMULATION AND PERFORMANCE ANALYSIS

We have evaluated the performance of the proposed

protocols using OMNeT++ simulator [12]. The obtained results are compared with baseline HSVN, where the WG is the only sensor node that communicates with the vehicles' CHs as in [3,4] and the link reliability factor (11) is not used for maintaining a stable cluster.

A. Simulation parameters

We have studied a highway scenario consisting of 4 lanes (2 lanes in each direction). Five road segments, each measuring 2 km, have been simulated. The events along the road segment happen randomly in terms of both time and location. The simulation parameters are summarized in Table I.

TABLE I. SIMULATION PARAMETERS

Parameters	Values
Road length	10 km
Road width	20 m
Road segment length	2 km
Communication range (Vehicle)	250 m
Data rate (Vehicle)	5.5 mbps
Vehicle average speed	25m/s to 33m/s
Beacon message size	512 bits
Beacon interval	1 second
CH Eligibility Threshold (CH_{ET})	0.90
Communication range (Sensor node)	90 m
Sensing range (Sensor node)	90 m
Inter-sensors distance	45 m
Data rate (Sensor node)	250 kbps
Simulation time	1 hour

B. Performance metrics

The following metrics are evaluated:

- ***Cluster Head Lifetime***: is the duration of time in which the vehicle maintains its state to CH since it has been elected until it leaves this state.
- ***Cluster Head Changes Number***: is the number of state changes from CH to another state.
- ***Dissemination Delay***: is the required time to send an EM from a source sensor node to a target vehicle.
- ***Awareness degree***: is the ratio of the number of EMs successfully and timely advertised to the vehicles to the total number of the generated EMs by the sensor nodes.

C. Simulation results

This section discusses the various simulation results.

1) Cluster head lifetime

Fig. 1 shows that when a vehicle's velocity increases, the average CH lifetime decreases relatively. The reason for this is that the network topology becomes very dynamic owing to the high mobility of vehicles, which makes it difficult for the CHs to maintain stable connections with their CMs. Moreover, when the density increases, the average CH lifetime also decreases. This can be justified by the increase of the number of CH's neighbors which decrease its opportunity to maintain its state. Fig. 1 demonstrates that the proposed protocol outperforms the baseline protocol. This is related to the introduced metric MLRF (11), where the cluster formation is initiated only when the CH's MLRF value is below than a CH Eligibility Threshold (CH_{ET}).

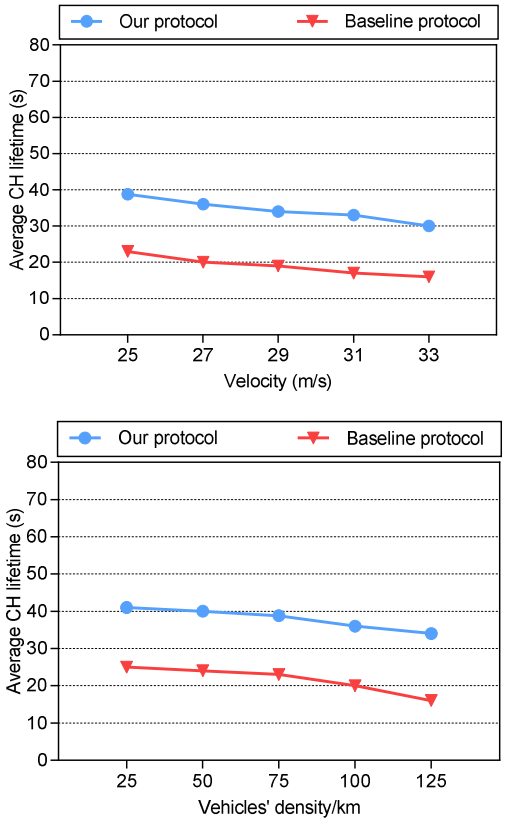

Fig. 1. CH lifetime.

2) Cluster head changes number

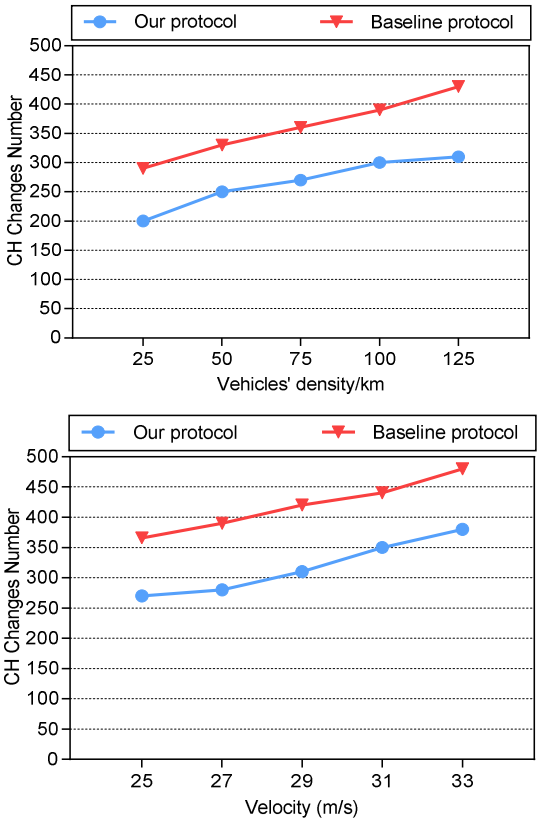

Fig. 2. CH changes number.

Fig. 2 demonstrates that the average CH's changes number of the proposed protocol is smaller than the baseline HSVN. The reason for this improvement is the effective metric MLRF (11), which increases the CH lifetime and consequently decreases the CH changes number.

3) Dissemination delay

Fig. 3 shows that the dissemination delay reaches only 1.9 s in case of 125 vehicles/Km in the proposed protocol and it is improved up to 77% compared to the baseline HSVN. This because in the proposed protocol, the sensor node transmits the EM directly to the vehicles' CHs or vehicles in AS whereas in case of baseline HSVN, the EM is relayed hop-by-hop until it reaches the WG to be then transmitted to the vehicles' CHs which causes additional delays.

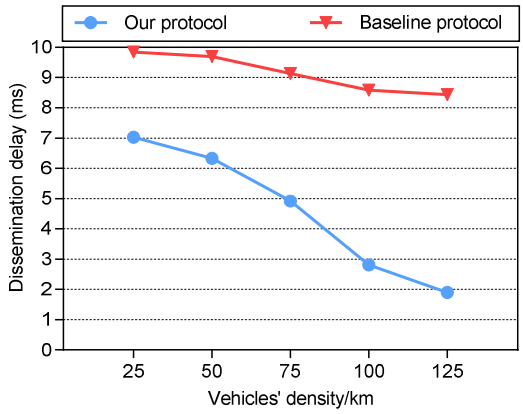

Fig. 3. Dissemination delay.

We can also observe that the increase in the vehicles' density decreases the dissemination delay of the EMs. This is because in case of high density, the sensor node has a great probability to have a CH in its transmission range to send it the EM.

4) Awareness degree

Fig. 4 shows that the proposed protocol outperforms the baseline HSVN and achieves a high awareness degree, on average of 99.25 %.

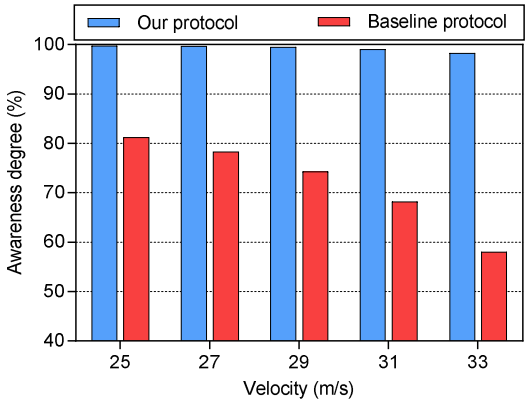

Fig. 4. Awareness degree.

It appears also that the velocity affects slightly the awareness degree of the proposed protocol compared to baseline HSVN which is significantly affected. This is because in the baseline HSVN, the WG is the only sensor node that communicates with the CH, therefore all the EMs received by the WG after the vehicles' CH has left the WG transmission range are not transmitted to the vehicles' CH and to the CMs, which justifies the degradation in the awareness degree. In contrast, in the proposed protocol, any sensor node holding an EM can transmit it to the vehicles' CHs or vehicles in AS within its transmission range.

V. Conclusion

In this paper, we have proposed a new one-hop weight-based clustering algorithm for V2V communication aiming to reduce the broadcast storm problem and to increase the stability of clusters. The CH lifetime is improved up to 87% by introducing a new metric, where the cluster formation is initiated only when the CH's MLRF value is below than a CH Eligibility Threshold (CHET). Moreover, we have proposed a fast and reliable emergency messages dissemination protocol for HSVN, where the dissemination delay is reduced up to 77% and the awareness degree of vehicles is improved from between 58 – 81,3% up to 98,3 – 99,8%. As future work, we continue by the enhancement of communication between WSN and VANET to increase the exchange time of road information between the two networks.

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