Adaptive Routing for Vehicular Ad Hoc Networks Using Cluster Networks

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Summary
The traditional routing protocols of vehicular ad hoc network (VANET) are designed specifically for an environment known for its requirements. For example, a downtown environment is known for high node density and the short distance between nearby nodes. However, these protocols have fundamental properties that make it difficult to forward data from a source node to a target node when the environment changes. In order to improve routing in VANET networks, this paper has proposed an approach that aims to enhance the quality of communications between nodes in the network, while reducing system time messages and ensuring communication with less possible transmission difficulties. The proposed approach is based on the adaptive routing in cluster networks to make a correct classification according to certain criteria (speed, density, number of hops, environment, and the knowledge of the information of the position) after selecting one of the Dynamic Source Routing DSR routing protocol conditions. This approach was able to show its power in terms of performance and results.
Key words:
Vehicular Ad hoc Networks; Adaptive Routing Protocol; Dynamic Source Routing; Cluster Network.

1. Introduction

Ad hoc networks are a group of sets of mobile devices (or nodes) that can dynamically exchange information among themselves and theses networks do not need for a pre-existing and centralized administration or fixed network infrastructure. The nodes communicate directly with each other, and each node sends and receives messages in its communication radius (its radio range). Thus, the nodes forming this group can route the messages through the routing protocol. For this purpose, several routing classes exist for ad hoc networks [1]. Although ad hoc networks were originally developed for military environments, these types of networks have been able to demonstrate much more in a number of applications, such as emergency applications, multimedia applications, and soon collaborative driving applications. In this context, there are two classes of ad hoc networks: vehicular ad hoc network (VANET) and mobile ad hoc network (MANET). Note that VANET networks are a special case of MANET networks. However, VANET networks are more responsive to node speed requirements, abrupt topology changes, diverse environments and the energy problem (which is a challenge for MANETs) and have much better data processing capability than MANET. The communication between the nodes is guaranteed by several protocols that manage the different functionalities during a given communication. The IEEE 802.11p standard provides a medium access solution for nodes (vehicles), which was previously a major problem [2].

The goal of VANET networks is to apply certain notifications, such as crash alert messages to neighboring nodes, to reduce the likelihood of collision between vehicles, real-time multimedia applications, and many other applications. Since these nodes are mobile and can connect or disconnect the network at any time, they face a number of challenges, including security, quality of service, and routing. Several proposals and research are focused on working to solve these challenges [3-5].

Mobility management is also a major challenge, and several solutions and approaches have been proposed to improve mobility. Each of these proposals treated just a particular environment, whereas in reality, the node moves in several different environments (urban and residential environments, highways, tunnels, mines, etc.), which leaves these solutions adapted during the change of environment [6].

Managing the high frequency of disconnection caused by environmental change, and sometimes high-speed nodes or other factors, differs from one environment to another. No single management is therefore suitable for all different environments.

In this paper, it developed an efficient protocol based, on the one hand, on the most efficient routing protocols for each environment, and on the other hand, on the adaptive routing method in cluster networks for categorization. Thus, our approach is supposed to solve the aforementioned challenges while increasing the performance of the network by dynamically adapting existing routing protocols. To achieve our goal, the paper explores in this study the use of adaptive routing in cluster networks.

This paper is structured as follows. Section 2 provides an overview of VANET networks. Section 3 describes the routing protocols for VANET networks. The proposed approach is detailed in section 4. A performance analysis

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and results are given in section 5. At the end, the conclusion of the paper is presented in Section 6.

2. VANET Networks

Inter-Vehicle Communication (IVC) considers as a part of Intelligent Transportation Systems (ITS), and it is a new category of wireless network. This kind of network is characterized by the spontaneous formation of vehicles with radio interfaces of similar or different technologies. There are two forms in communication exchange the first one is vehicle-to-infrastructure and the other one is called vehicle-to-vehicle. This type of ad hoc network is characterized by instant communication between vehicles, whether they have radio interfaces of similar or different technologies [7, 8].

Several applications of VANET networks are geared towards road safety (for example the broadcasting of collision alert messages, works, accidents, etc.). These applications aim to reduce the number of accidents, improve traffic, and make driving more collaborative for drivers and passengers.

Indeed, several communication networks (2G, 3G, WLAN, WiMAX and IEEE 802.11a/b/g/p) can be utilized in order to offer passengers new services and, other than security applications, for example applications entertainment (electronic toll, fleet management, Internet access, online games, etc.), which can depend on the vehicular network itself.

Advances in wireless technology have opened the door to new trends in deploying ad hoc network architectures of VANET vehicles on the highway, in urban and other environments. The proposed communication for VANET is shown in Figure 1.

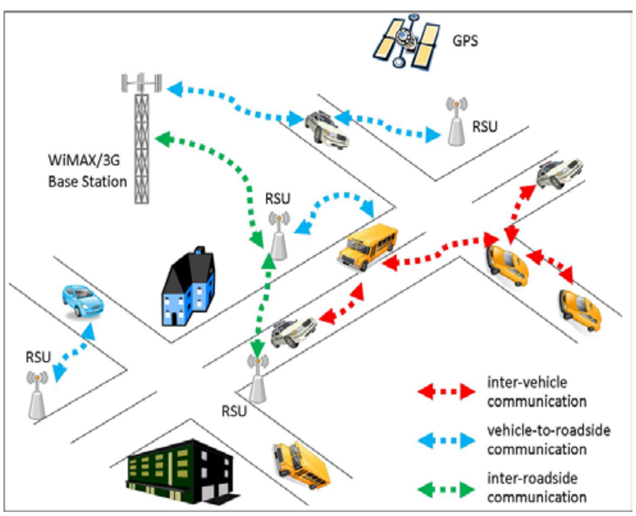

Fig. 1 Communication of VANET

- An ad hoc vehicle-to-vehicle network (V2V) enabling communication without the need for infrastructure.
- A basic WiMAX network (backbone wireless).
- A hybrid solution based on ad hoc vehicle networks and Roadside (V2R), exploiting improved performance through the combination of infrastructure and wireless network, thus ensuring better communication between all vehicles.

Vehicle-to-Vehicle Communication (V2V) has proposed a reference architecture for ad hoc vehicle networks [1]. We distinguish three units: inside the vehicle (in-vehicle), ad hoc and infrastructure. The architecture of V2V is shown in Figure 2.

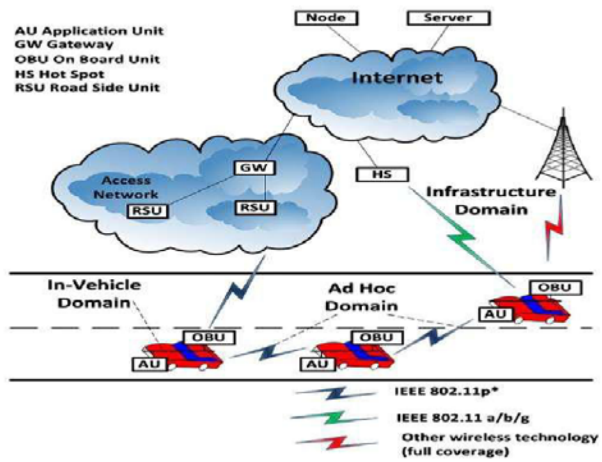

Fig. 2 Architecture of V2V

The domain inside the vehicle (in-vehicle) indicates to a local area network within every vehicle and it contains of two parts: Application Unit (AU) and On-Board Unit (OBU). In VANET networks, each vehicle must have both units. The first unit, the AU, allows one or more applications to be executed when using the communication facilities of the OBU. The AU is in permanent connection with the OBU. The second unit, the OBU, allows the vehicle to have communication facilities wireless or wired. The ad hoc domain is a network of vehicles provided with OBU devices and Roadside Unit (RSU) which remain stationary alongside the road. The OBU and RSU units are considered as nodes of an ad hoc network, mobile nodes and static nodes, respectively. RSU are seen as units connected to the Internet via an existing infrastructure network. They help to improve road safety and to run certain applications in the ad hoc domain. There are two kinds of access to the infrastructure domain RSUs and wireless hot spots. RSU gives OBU units access to the infrastructure, giving them the ability to connect. In the

case where there is no RSU and no wireless access point, the OBUs can communicate directly via the existing cellular networks if they are integrated with the OBUs [9-11]. VANET considers a part of MANET, which is formed automatically by moving vehicles and allow a several of services to be performed for passengers and car drivers.
Several research studies have been in MANET routing protocols, in order to adapt them to the VANET network. Moreover, for some applications, recent research is competing to establish new standards.

3. Routing Protocols for VANET Networks

The principle of a routing protocol is the establishment of routes between a group of nodes to ensure a continuous and efficient exchange of packets. Since ad hoc networks are depending on the notion of multi-hop routing, it may happen that some nodes will become unreachable and out of the communication. Using a few routing protocols, the packets will be able to be forwarded from source node to the destination node. VANET networks use several routing protocols. We perform in this section the classification of these protocols, and then we detail the few protocols chosen for exploration in the environments (highway, urban, downtown, and residential). Vehicular networks, divide ad-hoc routing protocols into four categories: based on position, groups, broadcasting and topology [12].

3.1 Ad Hoc Routing Based on Position

In geographic routing (position-based), the transmission occurs through a node is depending on the location of the target packets and the location of the neighboring node at a hop. The destination location data is stored in the packet header through the source. As for the location of the neighboring node, it is attained by transmitting tags frequently with a random jitter in order to evade a collision in a communication. And the nodes become neighbors of other nodes when they are within radio range. Position-based ad-hoc routing means that every node recognizes its own location and the sender node recognizes the location of the target node. An instance of this kind of ad-hoc routing is the Global Positioning System (GPS), which is the foundation of numerous embedded navigation systems and recent research on location services [13, 14].
Geographic routing protocols define a transfer zone that allows flooding to flood packet so as to decrease the overhead and congestion of the network. Single-destination routing (unicast) is utilized to forward packets to the destination node. Indeed, the packets are sent first with a unicast mechanism to the area where the destination is located, and then they are broadcast at the entire flood transfer area to reach the packet destination. In other words, it is by the specific route depending on the geographical location of the neighboring nodes that the packet is transmitted.
Geographic routing is divided into three types: Delay Tolerant Network, Non-Delay Tolerant Network, and hybrid networks.

3.2 Ad Hoc Routing Based on Groups

In this kind of routing protocol, the vehicles or mobiles that are in close nearness to each other, will structure a group called node member and every group has a group leader called node cluster. The formation of node member and the selection of node cluster are critical processes. Every node cluster will act as the link among his node member group and the other node member groups. Moreover, in VANET networks, recognize as active mobility, the formation of node member and cluster node considers a major process [15-17].
This kind of protocol has a significant advantage: the reduction of delays in the delivery of data packets. Indeed, each node cluster is responsible for supervision of member nodes, and also the supervision among the other groups.
Communication differs in these two methods. The communication among the member nodes occurs through direct links among them, whereas the communication among the groups is occurred by the cluster node. Examples of group-based routing protocols include: Hierarchical Cluster Based (HCB) [18], Cluster Based Location Routing (CBLR) and the Cluster-Based Directional Routing Protocol (CBDRP) [19].

3.3 Ad Hoc Routing Based on Broadcasting

This kind of protocols characterizes by its easy mechanism, however, it remains incapable to address the issue of the storm packets which are generated by diffusion mechanisms. Broadcasting packets in ad hoc routing is depending on the hierarchical of the road network. The road is spilt to several cells that move like vehicles. There are two levels and kinds of hierarchy in the organization of the nodes of a road: the hierarchy of the first level, which includes all the nodes in a cell, while the hierarchy of the second level which is few nodes located very close to the center of the cell [20]. This protocol is depending on the floods to make the diffusion. For example, Distributed Vehicular Broadcast Protocol (DVCAST) [21] uses the diffusion principle. Every vehicle utilizes a flag to ensure whether the packet is redundant otherwise not and utilizes local topology information through sending frequent hello messages in order to transmit the packets. Moreover, it splits vehicles to three categories based on their local connectivity: connected, poorly connected and entirely disconnected neighborhood area.

3.4 Ad Hoc Routing Based on Topology

There are two types of ad hoc routing protocol founded on topology: proactive protocols and reactive protocols. For the proactive protocol, the network topology is frequently updated by exchange the packets among the nodes inside the network. Therefore, every node stores complete information of its node neighbours. This information helps the nodes to construct the optimal routes from the source node to destination node with low delay, as the result the packet will send efficiently and forwarding packets in critical real time traffic application, also will become optimal [22, 23].

Reactive protocols are founded on the principle that the nodes will construct the routes when there is data communication needed, this stage called route construction process, moreover, in this kind of this protocol, the nodes do not have any information about the networks [24].

This kind of protocol frequently depends on the mechanism of flooding inside the network by using Route Request (RREQ) message and Route Reply (RREP) message during route construction process phase. However, this kind of routing protocol is very efficient and has low packet overhead contrast to proactive protocol, but it has more delay [25].

The Dynamic Source Routing (DSR) protocol [26] is an example of reactive protocols, and the nodes automatically determine a path in a multi hop network from source node to the destination node. This protocol does not use periodic routing messages, which reduces the overhead of the network bandwidth by avoiding a large update of the routing throughout the ad hoc network. In the DSR protocol, all routes are stored in the cache. If the route is not available, it sends another RREQ message to find the best route. This request broadcasts to the target or to a node that recognizes the path to the destination. When the response is favorable, a unicast RREP response message is returned to the originating node. Path maintenance is the method by which a packet sender node A discovers the change in network topology. The sender node A cannot utilize the path to destination node B. This can happen because a node named in the source route list has left the wireless transmission range. Subsequently, an error message indicating the failure of the route is sent to all nodes. When detecting a problem on a path in use, a negative acknowledgment packet is forward back to the source node. Once this packet has reached, the path is cleared from the node cache [27].

4. Proposed Approach

The classification of the routing protocols is done according to several criteria representative of the VANET network. This classification is the assignment of a specific class (in this case a routing algorithm) to a given object (appropriate environment). This attribution needs a certain degree of abstraction to be able to extract generalities from the examples we have.

Cluster networks have been successfully applied in task classification and function approximation tasks. This learning with cluster networks is currently done by following two approaches. Some algorithms such as gradient adaptive need to introduce a priori the number and connectivity of hidden units and to determine the weights of connections by minimizing a cost. The resulting network is eventually pruned. With a constructive approach, we learn at the same time the number of units and the weights. As part of a fixed architecture, usually starting with a single unit, we used the first approach of classification for routing.

VANET networks are characterized by a variable vehicle density. Even in the case of heavy traffic and traffic lights, network partitioning is common. This means that some data packets may eventually reach a node that is unable to continue routing the message as expected. Some protocols simply ignore this issue, assuming there is always enough node density.

Several solutions have been proposed to deal with these situations. For example, the node that detects this situation may try to find a different path. Some protocols use geographic routing based on the street map, while other algorithms propose to store the message until the appearance of a new neighbor node that can route it to the destination. The best approach would be an adaptive solution that, on the one hand, varies according to the network conditions and, on the other hand, adapts the solution taking into account the tolerance of the information to the delay.

Several important criteria of the VANETs such are the mobility constraint, number of hops, the density of the nodes, the knowledge of the information of the position and the speed of the nodes make it possible to predict the future positions. The exchange of this information among a node and its neighbors gives the opportunity to make the best decision regarding certain metrics of the routing protocols. This choice is based on prediction, and therefore needs to be carefully considered. Incorrect information can influence the prediction and subsequently lead to false decisions for routing protocols.

The DSR routing protocol has several important criteria. The proposed approach is therefore to modify the DSR routing protocol according to the conditions specific to each environment (highway, urban, downtown, desert, etc.). By taking the characteristics of the DSR protocol with those of each environment, we obtain several conditions of the DSR routing protocol. These conditions are based on the same operating principle as the DSR protocol, but they are distinguished by a few parameters that are related to the requirements of each environment.

For example, the information processing of a node density in a residential environment characterized by a high stopping frequency cannot be the same if it is a highway medium, where there is a presence of multipaths and a low stop frequency.

Most of the algorithms proposed to solve the problems of the ad hoc networks of vehicles treat them in a very specific environment. These solutions then remain invalid in other environments. In addition, the great problem of mobility and its constraints leave no freedom to adapt solutions. Our contribution is to use multiple conditions of the DSR routing protocol, and subsequently each condition will match a given environment.

As a vehicle moves from one point to another, it builds a route that has experienced several changes in density, number of hops, number of stops, speed and many other factors. Note that, during the construction of the route, the node exchanged messages of the discovery of the network, and therefore has a list of different information.

The proposed approach exploits this information to select the appropriate routing, hence the design of a technique capable of solving the mobility problem with adaptive and at the same time increasing the performance of the network.

The first phase consisted in collecting the information (speed, density, type of environment, number of hops, and the knowledge of the information of the position) in order to treat them with the best performing routing protocols for each environment. This data processing will focus on learning the cluster network for use in the next phase. The second phase was to do the classification to select the routing protocol most appropriate to the environment in terms of network performance.

The approach proposed for routing in VANET networks is designed in such a way that a routing algorithm is well configured for each environment, which is determined by various criteria, namely density, speed and environment type (urban, highway, downtown, residential), number of hops, and the knowledge of the information of the position. Then, by using the power of the cluster networks in the classification, we can have a compromise for a routing protocol that is driven for each scenario.

Usually, the input examples of the learning system are pretreated to facilitate learning. A pretreatment consists of extracting the representative properties of the examples or selecting only a subset of the properties when these are too numerous for the learning system. The learning base was built from simulated input results using two computer network simulators: Network Simulator (NS2) and Mobility Model Generator for Vehicular Networks (MOVE).

The proposed approach is to use the adaptive routing in cluster networks and a set of data (as a sample for each environment) for learning. For this, we have injected into a cluster network a list of ad hoc routing protocols of vehicles adapted for each environment. In the learning phase, we fed the cluster network by these parameters speed, environment, density, number of hops, and the knowledge of the information of the position, which can characterize all possible scenarios.

After the learning step, the network is able to select the appropriate routing protocol. This phase is called the path classification. This operation is repeated with each change of environment by the node. In our simulations, the results were very interesting in terms of performance, but especially in terms of mobility management. The choice of environments for our simulations is limited to the following choices: downtown, urban, residential, and highway since the simulation software "MOVE" only allows these possibilities.

The results obtained with the "MOVE" software gives a realistic mobility model that supports both macro-mobility and micro-mobility characteristics. This simulator, thus makes it possible to change the characteristics of the macro-mobility (the number of lanes, the direction of single or double movement), as well as the characteristics of the micro-mobility (the lights on the roads, the limits of speed). The following table presents the simulated environments in this proposed approach.

Table 1. Simulated environments

	Residential	***Downtown***	***Urban***	***Highway***
Density	From 13 nodes to 37 nodes.	From 70 nodes to 90 nodes.	From 19 nodes to 50 nodes.	From20 nodes to 70 nodes.
Speed	From 15 km/h to 80 km/h.	From 30 km/h to 75 km/h.	From 90 km/h to 110 km/h.	From 70 km/h to 140 km/h.

5. Performance Analysis

5.1 Modeling of Vanet Networks

The proposed approach is based on the DSR routing protocol. However, since the environments differ on several criteria (density, speed, environment), the DSR routing protocol has been configured differently for each environment and for each criterion in order to be valid for any situation. Figure 3 shows the use of both MOVE and NS2 simulators. Indeed, after defining environments, as mentioned in the previous paragraph, we take the mobility trace file generated during the simulation of an environment and insert it into the NS2 network simulator to evaluate and assess the performance of the DSR routing protocol conditions.

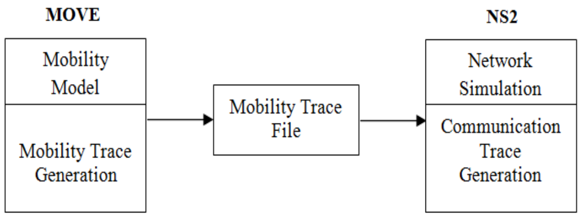

Fig. 3 Simulation architecture

After analyzing the DSR routing protocol, we were able to determine some criteria for parameter configuration that can increase routing performance. Figure 4 summarizes the modified parameters for each DSR condition Protocol that will be used in the simulation of the various scenarios. Table 2 details the characteristics of the DSR routing protocol conditions.

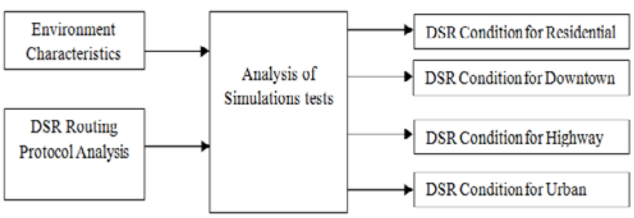

Fig. 4 DSR conditions design

Table 2: Characteristics of DSR routing protocol conditions

Settings	***Highway***	***Urban***	***Residential***	***Downtown***
Traffic type	64 bytes/s CBR	64 bytes/s CBR	64 bytes/s CBR	64 bytes/s CBR
Source /Destination	Random	Random	Random	Random
Max Speed	45 m/s	30 m/s	15 m/s	10 m/s
Simulation time	1000 s	1000 s	1000 s	1000 s
Connections	15, 20, 25,30	15, 25, 35, 50	20, 25, 30, 40, 45, 60	40, 50, 60, 70, 80,90, 100,110
Package size	256 bytes	256 bytes	256 bytes	256 bytes
Number of nodes	45	70	90	130

5.2 Effect of the Adaptation of the Routing Protocol

The cluster network used here is called the "Adaptive Network" to select the appropriate routing protocol for a given environment. Figure 5 shows the two network layers, one for hidden nodes members and one for output nodes members. We used the "Trace" function for the hidden layer and the "Mobility" function for the output layer.

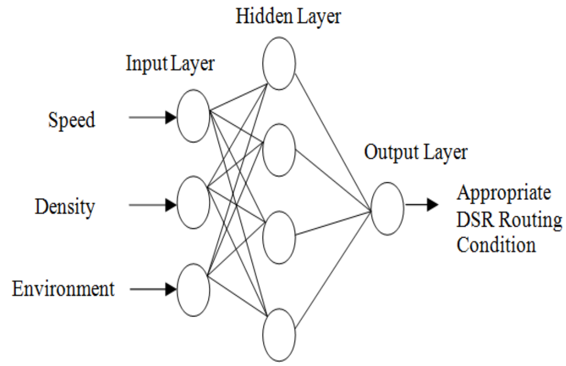

Fig. 5 Cluster network with a hidden layer and an output layer

In order to validate the proposed approach, we first perform the learning and then run the cluster network test at a certain percentage of the data in Table 3.

Table 3: Inputs and outputs of the cluster network

Cluster network inputs			***Cluster network outputs***
Environment	***Density (nodes)***	***Speed (m/s)***	***DSR routing condition***
Downtown	From 70 to 90	From 30 to 75	DSR Downtown
Residential	from 13 to 37	From 15 to 80	DSR Residential
Urban	From 19 to 50	From 90 to 110	DSR Urban
highway	From 20 to 70	From 70 to 140	DSR highway

After completing both phases, i.e., learning and testing, we validate the network with other completely new data to evaluate the success rate of the classification. This validation is important in order to know the success rate of selecting the right DSR routing protocol condition. We are learning cluster network with 70% (respectively 60%, 50%) of the data, and the test with 40% (respectively 50%, 60%) of the data. When we do a range validation of new entries, we get a match rate of 80%. These results show the success of the classification. Indeed, having such success with little information for the learning and testing phases proves that the cluster network is able to increase network performance with respect to routing. By selecting the right DSR routing condition, routing will be improved, since this condition meets topology characteristics (speed, density, number of hops, environment, and the knowledge of the information of the position). From the results obtained, we conclude that the proposed approach was able to show its performance successfully.

5.3 Speed Effect

Figure 6 illustrates the delivery rate of Packet Delivery Ratio (PDR) packets based on speed. This rate decreases significantly in the first scenario, since the speed increases and the number of nodes is low. Each scenario is developed using the average of several sub-scenarios, which means that one scenario represents at least five to ten sub-scenarios. In all sub-scenarios, we change the speed and we keep the other parameters constant. We therefore conclude, as shown in Figure 6, which based on the PDR rate, the best configuration is at a speed of 35 m / s for all scenarios.

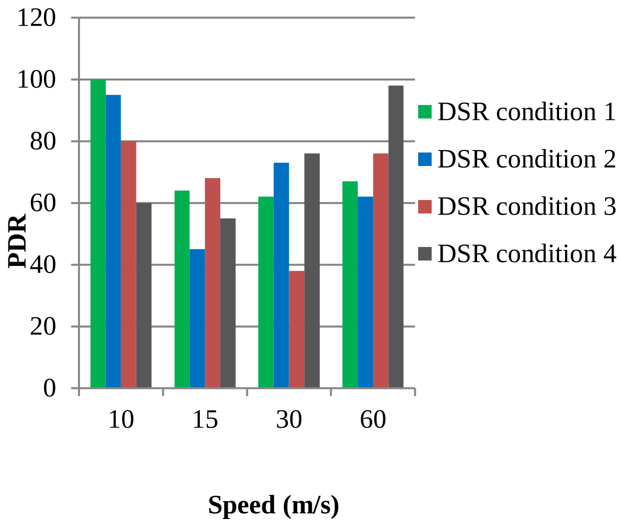

Fig. 6 Speed vs PDR

Figure 7 illustrates the effect of node speed on the average end-to-end delay. Indeed, the scenario of 13 nodes with 4 CBR connections shows that the delay is less important with a speed of 35 m/s, if one compares it with the delays of the other sub-scenarios with speeds of 40 m/s, 50 m/s and 60 m/s. The average End-to-End Delay increases with the number of nodes. This increase is due to the discovery of routes by the nodes and the large number of packets in the buffer. In addition, we notice that the longer the pause time, the more stable the network is and the lower the end-to-end delay.

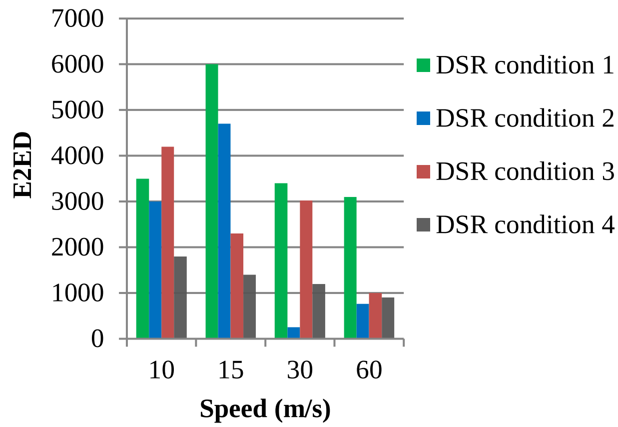

Fig. 7 Speed vs E2ED

In Figure 8, we illustrate the overhead results generated by normalized routing overhead (NRO) protocols to reach this level of data packet delivery. These results also show that we can establish a direct proportional relationship among the overhead and the number of packets sent. In the first scenario, with low mobility, we notice that as the node speed increases, the overhead also increases. As shown in Figure 8, in the first scenario, with a normal speed of 35 m/s the overhead decreases. Given the many destinations in the other scenarios and the high mobility of the nodes, we notice that the overhead increases, or sometimes decrease, as the network then tries to adapt to maintain the functional links.

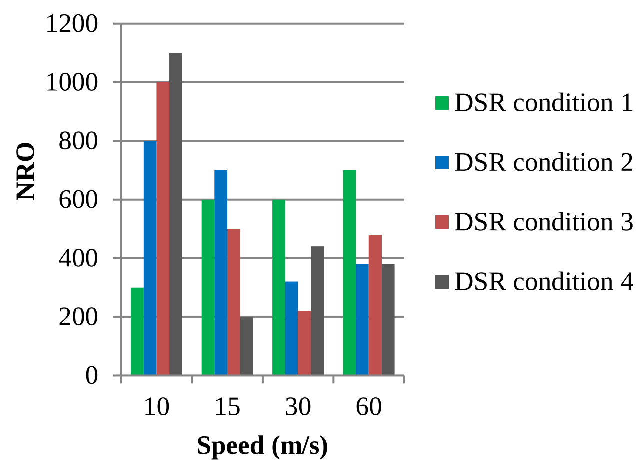

Fig. 8 Speed vs NRO

5.4 Effect of Density with the Change of Environment

Figure 9 shows that the PDR rate of all these routing protocols decreases more and more when the density of the nodes is increasing.

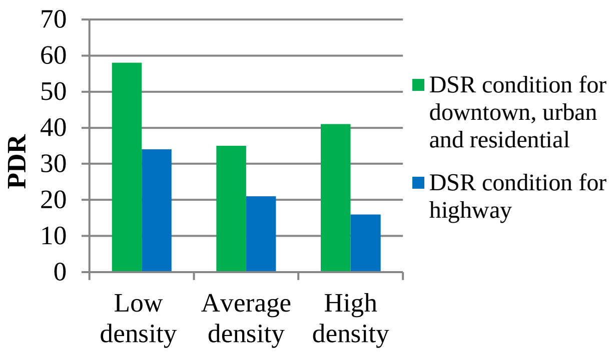

Fig. 9 Density vs PDR

Figure 10 shows that the average End-to-End Delay (ETED) decreases as we move from one environment to another environment that contains more channels and more nodes. As the density increases, the chances of finding links to the destination for the packages are numerous.

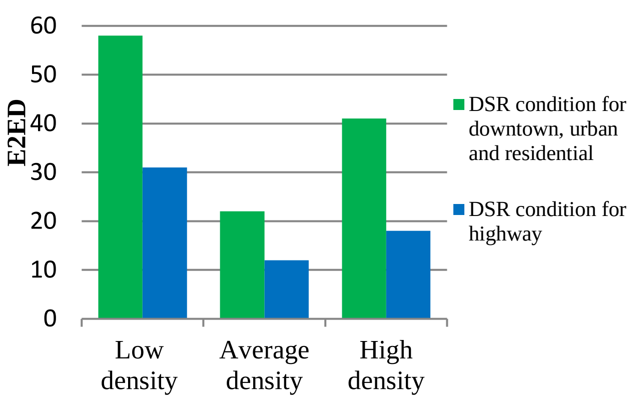

Fig. 10 Density vs E2ED

Figure 11 confirms the proportional relationship between normalized routing overhead (NRO) and speed and density. Indeed, changing the environment implies a change in speed and density. For this reason, the higher the density and speed, the more the NRO parameter increases.

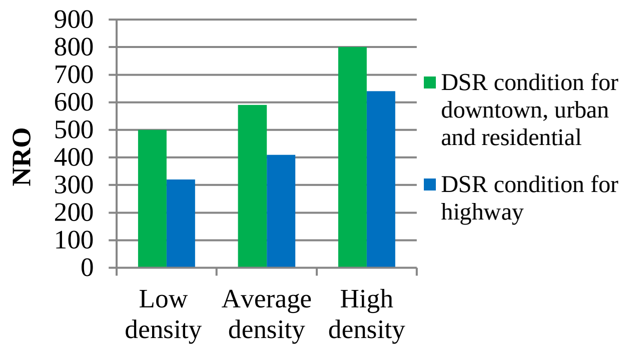

Fig. 11 Density vs NRO

6. Conclusion

This paper has shown how the use of cluster network can improve network performance with respect to routing. Indeed, the choice of three parameters (speed, density and environment) as inputs for the cluster network in order to obtain an output that represents the routing condition to be used has made it possible to improve the routing parameters. Since all VANET routing protocols are valid only for the environments for which they were designed, the protocols are invalid for other environments. So to solve this problem, the proposed methodology is based on the use of several protocols. Each protocol corresponds to an environment known by metrics that characterizes it from another environment. The node that collects information from its neighbors will be able to use the classification based on this collected data. Finally, the node will use the most appropriate routing protocol for its environment. The results show that even though we are reducing the amount of data, the proposed approach still provides a better classification for selecting the appropriate DSR routing protocol condition. This shows the effectiveness of adaptive routing in cluster networks to drive these routing conditions in all environments.

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