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Optimal model of vehicular ad-hoc network assisted by unmanned aerial vehicles and information-centric networking to enhance network performance

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ABSTRACT

Vehicular ad-hoc network (VANET) is a promising project related to intelligent transportation systems (ITS), which aims at connecting vehicles and providing a set of functionalities for the efficient management of the network. However, the high mobility of the network nodes is considered a significant challenge for implementing a reliable, secure, and efficient exchange system. Furthermore, VANET faces the issue of packet delivery due to the high mobility of the nodes and packet collisions complicate the process of sending and receiving packets. We propose to combine two technologies which are unmanned aerial vehicle (UAV) and information centric networks (ICN) and apply it in VANET architecture as supporting technology. The UAV are more reliable and less affected by channel fading. And can be used in areas where we cannot install network infrastructure. The UAV has many advantages that we have cited in this article and can solve many issues of VANET. Using ICN can solve some of the problems of VANET since ICN has many strategies to capture and retrieve data. This study proposes a new VANET model based on an UAV and ICN, to reduce the overload of the vehicles, which in most cases require more resources and have a limited time to process and act especially in case of an accident or emergency.

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1. INTRODUCTION

Improving the vehicle's autonomy level has become a requirement for most car manufacturers [1]. For this reason, several functionalities have been integrated on board the vehicle such as sensors, cameras, processing units, and storage space in order to warn the drivers of the various threats they might face and consequently reduce the number of accidents and traffic jams, therefore, the increased interest in intelligent transport systems (ITS). An efficient and reliable intelligent transportation system represents a fundamental component of any smart city, especially with the increasing advances in wireless communication technologies which facilitate its conception and deployment. Among the promising projects related to ITS, there is the vehicular ad-hoc network (VANET) project, which is a specific case of a mobile ad-hoc network (MANET) network where nodes are vehicles, the aim is to connect vehicles to exchange different information about the road condition, and report possible incidents that may occur. VANET has been deployed mainly as a user-oriented service such as road traffic monitoring [2], on-board passenger entertainment platform [3], and driving assistance by giving multidimensional maps [4]. These features aim to provide a safer and more enjoyable travel experience for road users. Although these different functionalities need certain prerequisites to be used efficiently, for instance, most applications related to intelligent systems (mainly for transportation) need a delivery guarantee and are therefore delay-sensitive, while entertainment and location-based applications typically require significantly larger bandwidth to support faster throughput. Despite the various advances made by manufacturers and automotive experts, most VANET architecture faces several challenges, such as connection disruptions, unstable communication infrastructure, and important packet collision rates.

As mentioned earlier, guaranteed delivery is a major issue for VANETs. The stability of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication is negatively affected by the constant mobility of the vehicle. The constructions, the poles, and the trees also disturb the radio waves causing path loss. While ITS applications and programs require a reliable and stable connection for sending and receiving messages, especially for urgent messages, which require fast-forwarding and a guaranteed delivery [5], otherwise there is a high risk of getting into traffic jams or provoking road accidents [6].

In the V2V communication mode, vehicles communicate while maintaining a routes map to avoid sending data packets at multiple hops. However, the high mobility of different vehicles disturbs the data paths since the source, target, and intermediate node positions are continuously changing, which negatively impacts the network performance. V2I mode also faces the effect of mobile nodes, provoking handovers across base stations and roadside units (RSUs) and consequently, increases sending and receiving delays and eventually leads in some situations to service breakdowns.

VANET network offers a static communication infrastructure through which ITS programs can provide their own services to the different road users, this prevents the implementation of dynamic on-demand access, as well as extending the coverage area, which remains relatively limited [7]. Even though with multi-hop functionality provided through V2V, the coverage area can be extended and consequently can offer on-demand access to the network infrastructure. This extension remains after all limited, and such an operation in a dense environment based on multi-hop communication would lower the network performance even more [8]. Furthermore, the growing number of nodes also decreases the VANET's performance, leading to network congestion and a higher latency, which results in a larger routing table and a higher risk of collision of transmitted packets [9]. In such a context VANET applications offered to users are unable to provide their services on a reliable and efficient platform. In the case of ITS alert applications, they require guaranteed delivery of urgent messages within a short delay, otherwise accidents may occur, and lives may be lost.

To overcome the previously mentioned challenges, unmanned aerial vehicles (UAVs) can be employed in a VANET architecture as a supporting technology [10]. Indeed, compared to VANET communication modes, UAVs are more reliable as they have direct air-to-ground communication links to users and are less affected by channel fading. In areas where it is difficult to deploy and maintain network infrastructure due to the high installation costs, UAVs can be the right choice, especially as they allow the collection of critical information from relevant areas and transmit them to the ground-based VANET. It can also relay exchanged packets to the ground network when direct inter-node communication is not supported.

Using information-centric networks (ICN) in the context of VANETs is another approach to overcome some of these issues. ICN has several strategies for caching and retrieving data [11], useful in inter-vehicle communications. ICN accelerates content retrieval cached on different nodes, saving both energy and retrieval delay. In this paper we propose a VANET architecture assisted by UAV and ICN (uVANET_icn), a comparative study is conducted to show the effectiveness of such a model to make reliable inter-vehicle connections to achieve a high level of delivery guarantee and improve the performance of the network.

2. RELATED WORK

Many research studies have been conducted to solve the problem of high mobility, delivery guarantee and unreliable connections between vehicles in VANET. In order to ensure stable connections for vehicles, the drone assisted vehicular network model was introduced for the first time by Shi *et al.* [12]. In this research the author has detailed the composition of a UAV-assisted VANET architecture, while highlighting the potential of the provided services as well as the challenges encountered for its proper functioning. Ahmed *et al.* [13] suggested a new collaborative communication model of internet of drone (IoD) serving VANET vehicles in urban areas. The main objective is to dynamically deploy the drone to achieve optimal coverage, however, the model does not show the impact of velocity and vehicle density on the communication breakdown and providing alternative paths in the case of disrupted links. Oubbati *et al.* [14] implemented a routing method involving a flooding technique to guarantee the reliability and delivery of exchanged packets. In this study, a predictive technique is applied to determine the link timeout. Seliem *et al.* [15] suggested a mathematical model to determine the separating distance within co-located UAVs and to identify the density that bounds the worst-case exchange packet transmission delay between UAV and vehicle, the objective is to enhance VANET communication based on drone infrastructure to reach the shortest possible packet delivery time for drone-to-vehicles mode communication. In a recent study by Xiao *et al.* [16], they used UAVs to forward messages from vehicles and enhance the communication quality and performance of VANETs against threats from intelligent jammers observing on-board units (OBUs) and UAV communication states. Sedjelmaci *et al.* [17] explained the consequences of high latency, message loss, repeated disconnection in a VANET network and proposed a solution to integrate UAVs in VANET, the idea was to consider UAVs as relay point between the unconnected segments on the road in such situations, the efficient communication is rather between vehicles (VV) or between vehicles and UAVs, the article proposes a new framework using UAVs as an infrastructure of mobile nodes to enhance inter-vehicle connection.

3. PROPOSED MODEL

Inflexible communication infrastructure, high packet collision rate, inconsistent connection, and energy consumption optimization are some of the key issues in traditional VANET architectures. The objective of the UAV and ICN assisted VANET model is to resolve these issues to achieve a pleasant user experience and better performance. In this part we describe in detail the role of each component of our model, as well as its advantages.

3.1. Vehicles

The network nodes are the vehicles which are already employed in a VANET architecture. Vehicles are equipped with OBUs allowing them to communicate with each other via V2V mode or with the road infrastructure composed of RSUs (static or mobile) using V2I mode [18]. OBU also includes a GPS sensor to track its position and has memory to store and retrieve information using the standard IEEE 802.11p communication support. It is also linked to the wireless sensor implemented in the vehicle to manage the physical vehicle condition.

3.2. Wireless communication channel

Dedicated short-range communication (DSRC) is one of the most common wireless technologies used in V2V and V2I communication which is employed as a medium for short range communication [18]. The frequency communications commission (FCC) has assigned it a bandwidth of 75 MHZ at a frequency of 5.9 GHz [19]. This technology is mainly employed to connect vehicles to each other, but also to connect vehicles to the network infrastructure. In our case, the network infrastructure consists of both RSUs and UAVs.

3.3. Road side unit

Road side units (RSUs) are roadside stationary nodes usually installed in a dense area. The RSU has two different communication interfaces, one allowing it to connect with the vehicles of the network and another to provide an internet access point for the benefit of vehicles and road users [20]. The RSU acts as a relay node to extend the communication coverage area over several hops [21], as well as securing the connections between vehicles and the road infrastructure, it also defines the centralized architecture for V2I communications in VANET network.

3.4. Unmanned aerial vehicle

It is considered an important component in our model. It is designed to fly over an area at a relatively high altitude to provide a range of communication services [22]. UAV is also equipped with an OBU that allows it to interact with other nodes of the network, it also has an altimeter and a global positioning system (GPS) to determine its location in the air and adjust its position. Compared to static RSUs, the advantage of employing the UAV as an air mobile base station is its facility to overcome obstacles, changing altitude according to the situation and enhancing the targeting of the node with which it communicates on the ground.

3.5. Information centric networks

The information-centric network is a content-oriented network architecture proposed to replace the classic IP protocol on which the Internet is based [23]. In order to achieve the ICN approach, several implementations have been suggested. Named data networking (NDN) [24] is one of them (used in our study). In a typical scenario, a user expresses an interest in a specific information or resource, a request is broadcast over the network, and any of the nodes containing the requested information or resource will return it. The objective is to dissociate the content from the physical medium and improve the performance of the network.

3.6. Advantages of the proposed model

In our model we are interested by the storage and processing capacities of the vehicles covered by the UAVs, in order to reduce the overload of the vehicles, which in most cases require more resources and have limited time for processing and acting in case of accident or emergency. As mentioned above, we're going to use UAVs for data storage, which will make data access easier and retrieval faster. The data processing aspect of the vehicle nodes will enable us to handle incoming requests from other nodes, and to process packets transferring over the VANET network. Besides, we aim also to increase the guarantee of delivery of emergency messages, since in case of road accident, an emergency message is delivered to all the nodes that are getting closer to the accident location. The corresponding ratio for packet delivery success will be called public distribution system (PDS) henceforth, calculated as (1).

$$PDS = \frac{Number\ of\ received\ Packet}{Total\ Number\ of\ nodes} * 100 \quad (1)$$

A high value of PDS indicates that a significant number of vehicles have received the packet and can therefore take safety measures and reduce the potential number of collisions or incidents that may occur. Latency of the packet is a determining criterion in real time safety applications requiring a specific action to be executed within a particular time frame, in case of non-response in the allotted time may result in irreversible damage. It also has consequences on the network throughput as well as on the performance of interest-oriented applications such as NDN applications allowing data caching. The processing time covers in our study the duration from the transmission of the packet to its reception, including processing time, waiting time as well as propagation time. The proposed model is mainly oriented towards extended V2I communications. In classical VANETs the communications between vehicles and infrastructure are mainly through RSUs, whereas with our model UAVs play the role of mobile RSUs providing more flexible coverage, reaching areas where there is no network infrastructure, and using line-of-sight communications, as well as reducing the packet traffic in condensed areas.

In order to reach a particular data, perform a complicated task or simply request additional space thanks to the ICN paradigm, a vehicle submits its request (called an interest) to a UAV, which will then consult the pending interest table (PIT) containing the list of interfaces where interests are received, to determine which nodes satisfy the requirements. Once the request has generated a result, the target node will make a response using the same sending path, in parallel the PIT table is updated with the new elements to be used for the next requests. In addition to the interest information and the node interface, the PIT table also contains the corresponding operation type if it is a storage space, processing unit, network data or any other operation. In case the UAV does not host the node corresponding to the requirement, the request is automatically sent to the neighboring UAVs so that the latter can proceed in the same way [25].

4. CASE STUDY AND RESULTS

In order to validate our model, we developed a case study for tracking a suspect vehicle as shown in Figure 1. In our scenario the vehicles are moving in a multiline road each one follows the line associated to it. A police vehicle initiates a query for a suspicious vehicle moving on the city in order to apprehend it, for this purpose it emits an interest containing the registration of the vehicle which will be submitted to the UAV which is under its coverage area. If the vehicle is not found in its area, the UAV saves first the information of the tracked vehicle, and then it transmits the interest to the next UAV, so that it can investigate in its area. In our case saving the vehicle registration will allow the UAV to find the vehicle in case it joins its coverage area.

For this test case, we assume that the UAVs relay messages between them as well as vehicles on their coverage areas. In addition, each UAV has its own PIT table to locate each vehicle in the VANET network. To simulate our scenario, we generate a message/ interest according to an alert issued by the police vehicle, the objective of this message is to inform the other vehicles moving on the network of the existence of a suspect vehicle. the message flow shown in algorithm 1. This case of figure is reproduced with each report from a police patrol, the latter broadcast an interest, including the identifier of the vehicle, its direction as well as its location. In our case the vehicle ID refers to the license plate. The suspicious vehicle is tracked in both traffic directions and the location parameter informs about the position of the vehicle. the information on the position of the vehicle is important because it allows to locate the searched vehicle in the city. The police vehicle compares its position with that of the suspect vehicle to find out in which area it is and also in which direction of traffic. In order to control the message delivery and to avoid overloading the VANET network with several requests of the same interest, the vehicles are disabled to retransmit the message between them (in V2V mode). It is only the UAV which is in charge of retransmitting and caching the information of the tracked vehicle.

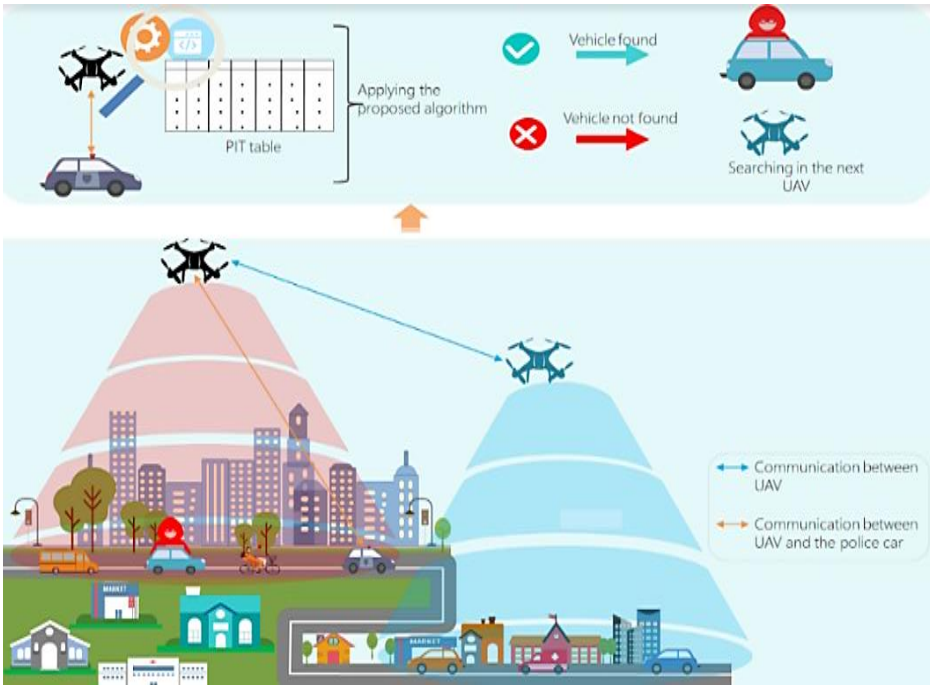

Figure 1. Case study of tracking a suspect vehicle

Algorithm 1. Message flow algorithm in VANET supported by UAV and ICN

```
Set of Vehicles moving on the Network is V
Set of UAVs flying above the area U
Set actualU
START
Message/Interest is initiated by the POLICE PATROL
WHILE Suspect vehicle is not reached do
        IF Receive Node n ∈ V then
                IF message received ==YES
                ELSE
                drop the message
                                END IF
        ELSE IF Receive Node n ∈ U then
                actualU ← n
                               IF PIT of actualU contains Vehicle ID of the Suspect
vehicle then
                     return position of Suspect vehicle
                ELSE
                     Save_ICN (Vehicle ID) in PIT of actualU     and broadcast message
                END IF
                END IF
END WHILE
```

Table 1 describes the simulation parameters. We used the network simulator version 2.1b9 to run the test case described above. we used VANET, UAVs and ICN in our topology. we used BonnMotion to generate the different movement of vehicle nodes and UAVs and pass them to NS-2, who generates the packet and run the simulation based on the position of the vehicles and UAVs. A C++ function is used to cache the suspect vehicle information in the PIT table on each UAV. The UAVs overfly the vehicles at a distance of 1,000 meters. For the UAV it acts as a packet relay for V2I and UAV-to-UAV (U2U) communications. To demonstrate the efficiency of our model in comparison with the classical VANETs and those assisted by UAVs without ICNs, we carried out several simulations by changing the size of the road, the location of the suspect vehicle in relation to the police vehicle and the density of the vehicles in the target area. We simulated a total of 1,500 cases of a tracking message sent from several nodes, setting the number of UAVs at 50 as a threshold.

Concerning RSUs, they are used as a secondary relay point, replaced by UAVs considered as mobile RSUs, a temporal ordered routing algorithm (TORA) has been implemented for this purpose. The static RSU infrastructure was only taken into account in few test scenarios since UAVs serve as mobile RSUs and facilitate better the communication within VANET. The proposed model is compared with the UAV assisted VANET (uVANET) and also with multi-hop standard VANET. uVANET has a preference to use V2V communications and relies on the drone as a relay point when the target vehicle is out of range. Regarding VANET each vehicle calculates its proper waiting time to decide about the next relay node. vehicle with the lowest waiting time will be the favorite candidate to be the relay point. The waiting time is calculated according to (2):

$$w = \left(1 - \frac{d}{r}\right) \times w_{max} \quad (2)$$

with d is the distance separating the vehicles. r is the transmission range. And finally, w_{max} which is the maximum waiting time.

Table 1. Simulation parameters

Parameter	Value
Network simulator	NS-2
Mobility simulator	BonnMotion
Mobility simulator tracer	VanetMobiSim
Number of nodes	50, 70, 90, 100
Road length	5, 10, 20, 100 km
UAVs per KM	2
Vehicles speed	20, 60, 100, 120 km/h
UAV altitude	100, 500, 1000 m
Simulation time	5 min
Packet sent	15,000
Routing protocol	TORA
IEE standard	802.11p
Frequency V2U	5.2 GHz
Frequency U2U	2.2 GHz
UAV transmission power	1.5 dBm
Vehicle transmission power	1.2 dBm

Packet latency is a critical factor for real-time and security related applications, as it requires that an action must be executed as soon as possible to avoid a collision or blocking anomaly. It also has a direct impact on the performance of the network for data-oriented applications. The delay in our case is the time spent from the transmission of the packet from the patrol vehicle to the reception of a reply. Including processing time, caching time, waiting (before relaying) and propagation time.

$$T = T_{processing} + T_{caching} + T_{waiting} + T_{propagation} \quad (3)$$

For a given distance between the police vehicle and the suspect vehicle in the case of a multi-hop VANET, more hops mean more time T. Similarly, in a VANET context with dense traffic, this results in a higher number of packet collisions and consequently an additional waiting time $T_{waiting}$. Figure 2 shows the result of an experiment comparing the delays of time performing between the different VANET models, VANET assisted by UAV (uVANET) as well as VANET assisted by UAV and ICN (uVVANET_ICN).

We notice that the delay has a weak correlation with both density and velocity for the case of uVANET and uVANET_icn. For VANET case, as the number of nodes increases, so does the delay, and as the speed increases, so does the difficulty of transferring packets between nodes, as well as the number of collisions, which becomes more important. In opposition to our model in which there are no more collisions, which largely decreases the waiting time. In contrast to our model, where there is no more collision, which largely decreases the waiting time. Regarding the propagation time, it largely decreases compared to uVANET, because caching the required information (in our case, the suspect vehicle) on the UAVs reduces the searching time in the covered area.

The second indicator in which we were interested was the PDS indicator. As mentioned before, this ratio is useful to check the delivery of the message propagated on the network. This ratio is especially variable in urban areas since direct connections between UAVs and vehicles are negatively affected by road obstacles and high buildings. To express the latter statement, Al-Hourani *et al.* [26] developed a formula to describe the packet path loss from the air to the ground:

$$P_{Los} = \frac{1}{1 + e^{-b\left(\frac{180\theta}{\pi} - a\right)}} \quad (4)$$

where θ is the elevation angle between the vehicle and the UAV, a significant value of the latter will tend the probability of direct sighting to approximately approach 1. The ratio depends mainly on the receiver's sensitivity, the technology used for communication, and the quality of the provided service. It has also been observed that the theoretical optimum altitude that can be reached exceeds the atmospheric layer and that in our case the use of the UAV avoids this constraint.

The other advantage of the new approach is that it reduces significantly the number of packet collisions, as packets are sent simultaneously by the UAV to the nodes within its area. Using ICN in the other side, the packet containing the requested information is stored in the UAV, making it possible for it to detect the suspicious vehicle entering its zone and report it to the patrol police. Figure 3 shows the comparison of the PDS of the proposed model with the two competing models.

In Figure 3, it is clear that our model far outperforms the classical VANET model in terms of PDS ratio regardless of network density and road length. In comparison with the uVANET the two models are practically similar with a small difference and this is mainly due to the employment of UAVs by both models. For VANET, the density and the road length affect negatively the packet delivery, and this is mainly explained by the high mobility of the nodes as well as the absence of the static infrastructure (RSU) in some areas that interrupts the process of packet routing.

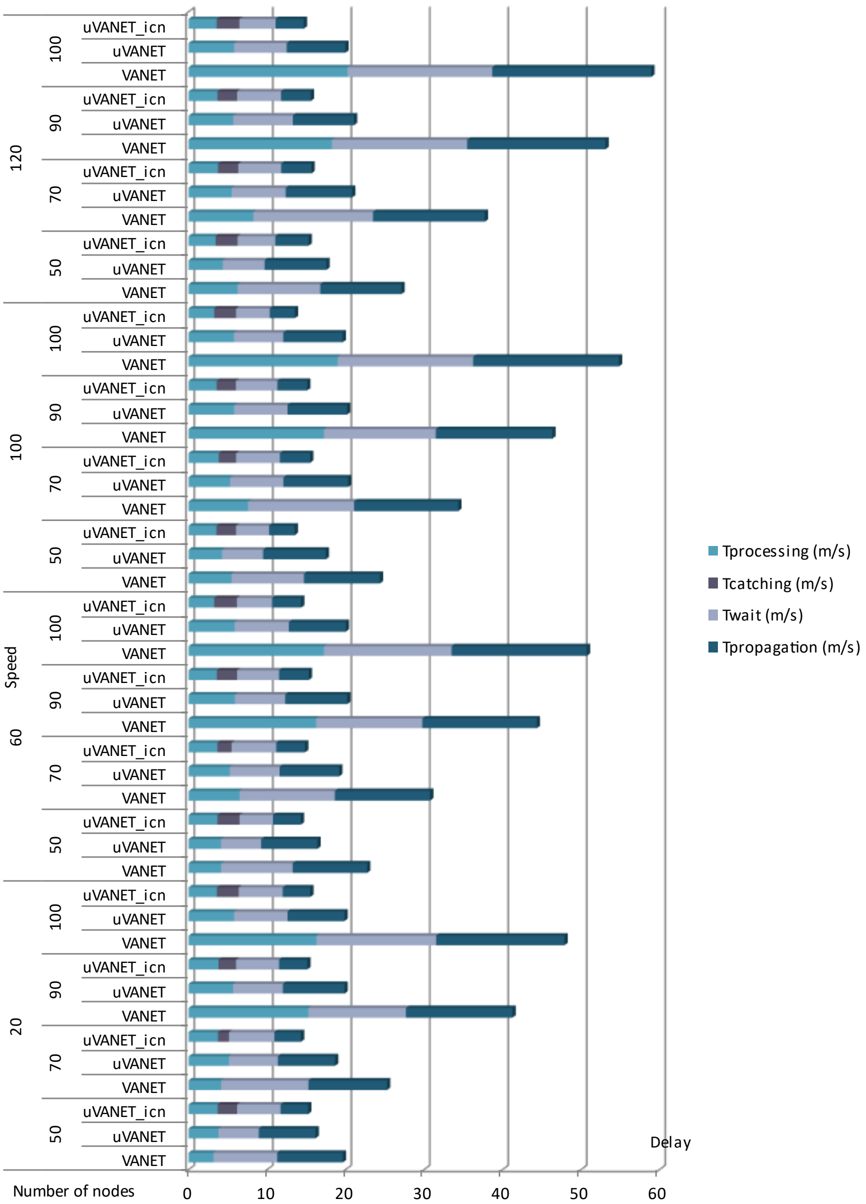

Figure 2. Time performing comparative study

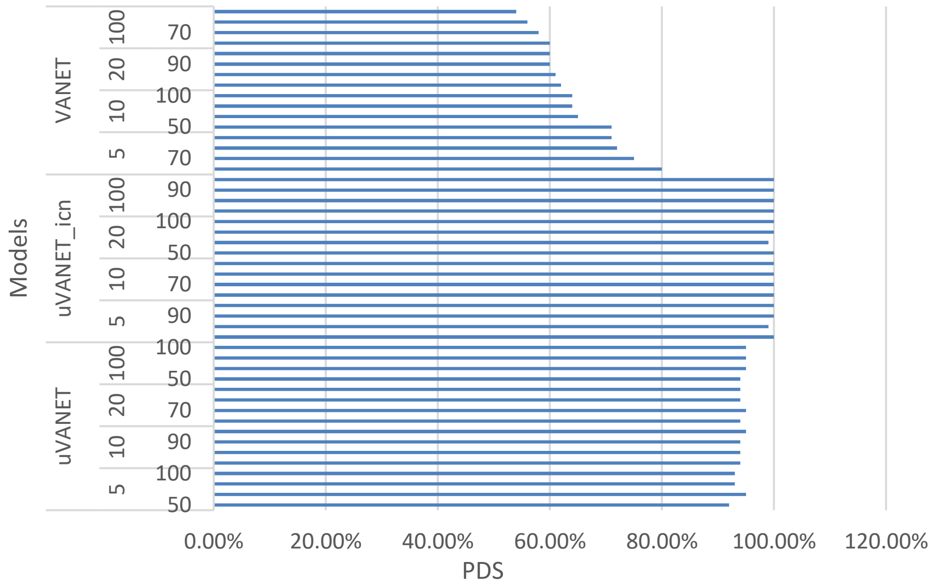

Figure 2. PDS result of the three models

5. CONCLUSION

In this paper we propose a new model of VANET assisted by UAV and ICN in order to improve the network performances and to guarantee the delivery of exchanged packets. We began by presenting the VANET network with its different communication modes and the different main challenges encountered, as well as the role of the ICN and the UAV in our new model. Next, we review the different researches that have been carried out for the application and relevance of UAVs and ICNs in a VANET context. Afterwards, we present our model, its advantages compared to the classical VANET model. Lastly, we conclude the study by simulating a case study, which demonstrates the effectiveness of our model on the two aspects of this study which are the delivery guarantee and the improvement of the network performance in terms of packet latency and processing time.

This study will be used in future works oriented towards the improvement of services and performances of road networks in a smart city. The objective of the next study is to test the behavior of this model in the case of networks without road infrastructures in order to test the continuity of the services in non-urban areas. In future articles, we intend to prove the effectiveness of 6G technologies in solving problems such as guaranteeing the delivery of exchanged packets and reducing data search and retrieval delay.

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