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SDN Architecture for Intelligent Vehicular Sensors Networks

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***Abstract*—Intelligent Vehicular Sensors Networks is a vehicle collaboration system enabling vehicles to collect and share sensors data with each other. This collaboration results in the production of new knowledge that makes sense for both applications and users. To ensure a successful integration of intelligence functions in vehicles a reliable and efficient communication system is required. However, in the actual VANET architecture, it is quite difficult to maintain good performance of data transmission. This paper proposes the usage of topology prediction for routing path computation. Based on the regular collected vehicle status, the proposed SDN-VANET Controller is able to predict the trajectory of each vehicle thank to the Kraus microscopic traffic flow model. With the knowledge of routing path, the SDN-VANET Controller generate the corresponding flow table and distribute commands for the concerned vehicles. The main advantage of the proposed routing scheme resides in the fact that it is less affected by the high topology changes in VANET contrary to traditional routing protocols (OLSR, GPSR) which cannot instantly determine the new change of topology. From the simulation results, the SDN solution performs than the traditional routing protocols.**

Keywords— Software-Defined Network (SDN), Vehicular Adhoc Network (VANET), Geocast

I. INTRODUCTION

Vehicular Sensor Networks (VSN) [1] is a network paradigm inheriting the concept of Vehicular Ad hoc Networks (VANET) and Wireless Sensor Network (WSN). This gives VSN unique properties such as dynamic change of areas interest, collecting data from the vehicle itself (driver and vehicle condition monitoring) and its immediate environment (traffic conditions, pollution level, surveillance camera ...). Research on VSN focuses mainly on dissemination techniques, collection and data aggregation. Internet of Vehicles (IoV) [2] is a new emerging concept based on the Internet of Things (IoT) to move vehicle, from a single node on VANET, forward an intelligent platform able to learn, think and understand the physical systems themselves. A good sensor system is a guarantee of a successful integration of intelligence functions in vehicles. Hu et al. [3] pose the main challenges faced in Intelligent Sensor Networks (ISN). They argue that ISN can be achieved in four types of awareness: Spatial awareness, Data awareness, Group awareness and Context awareness. In [3], Allen et al., develop a concept for collective spatial awareness in ICT systems based on three components: *Self*, *Others* and *Environment*. The concept of Intelligent Vehicular Sensors Networks (IVSN) can be considerate as the combination of the concepts cited above. Thus, vehicles with IVSN access, consume, create, enrich, direct and share sensors data with each other. In other words, IVSN is a communication model based on data dissemination and collaborative data processing. The key challenge faced by IVSN is the data communication on VANET.

Routing on VANET is a complex operation that faces multiple constraints such as the high mobility of vehicles, highly dynamic topology, intermittent connection… Several research work has been conducted for designing efficient routing protocols. However, the inherent limitations of VANET (poor connectivity, less scalability, less flexibility, less intelligence) soon became apparent and its development is stagnating [4], [5]. Software Defined Network (SDN) is a new network paradigm which enabling network programmability. SDN is designed to make the network more flexible and agile by decoupling control and data plane. Thus, the whole network intelligence is placed in the control plane and managed by a central entity named Controller. In this way the infrastructure is in the data plane. The flexibility of SDN makes it an attractive approach that can be used to satisfy the requirements of VANET scenarios [6]. However, with the high mobility of vehicles, it is hard for SDN controller to collect vehicles status and send commands in real time. He et al. [5] propose to make on generic SDN several changes such as the utilization of topology prediction. However, the authors do not detail how the SDN controller may predict the trajectory of the vehicle, or how SDN controller generate flow table for vehicles. Kraus [7] microscopic model for traffic flow is used to predict the trajectory of the vehicle, and based on this prediction, routing path selection algorithm is proposed.

The reminder of the paper is structured as follows. Section II presents the related work on SDN-based routing for VANET. In section III, we present the IVSN model by essentially describing the role of different entities. The proposed SDN architecture is detailed in section IV and the SDN-based routing scheme is presented in section IV. We discuss, in section V, the performance of the proposed routing scheme. Finally, Section VI concludes this paper and give the future work.

II. RELATED WORK

SDN based routing protocol for VANET is a new domain of research, and we find in literature only some relevant paper covering this topic. Ku et al. [6] are the pioneers on the introduction of SDN on VANET. Two types of channel are used: a long-range channel (LTE/WiMAX) for control plane and a short-range channel (WiFi) for data plane. RSU (Roadside Unit) and OBU (On Board Unit) act as SDN Switches controlled by a centralized SDN Controller.

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Compared to traditional routing protocols (GPSR, OLSR, AODV and DSDV), their architecture gives some advantages such as best routes selection, improving frequency/channel selection and best packet delivery ratio. Zhu et al. [8] propose an SDN-based routing framework for reducing latency and overhead. The vehicles periodically update their status to the central routing server via a WiMAX link. Once the vehicles receive routing information from the routing server, there can exchange data between them via a WiFi link. When the link with routing server is broken, a new metric named MOT (Minimum Optimistic Time) is used to compute the shortest route from the source node to the destination. The limitation of this framework resides in the fact that 802.11p/WAVE protocol is not used. In contrast, Liu et al [9] use the classic VANET architecture and SDN to design a new GeoBroadcasting algorithm. The SDN controller built routing path based on the topological and geographical information of the RSU. Compared to C2CNET broadcasting technique, their solution presents best bandwidth with reduction of overhead and latency. This solution is limited only to the implementation of SDN on RSU which acts as a relay from a source vehicle to destination vehicles. Ji et al. [10] propose an SDN-based geographic routing protocol for VANET. The Base Station and RSU are used for control plane transmission, whereas V2V is reserved for data forwarding. When the destination is not present in its routing table, the vehicle sends a request message to the routing server. With vehicle location (sent periodically), vehicles density and digital maps, the SDN controller use optimal forwarding path algorithm and packets forwarding selection to calculate the shortest path. With the dynamic change of topology, the optimal forwarding path may be non-valid when the routing server replies with a certain delay. He et al. [5] propose a generalized routing protocol based on VANET and V2-Cloud. Vehicle trajectory prediction is used to update the vehicle status (localization, speed, connectivity…) to reduce network overhead. Two main entities are used: status manager and topology manager. A personalized Openflow API is proposed to take into consideration the VANET constraints. Thus, mobile data plane (for vehicles) and stationary data plane (for RSU) are defined and different management policies are applied to them. A specific topology and routing protocol are dynamically selected depending on the application.

III. Model of Intelligent Vehicular Sensors Networks

Fig. 1 represents the model of the proposed Intelligent Vehicular Sensors Networks (IVSN). The first entity is the *Self*, materializing a unique vehicle with its own sensors, processing unit and communication interfaces. This vehicle develops a cognitive process with the aid of data from its own sensors and sensors from surrounding vehicles (*Others*). With *Spatial awareness*, a vehicle is able to know the physical location of the surrounding vehicle and infrastructure. This awareness automates sensors self-calibration by taking into account measurements from the sensors of *Others*. Thus, *Self* can verify if a sensor measures a reasonable value, validate the measurements made by sensors of surrounding vehicles, make accurate predictions… With *Group awareness*, a *Self* and *Others* are able to process and disseminate information related to the movement of surrounding vehicles and therefore adjust their own behavior. An intelligent vehicle can thus be aware of some failures from other vehicles around. *Infrastructure* is the raw data aggregator and returns data, once the latter turned into information, to *Self* and *Others*... Indeed, with *Data awareness*, *Infrastructure* can extract high quality information exploring spatial and temporal data correlation, predict and construct statistical models. Thus, *Self* with this information, make a decision and therefore act in the best possible way. Finally, with *Context awareness*, *Self* can collect and process context information from sensors, and change its mode of operation based on that context. Thus, an intelligent vehicle will, in response to a driving situation change its operating mode.

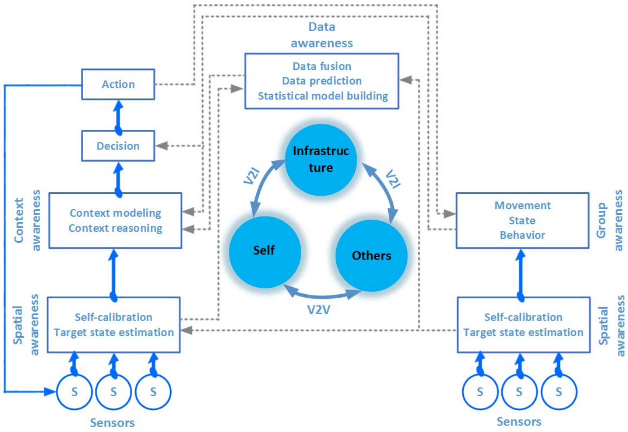


Fig. 1. Intelligent Vehicular Sensors Networks model

IV. Proposed SDN Architecture for IVSN

The aim of the proposed architecture, Fig. 2, is to give a fast, dynamic and programmable communication management between the entities of IVSN. The network intelligence is centralized in SDN Controllers which have a global vision of network

- *RAN (Radio Access Network):* consist of a set of wireless communication systems such as WLAN (802.11n/ac), cellular network (3G, LTE) and vehicular network (802.11p, WAVE). To meet the communication needs of the vehicle, the RAN has several Points of Attachment (PoA) consisting of RSU, Access Point and eNodeB.
- *SDNRAN Controller:* manage the control plane of RAN and handover. This controller also manages the resource allocation of PoA.
- SDNVANET Controller: manage only VANET control plane for V2V and V2I communication. The main purpose of this controller is routing optimization by managing vehicle status and topology.

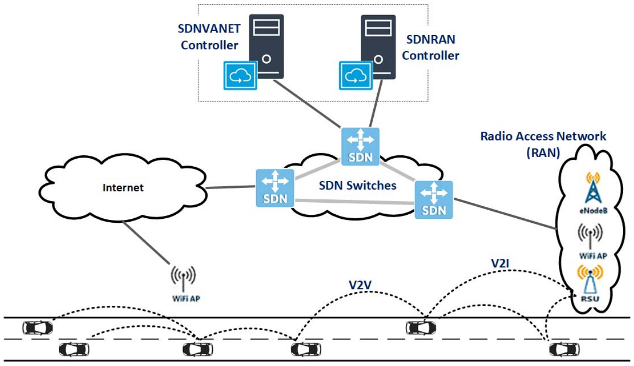


Fig. 2. SDN-based architecture for IVSN

With vehicle equipped with several wireless interfaces a strategy of flow/interfaces association is a need.

- *802.11p interface:* as this interface is optimized for ad hoc communication, so data plane related to IVSN is transmitted via the 802.11p interface. On the other hand, control plane is not transmitted via this interface because of frequents disconnections with the RSU.
- *802.11n/ac interface:* WiFi is characterized by a large bandwidth and is omnipresent in an urban area. Moreover, it is a cheap relative communication system. Thus, WiFi will be used as the privileged interface for the transmission of the control plane.
- *LTE interface:* cellular networks are characterized by a long transmission range and are omnipresent both in the urban and rural area. However, cellular network is a costly communication system, so LTE will not be the privileged interface for control plane transmission.

V. SDN-BASED V2V/V2I ROUTING SCHEME

The IVSN is a communication model based on data dissemination and collaborative data processing. For collaboration, a group of vehicles uses geocast; and for data gathering, RSU uses unicast.

A. Geocast

Geocast consists of sending data packets from a single source to all vehicles belonging to the destination area called Zone Of Relevance (ZOR) [11]. For geocast, the routing path computation has several steps:

- *Step 1: vehicles status collection*

Each vehicle must send in regular intervals its status to SDNVANET Controller via their WiFi or LTE interface.:

$$Status_i = \{p_i, v_i, dir_i, dst_i, PW_i\}$$

Where p_i is the position of the vehicle V_i, v_i is the velocity, dir_i is the direction, dst_i is the destination and PW_i is the 802.11p interface transmission power.

- *Step 2: topology generation*

Once receiving vehicles status, the SDNVANET Controller can determine the topology of ZOR at an instant t. At the instant $t + \delta t$, the ZOR topology is determined by the using the prediction trajectory algorithm derived from the car-following model proposed by Krauss [7]. This is a microscopic mobility model that describes the dynamics of each individual vehicle as a function of positions and velocities of the vehicles in the neighborhood. The Krauss model can be formulated as follows:

$$\begin{aligned} v_{safe}(t) &= v_l(t) + \frac{g(t) - g_{des}(t)}{\tau_b + \tau} \\ v_{des}(t) &= min\left[v_{max}, v(t) + a(v)\Delta t, v_{safe}(t)\right] \\ v(t + \Delta t) &= max[0, v_{des}(t) - \eta] \\ x(t + \Delta t) &= x(t) + v\Delta t \end{aligned} \qquad (1)$$

v_{safe} is the maximum safe velocity, v_l and v_f are respectively the velocity of the leader and the follower vehicle. $g = x_l - x_f - l$ is the gap between the vehicles and depend on the position x_l of leader vehicle, the position x_f of the follower vehicle, and l the length of the car. The desired gap is chosen to be $g_{des} = \tau v_l$ with τ the reaction time of the drivers. $\tau_b = \bar{v}/b$ is the time scale with $\bar{v} = (v_l + v_f)/2$ the average velocity of the leader and the follower, b is maximum deceleration. v_{des} is the desired velocity and is defined as the minimum between maximum velocity v_{max}, the maximum safe velocity v_{safe} and $v(t) + a(v)\Delta t$ is the velocity due to maximum acceleration a. The random perturbation $\eta > 0$ has been introduced to allow for deviations from optimal driving. In this paper, we introduce the velocity v_t to take account the presence of traffic lights. Thus, when the light turns yellow or red, v_t is defined as follows:

$$v_t(t) = \frac{g(t) - g_{des}(t)}{\tau_b + \tau} \qquad (2)$$

Difference between v_t and v_{safe} is that the traffic light is imagined as a leader vehicle in stationary state ($v_l = 0$).

- *Step 3: routing path selection*

The route path computation is based on the knowledge of the predicted topology of ZOR. The notations for the routing algorithm are summarized in TABLE 1. The *Algorithm 1* gives details of the proposed geocast method.

TABLE I. SUMMARY OF NOTATIONS FOR GEOCAST ALGORITHM

V	The set of vehicles belonging to ZOR
R_i	Transmission range of 802.11p interface of vehicle V_i
D_{ij}	Euclidian distance between vehicles V_i and V_j
$V_{i,direct}$	Set of one hop neighbors vehicles of V_i
$V_{i,\phi}$	Set of vehicles that are not yet received geocast msg from V_i
$V_{i,relay}$	Set of vehicles that may be a relay for vehicles in $V_{i,\phi}$
$V_{i,relay}^{j}$	Set of vehicles selected to be a relay for a vehicle $V_j \in V_{i,\phi}$
V_{direct}^{opf}	Set of one hop neighbors vehicles of V_i. This variable is used for Openflow flow table generations.
V_{relay}^{opf}	Set of vehicles selected to be effectively a relay. This variable is used for Openflow flow table generations.

Algorithm 1 routing path selection

```
Require : $V$
Output : $V^{opf}_{direct}$ , $V^{opf}_{relay}$
for each $V_i \in V$ do
    select $V_{i,direct}$
    $V_{i,relay} \leftarrow V_{i,direct}$
    $V_{i,\phi} \leftarrow V_{i,\phi} \setminus V_{i,direct}$
    $V^{opf}_{direct} \leftarrow V^{opf}_{direct} \cup \{(V_i, V_{i,direct})\}$
    while $V_{i,\phi}$ != $\{\phi\}$ and $V_{i,relay}$ != $\{\phi\}$ do
        for each $V_j \in V_{i,\phi}$ do
            select $V^{j}_{i,relay}$
            $V^{next}_{i,relay} \leftarrow V^{next}_{i,relay} \cup V_j$
            $V^{opf}_{relay} \leftarrow V^{opf}_{relay} \cup \{( V_j, V^{j}_{i,relay})\}$
        end for
        $V_{i,relay} \leftarrow V^{next}_{i,relay}$
        $V_{i,\phi} \leftarrow V_{i,\phi} \setminus V^{next}_{i,relay}$
    end while
end for
return $V^{opf}_{direct}$ , $V^{opf}_{relay}$
```

The first phase consists of detecting vehicles belonging to $V_{i,direct}$ i.e. the set of vehicles presenting a ratio $\frac{D_{ij}}{R_i} < 1$. For each vehicle $V_j \in V_{i,\phi}$, only two vehicles in $V_{i,relay}$ presenting the lowest ratio D_{ij}/R_i are selected to be in $V^{j}_{i,relay}$. The advantage of selecting only two vehicles for relaying packet to another vehicle is lying on network overhead reduction. After receiving a from $V^{j}_{i,relay}$, the vehicle V_j will form the next group of vehicles forming the set $V_{i,relay}$. The geocast is stopped when $V_{i,\phi} = \{\phi\}$ or $V_{i,relay} = \{\phi\}$. At the end of its execution, V^{opf}_{direct} will contain for each vehicle $V_i \in V$, the set $V_{i,direct}$. V^{opf}_{relay} will contain for each vehicle V_i, the set $V^{j}_{i,relay}$.

- *Step 4: Openflow flow table generation*

The flow table generation is conducted based on V^{opf}_{direct} and V^{opf}_{relay}. Vehicles send their status to SDNVANET Controller in a regular period T. This period is divided into a small interval of time δt. Thus, for each interval δt, *Algorithm 1* is executed to obtain a new flow table. The SDNVANET Controller send, for each vehicle V_i, the Openflow commands containing flow table.

B. Unicast

V2I communication will be via unicast mode based on geographical routing. The vehicle status collection (step 1) and topology generation (step2) will serve for routing path construction (step3) by SDNVANET Controller. The unicast routing is computed based on the greedy forward algorithm. Openflow flow table generation (step 4) is conducted in the same logic as for geocast.

VI. PERFORMANCE EVALUATION

The simulation, Fig. 3, is conducted using Python script and consist of implementing Kraus car-following model, the proposed SDN-based routing protocol, OLSR and GPSR.

A. Simulation setup

The principle is to simulate the behavior of vehicles in IVSN. Thus, each vehicle present in ZOR disseminates (broadcast mode) regularly its sensors data. RSU, also, collect measurements by using pull method (unicast mode). Being a unicast routing protocol, GPRS will not be used in broadcast mode. Instead, flooding is used for data dissemination. The simulation parameters are shown in TABLE II. The simulation is running for 100s.

TABLE II. SIMULATION PARAMETERS

Kraus model parameters	$\tau = 1s, l = 7.5m, a = 0.8m\,s^{-2}$, $b = 4.5m\,s^{-2}$
Intersections position (x, y)	(500m, 250m) and (1000m, 250m)
Vehicle flow along principal road	lane1 = 1/6veh/s, lane2 = 1/25veh/s
Vehicle flow along intersection 1	lane1 = 1/30veh/s, lane2 = 1/23veh/s
Vehicle flow along intersection 2	lane1 = 1/23veh/s, lane2 = 1/35veh/s
802.11p, 802.11n/ac and LTE transmission range	500m, 200m, 5000m
RSU position (x, y)	(1500m, 250m)
Interval *T* before sending *status*	17s
Data collection (pull) interval	5s
ZOR delimitation (x1, y1, x2, y2)	(100m, 150m, 2000m, 350m)

B. Packet delivery ratio

Fig. 4 depict performance result of the proposed SDN-based routing protocol, OLSR and GPSR in terms of packets delivery ratio. We note that, except OLSR, the packet delivery ratio decrease with the vehicle speed. For SDN-based routing, the cause comes from by losing accuracy in vehicle position prediction. Traffic light also has an impact on routing protocol performance by perturbing traffic flow and fracturing the topology of nodes. For unicast, Fig. 4 (a), SDN-based routing presents the best performance. The topology prediction capability of SDN Controller is the main cause of this success. Indeed, the proposed routing scheme is less affected by the high topology changes in VANET, contrary to traditional routing protocols which cannot instantly determine the new change of topology. The consequences are frequent wrong routing path selection and absence of finding next hop. For broadcast mode, Fig. 4 (b), GPSR/flooding performs better than SDN-based routing. This is because for flooding, all the vehicles re-broadcasting the received broadcast message. Despite all this, SDN-based routing present performances close to those of the flooding.

C. Routing protocol overhead

Fig. 5 show a quasi-absence of routing overhead for SDN-based routing. Indeed, the proposed strategy of flow/interfaces association exploit the propriety of SDN by sending control plane only via WiFi and LTE interfaces. Thus, zero beacon packets (hello message) are generated and

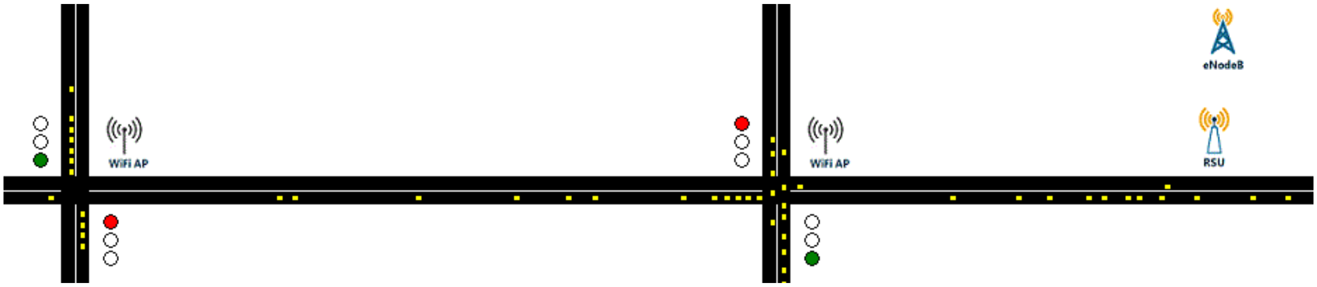
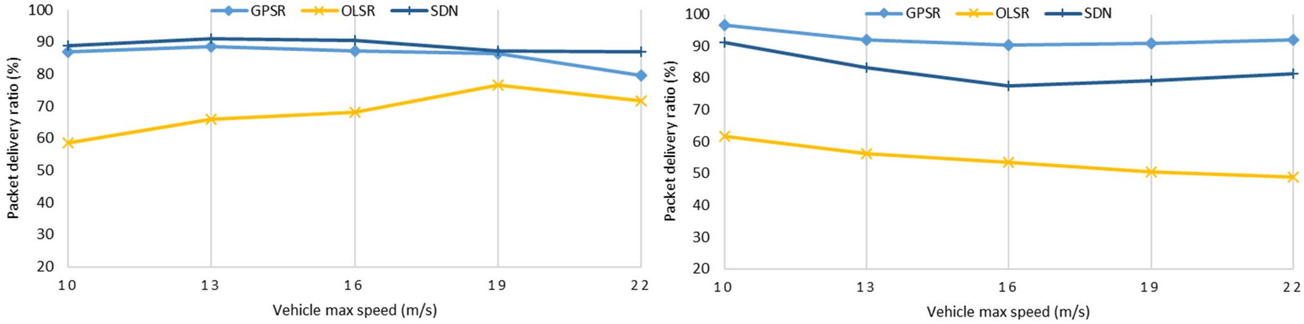


Fig. 3. Truncated simulator GUI



(a) Unicast mode

(b) Broadcast mode

Fig. 4. Packet delivery ratio comparison

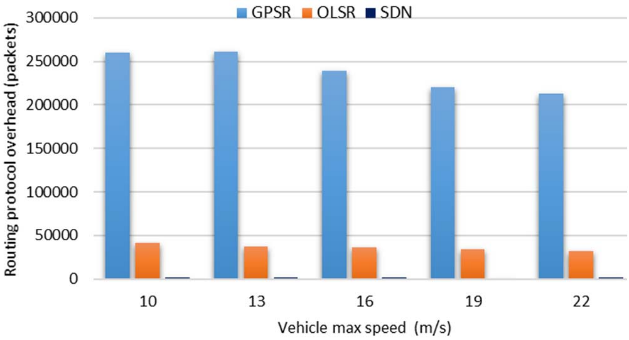


Fig. 5. Routing protocol overhead comparison

no routing information is exchanged in VANET. The only cause of routing overhead come from sensor data forwarding in ZOR. Consequently, more bandwidth is saved thank to the efficiency of the proposed SDN-based routing. The main disadvantage of GPSR/flooding protocol reside on its higher routing overhead and can cause a packet collision that affects the packet delivery ratio.

VII. CONCLUSION

In this paper, we propose an SDN-based routing protocol based on topology prediction. The Kraus microscopic traffic flow model is used to predict the trajectory of each vehicle which must periodically send its status to SDN Controller. With the help of the predicted topology, the SDN Controller generate flow tables based on the proposed routing path selection algorithm. To validate the proposed routing scheme, a simulation is conducted by implementing with Python script two model of communication: geocast for data dissemination and unicast for data collecting. Performance evaluation demonstrates that the proposed solution outperforms the traditional routing protocols (OLSR, GPSR) in terms of both the packet delivery ratio and routing overhead. The main reason is that contrary to the traditional routing protocol, the proposed SDN-based routing does not use a beacon frame transmission to determine the topology change. Thus, the proposed system is less affected by the high topology changes in VANET. In future work, we plan to implement Enhanced Distributed Channel Access (EDCA) to analyze the delay and throughput of the proposed routing protocol. To enhance the packet delivery ration, we also plan to implement an SDN-based adaptive transmission power control for IVSN.

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