Visible Light Communication Assisted Safety Message Dissemination in Multiplatoon

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***Abstract*—Platooning is a promising vehicle formation where autonomous vehicles are accessing each others information and grouped within a close proximity. Multiplatoon, on the other hand, is an enhanced version of platooning that refers to the chain of platoons where platoons follow one another. One of the primary objectives for the multiplatoon system is to support data dissemination for different information types. Multiplatoon systems usually adopt the current dominant radio frequency (RF) technology IEEE 802.11p for communication. However, IEEE 802.11p suffers from problems of performance degradation due to the congestion, the scarcity of RF and security that may degrade the delay and delivery ratio of safety application. Visible Light Communication (VLC), on the other hand, is a promising complementary technology with the potential to address IEEE 802.11p problems. In this paper, we propose an IEEE 802.11p and VLC based hybrid safety dissemination protocol and investigate the hybrid safety message dissemination scheme in the presence of application level data traffic. We develop a simulation platform to realize the hybrid multiplatoon. We demonstrate that the packet loss results in low packet delivery ratio in IEEE 802.11p based multiplatoon. Although VLC increases the safety message dissemination performance, hybrid multiplatoon architecture still suffers from the disconnected network.**

I. Introduction

Advances in automobile industry bring the autonomous vehicle into the reality where vehicles cruise themselves via cooperative adaptive cruise control (CACC) system. CACC enables autonomous vehicles to access each others information based on vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication and groups them within close proximity called platoons [1]. The chain of platoons that follow one-another instead of organizing vehicles as one big platoon, on the other hand, refers to multiplatoon [2]. Multiplatoon is a promising vehicle formation technique with the potential of offering benefits in terms of traffic safety, throughput and homogeneity.

A primary objective for the multiplatoon system is to support data dissemination for different information types. Table I demonstrates the information dissemination applications discussed in [3]: update rate refers to the packet generation rate of vehicles, latency is the maximum tolerable end-to-end delay for the dissemination, distance is defined as the scope within which the information needs to be disseminated, dissemination refers to information distribution characteristics that is either event based or periodic with communication modes: broadcast/multicast/unicast. Multiplatoon systems usually adopt the current dominant vehicular RF technology IEEE 802.11p for packet dissemination. However, IEEE 802.11p has many problems that may degrade the delay and delivery ratio of safety message applications [4]. First, IEEE 802.11p suffers from the scarcity of RF. The increasing wireless data traffic volume of rapidly growing wireless mobile devices causes pressure on RF spectrum. Second, congestion on the IEEE 802.11p channel may cause broadcast storm [5] which ruins the system performance. With the co-existence of different applications, vehicles attempt to transmit simultaneously. The contention based carrier sense multiple access scheme of IEEE 802.11p causes packet collisions at the medium access control layer that increase dramatically as the number of vehicles transmitting simultaneously increases. Third, IEEE 802.11p high transmission range makes this technology vulnerable to adversaries. Today, PC-based or FPGA-based software platforms such as GNU Radio/USRP are easy to obtain and an adversary with these devices can easily jam the IEEE 802.11p communication, preventing the proper functionality of safety message dissemination.

Up to now, most of the multiplatoon studies have focused on multiplatoon management based on the assumption that vehicles do not generate application level data traffic [6]–[9]. However, none of these works perform neither safety message dissemination scheme nor feasibility analysis of message delivery in the multiplatoon under the assumption of application level traffic with the goal of satisfying the safety application requirements. Only one study [9] investigates the performance analysis of multiplatoon communication with the assumption of connected platoons and single information dissemination application. However, delivering safety information over a multiplatoon under application level traffic requires a protocol handling the safety application requirements in terms of latency and packet delivery ratio.

VLC is a relatively new communication technology that uses modulated optical radiation in the visible light spectrum to carry digital information. VLC brings several advantages of not causing any health concern nor any electromagnetic interference, being license-free and easy integration with the existing light emitting diode (LED) equipped vehicles with low cost additional onboard units. VLC is a promising complementary technology with the potential to address IEEE 802.11p problems [10]. First, VLC uses unlicensed and

TABLE I: Requirements for Information Dissemination Applications in Multiplatoon

Type	Update Rate	Use Case	Latency	Distance	Dissemination
Status Monitoring	1 Hz	Road Condition, Vehicle Diagnostic	1 s	1000 m	Periodic, Broadcast
Vehicle Control	10 Hz	CACC	100 ms	-	Periodic, Multicast
Infotainment	0.01 Hz	News, Media, Advertisement	-	1000 m	Event-Based, Unicast
Safety / Warning	10 Hz	PCN, Emergency Brake / Lane Change	100 ms	1000 m	Event-Based, Broadcast

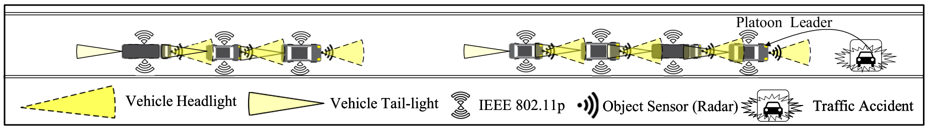


Fig. 1: Hybrid multiplatoon communication architecture

uncongested frequency band, which facilitate high throughput and low latency communication in a short range. VLC offers better scalability compared to RF based vehicular network, which experiences longer delay and lower packet rate due to congestion on the channel. Secondly, the directivity of the VLC limits the contention domain typically within the line-of-sight (LoS) vehicles, which lowers the packet collision and improves scalability in dense scenarios. Third, the directivity of the VLC transceivers facilitates secure communication where attackers need to direct strong light to jam the receiver which can only be performed on a single VLC link, as opposed to all vehicles in the communication range in the case of IEEE 802.11p.

Recently, many researchers investigate vehicular VLC for different purposes such as channel characteristics [11], [12], requirements [13], [14] and security [15], [16]. Moreover, it has been demonstrated that inter-vehicular space gap in the platoon is less than 15 m at vehicle speeds less than 100 km/h [6] and VLC can achieve data transmission up to 100 m for headlights and 30 m for taillights [12]. Expanding on this vision, hybrid platooning architectures together with IEEE 802.11p and VLC are proposed [17]. The large coverage of IEEE 802.11p and secure, high rate and low latency data transmission of VLC complement each other. Although message dissemination schemes for the vehicular network are viable, timely and reliable delivery of safety messages in the multiplatooned network is still challenging [18]. On the other hand, VLC has the potential to achieve the low latency and high packet delivery ratio in the platoon. Thus, we address the design of an IEEE 802.11p and VLC hybrid safety message dissemination protocol that ensures the requirements of safety applications.

The original contributions of this study are threefold. First, we propose an IEEE 802.11p and VLC hybrid safety message dissemination protocol. We develop a simulation platform supporting both IEEE 802.11p and VLC for the hybrid communication in the multiplatoon. Second, we perform an extensive analysis of the IEEE 802.11p and hybrid IEEE 802.11p-VLC based safety message dissemination in multiplatoon in the presence of application-level traffic, with different vehicle densities over a wide range of performance metrics including packet delivery ratio, delay and packet loss ratio. Third, we discuss the alternative ways to achieve the requirements of the safety application in multiplatoon.

The organization of the paper is as follows. Section II shows the multiplatoon and safety application model. The details of IEEE 802.11p-VLC hybrid safety dissemination protocol are presented in Section III, followed by the performance evaluation in Section IV. Finally, conclusions and future work are given in Section V.

II. System Model

A multiplatoon consists of a number of platoons where each consists of a platoon leader that is the front vehicle and one or more members that follow the leader, as shown in Fig. 1. Each vehicle in the platoon receives data from sensors, IEEE 802.11p and VLC receivers; and sends data to IEEE 802.11p and VLC transmitters. VLC transmitters and receivers are placed on both the front and the rear of each vehicle. VLC transmitters are connected to the headlights and taillights of the vehicle. The transmission characteristics of taillights and headlights are different, resulting in an asymmetric communication link between consecutive vehicles.

Platoon size is a significant metric in multiplatoon systems. Despite the fact that larger platoon sizes could increase the throughput, the platoon size is a factor affecting platoon management operations and the amount of application level data traffic. In the early design of automated highway systems, platoons had a larger size such as 20 [19]. However, recently in the SARTRE project [20], it is demonstrated that the maximum platoon size should be 15. To evaluate the effect of size on multiplatoon based safety message dissemination, different platoon size values (e.g. between 5 and 20) are adopted.

Platoon members communicate with each other through periodic packets and event based maneuver request/response packets. Each platoon is controlled by a platoon management protocol that supports platoon maneuvers of entrance, leave, merge and split. Apart from platoon management protocol, vehicles run multiple applications that are status monitoring, vehicle control and warning. The distance between two consecutive platoons, namely inter-platoon spacing, is mainly affected by the velocity and acceleration of platoons and it dynamically changes during the traveling. Although larger inter-platoon spacing may sometimes lead to disconnected platoons, it helps achieving safe lane change and collision avoidance.

Platoon members use VLC and IEEE 802.11p for message dissemination. Sending messages to all members in a platoon via VLC is not possible due to directivity and other vehicles as obstacles. Thus, the data from leader to platoon is disseminated by the headlight and taillight in a multi-hop manner through VLC. Vehicle keeps information of its neighboring vehicles in Vehicle Information Base (VIB), which includes maneuver requests/responses, application messages and last communication time.

As an example of safety message dissemination, Post-Crash Notification (PCN) application is utilized. PCN is a safety application where vehicles in an accident area send out PCN alert. The PCN alert contains the position of the crashed vehicle, heading, speed limit, vehicle status and it requires high packet delivery ratio with the short amount of delay in order to prevent the possible pileup in a platoon. The platoon, which receives the PCN alert, informs the other platoons by periodically broadcasting the alert until it exits from the range of accident location.

III. VLC-Assisted Safety Message Forwarding

To achieve hard delay and a high packet delivery ratio constraints, we consider the hybrid usage of VLC and IEE 802.11p. The unique features of VLC assisted safety message forwarding are; it utilizes full duplex light-to-light communication for intra-platoon V2V communication to improve the delay and reliability performance of transmission, it performs smart forwarding where vehicles adaptively decide to forward the received message via the IEEE 802.11p or VLC.

Algorithm 1 is executed by each vehicle in multiplatoon for safety message dissemination, where the aim is to reduce the delay and increase the packet delivery ratio of the safety messages from the leader to the other vehicles by using both IEEE 802.11p and VLC.

Algorithm 1: Hybrid Dissemination Protocol

```
1  foreach received PCN packet do
2      Check the VIB;
3      if PCN not received before then
4          if packet is received by VLC then
5              Send PCN only via VLC;
6          else
7              Send PCN via IEEE 802.11p/VLC;
8          Update VIB;
9          if tail vehicle of a platoon then
10             Broadcast PCN;
```

When a vehicle receives a PCN packet, it checks the VIB to control if PCN was received before (Line 2). If not, then the vehicle checks if PCN is received the by VLC (Line 4). If the vehicle receives the PCN via VLC earlier than IEEE 802.11p, it sends the PCN only via the VLC to the following vehicle(Line 5). The case of a PCN packet received via VLC earlier than IEEE 802.11p implies that the channel is congested and vehicles have failed to receive the PCN via RF. Thus, the PCN is forwarded only via the VLC for the purpose not to further congest the radio link. On the other hand, if PCN is received via IEEE 802.11p first, the assumption is that RF channel is not severely congested, then the vehicle sends the PCN via both IEEE 802.11p and VLC (Line 7). After forwarding the PCN, the VIB is updated (Line 8). When the PCN reaches to the tail vehicle in each platoon, the last vehicle of each platoon broadcast the PCN for following platoons (Line $9-10$).

IV. Performance Evaluation

To study the performance evaluation of safety message dissemination in multiplatoon, we compare the proposed VLC-IEEE 802.11p hybrid safety message dissemination scheme denoted by *VLC-IEEE 802.11p Hybrid* to the IEEE For the performance evaluation of safety message dissemination in multiplatoon, we compare the proposed VLC-IEEE 802.11p hybrid safety message dissemination scheme denoted by *VLC-IEEE 802.11p Hybrid* to the IEEE 802.11p based flooding, denoted by *IEEE 802.11p Flooding* and previously proposed multi-hop IEEE 802.11p based multiplatoon communication, denoted by *IEEE 802.11p Backbone* [9], in terms of packet delivery ratio, delay and packet loss ratio. In *IEEE 802.11p Backbone*, safety message is broadcast by only the leader and the tail vehicles in each platoon. Vehicles in multiplatoon are controlled via IEEE 802.11p based platoon management protocol [6]. Apart from platoon management, vehicles generate application level data traffic via services such as cooperative awareness, status monitoring, vehicle control and vehicle warning with broadcast communication mode and period of 0.1 seconds.

We use VEhicular NETwork Open Simulator (VENTOS) [21] for performance evaluation of various multiplatoon scenarios. VENTOS is an integrated simulator containing the; the realistic mobility generator, Simulation of Urban Mobility (SUMO) [22], discrete packet-level simulator, OMNET++ [23] and vehicular communication platform Vehicles in Network Simulation (Veins) [24]. VENTOS provides a platform to perform multiplatoon simulation under different vehicle mobility where platoons utilize the CACC. We have extended the VENTOS by including the previously developed VLC channel model [12], where the VLC channel model adopts the received signal strength that is a function of distance and bearing angle between vehicles. The end-to-end transmission delay is computed as the sum of the ratio of packet size to VLC achievable data rate at each hop of VLC transmission [10].

TABLE II: Parameters

	Parameter	Value
Simulation	Simulation Time	250 s
	Number of Vehicles	50
	PCN size	100 bytes
	IEEE 802.11p Range	300 m
VLC	Transmit Power / Packet Sensitivity	-60 dBm / -114 dBm
	Path Loss Exponent	2
	Headlight / Taillight Range	100 m / 30 m
	Angular Headlight Range	-45° $\sim$ 45°
	Angular Taillight Range	-60° $\sim$ 60°
CACC	Min. / Max. Speed	5 m/s / 20 m/s
	Max. Acceleration / Deceleration	3 m/s^2 / 5 m/s^2
	Platoon Size (numbers of vehicle)	5, 8, 10, 15, 20

The simulation scenario consists of a two-lane road with the leftmost lane reserved for multiplatoon. Vehicles enter the road from the right lane with Poisson distribution and an average of one vehicle every two seconds rate. Then, vehicles move to the leftmost lane to be part of the multiplatoon network. The mobility of the platoon leaders depends on the speed limit that varies between 5 and 20 m/s. Platoon members adjust their speed based on the platoon management data exchange, with the goal of following the speed of the leader vehicle and keeping a constant inter-vehicular space. For each scenario, three accident events are simulated in the right lane. When multiplatoon enters the coverage of PCN, it is delivered to multiplatoon based on the proposed safety message dissemination scheme. Table II lists simulation parameters.

A. *Packet Delivery Ratio*

Packet delivery ratio (PDR) is defined as the ratio of the number of vehicles successfully receiving PCN packet to the total number of vehicles within the target geographical area for dissemination of PCN.

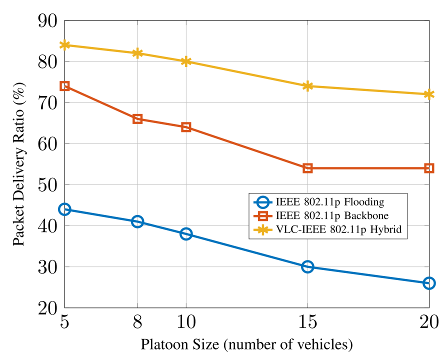


Fig. 2: PDR of different data dissemination schemes

Fig. 2 shows the PDR performance of different PCN dissemination schemes on multiplatoon as a function of platoon size. PDR has a tendency to decrease as the platoon size increases. Application level traffic causes medium contention on IEEE 802.11p and it increases the packet collision probability in *IEEE 802.11p Flooding* and *IEEE 802.11p Backbone*.

The PDR of *VLC-IEEE 802.11p Hybrid*, on the other hand, outperforms all the other dissemination schemes in all cases. The reason for the superior performance of VLC and IEEE 802.11p hybrid dissemination over the other schemes is the usage of VLC in intra-platoon data dissemination. VLC links cause limited or no inter-network interference and do not get affected by the channel congestion caused by application level traffic on IEEE 802.11p. However, as the platoon size increases, multiplatoon gets disconnected. Although the set of tail vehicles broadcast the PCN, it is not delivered to following platoons due to the limited transmission range of IEEE 802.11p.

B. *Packet Loss Ratio*

Packet loss ratio (PLR) refers to the ratio of the number of lost safety messages to the total number of safety messages subject to different volumes of background application data traffic. Application level data traffic is generated by each vehicle within the target geographical area for dissemination of PCN.

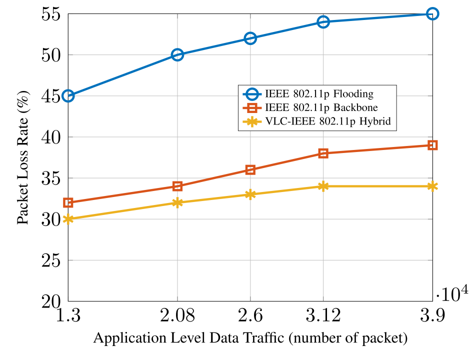


Fig. 3: PLR of different data dissemination schemes

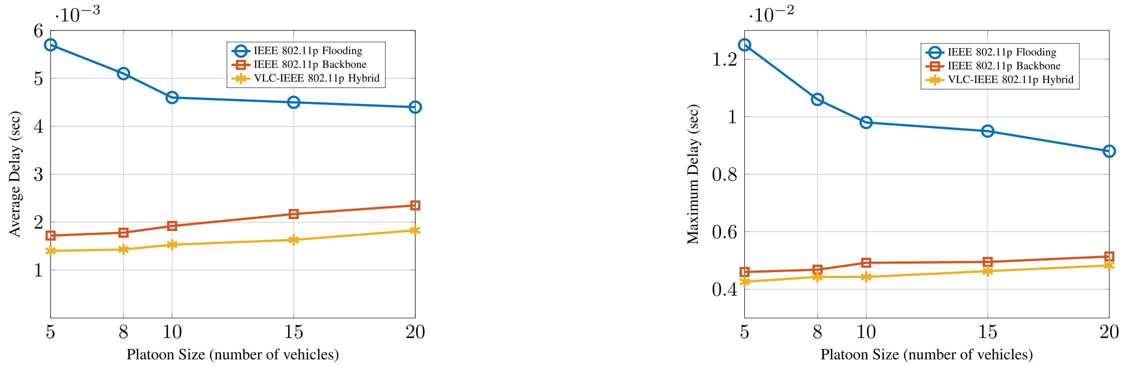
Fig. 3 shows the average PLR of the vehicles selected randomly within the target geographical area of PCN. As the application level traffic increases, PLR has a tendency to increase. Broadcast nature of *IEEE 802.11p Flooding* causes high PLR compared to *IEEE 802.11p Backbone* and *VLC-IEEE 802.11p Hybrid* schemes. Less number of PCN broadcasting in *IEEE 802.11p Backbone* decreases the PLR. PLR of *VLC-IEEE 802.11p Hybrid*, on the other hand, is below all the other dissemination schemes in all cases. Likewise, the main reason behind this is the utilization of VLC for safety message dissemination in multiplatoon. The directionality of light is beneficial in the vehicular VLC since the only small number of vehicles that are in direct LoS are in the same contention domain. When we consider this result together with Fig. 2, we observe that usage of VLC significantly increases the PDR and decreases the PLR compared to pure IEEE 802.11p based schemes.

C. *Delay*

The delay metric is defined as the time duration that the PCN travels from the source to the vehicles within the target geographical area of dissemination. The average is taken over all vehicles that successfully receive the PCN. The maximum delay, on the other hand, refers to the maximum latency of each PCN packet transmitted from the source to the vehicles within the target geographical area of PCN.

Fig. 4 shows the average and maximum delay of different PCN dissemination schemes as a function of platoon size. When these results are considered together with the PDR results of Fig. 2, we observe that there exists a trade-off between PDR and delay in terms of platoon size for *IEEE 802.11p Flooding*. As the platoon size increases the latency for PCN dissemination decreases whereas the *IEEE 802.11p Flooding* results in lower PDR.

In *IEEE 802.11p Backbone* and *VLC-IEEE 802.11p Hybrid*, on the other hand, as the platoon size increases, the delay has tendency to increase. As platoon size increases, the number of PCN transmission also increases in both *IEEE 802.11p Backbone* and *VLC-IEEE 802.11p Hybrid* to reach the set of tail vehicles. The delay of *VLC-IEEE 802.11p Hybrid*, on the other hand, is lower than the delay measured for all the other dissemination schemes in all cases. When we consider these results together with PLR results reported in Fig. 3, we can conclude that usage of VLC results in



(a) (b)

Fig. 4: Packet Delay Comparison (a) Average Delay (b) Maximum Delay

improved scalability in scenarios with high vehicle density where the IEEE 802.11p suffers from longer delays and higher PLR.

V. Conclusion and Future Work

In this paper, we proposed a VLC-IEEE 802.11p based safety message dissemination scheme and investigated the safety message dissemination schemes of pure IEEE 802.11p and hybrid VLC-IEEE 802.11p based multiplatoon for varying platoon sizes. We developed a simulation platform to model and evaluate the hybrid communication in multiplatoon. We show that IEEE 802.11p based multiplatoon safety message dissemination suffers from less PDR, longer delay and high PLR. Usage of VLC, on the other hand, significantly improves the performance that lowers the PLR and increases the scalability of safety message dissemination.

Future work would concentrate on designing a VLC-IEEE 802.11p hybrid safety message dissemination protocol for multiplatoon robust to the disconnected network. Such a protocol requires VLC communication for V2V to improve delay and reliability of safety message dissemination in high vehicle density, utilizing multi-metric mobile gateway selection for V2I communication when IEEE 802.11p gets disconnected and adopting a service migration scheme between gateways when the serving gateway loses its efficiency.

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