Joint Platoon Control and Resource Allocation for NOMA-V2V Communication System

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Abstract—**Platooning is considered as a promising technology in reducing fuel consumption, improving flow capacity to the future intelligent transportation system. Effective platoon control to maintain a stable platoon relies heavily on the vehicular communication performance. However, network resources become more limited due to the rapid growth in communication devices, and how limited network resources can be utilized to satisfy the platoon control demand becomes an emerging issue. To address this issue, in this paper, we investigate the problem of joint platoon control and resource allocation. Firstly, we model the relation between resource allocation and platoon control requirement based on the error bound and error correction ability. Non-orthogonal multiple access (NOMA) is introduced to support multiple vehicular users sharing a time slot, which improves resource utilization. A distributed control policy is applied based on the state estimation. Then, we propose an optimization problem to minimize total power consumption with control-related communication requirements and a two-staged algorithm to solve it. In the first stage, user scheduling is performed according to platoon control demands. With user scheduling determined, power allocation problem is directly solved in the second stage based on the NOMA decoding order. Finally, the result of experiments demonstrates that our proposed method is efficient in utilizing network resources to achieve effective platoon control.**

Index Terms—**Platoon Control, Network Resource Allocation, NOMA, Vehicle-to-Vehicle (V2V) Communication**

I. INTRODUCTION

In recent years, the rapid growth in vehicle numbers brings with serve traffic problems, such as traffic congestion, traffic accidents, air pollution and so on. Vehicle platoon is considered as an efficient way to solve the aforementioned problems by grouping and managing vehicles in a string [1]. Then, with reduced inter-vehicle distance and consistent behavior, platoons help to improve traffic efficiency and reduce fuel consumption. To achieve this goal and maintain a stable platoon, an effective platoon controller is strongly essential [1]. Generally, the vehicles in a platoon will periodically communicate with each other for information sharing via Vehicle-to-Vehicle (V2V) communications. Will acquired kinematic information about the other vehicles, one vehicle can regulate its velocity to maintain consistent inter-vehicle spacing. This then raise stringent requirements on communication performance for platoon control. Low reliability, high delay and low communication frequency will stop one vehicle from acquiring timely information [2]. The vehicle then fails to catch up with its desired state in time, and in the worst case, it may lead to collision. Besides, in the forecasting future internet, explosive growth in communication devices enlarge the limitation of network resources, such as frequency,

time slots and so on [3]. Without proper resource allocation, resources may be wasted and it becomes harder to satisfy the stringent control requirements. Hence, it is essential to investigate the relationship between platoon control and communication, and study how network resources can be wisely allocated to dedicated vehicular users in a platoon, according to their control demands and satisfying the communication requirements.

Nevertheless, researchers studied platoon control or resource allocation for vehicular communication separately in the past decades. For platoon control, [4] and [5] focus on guaranteeing the platoon stability. Prescribed performance control is applied in [4] to improve transient performance. A novel scalable platoon controller is proposed in [5]. It supports a resilient platoon under different information flow topologies and spacing policies. However, the aforementioned work assumed perfect network condition. They neglect the essential impact of vehicular communication on platoon control. Besides, for vehicular communication, [6] and [7] focus on efficient resource allocation. In [6], NOMA is applied to improve spectrum efficiency in platoon-based vehicular communications. In [7], a centralized resource allocation and distributed power control scheme is designed to improve the energy efficiency in a NOMA-Integrated Vehicles-to-Everything (V2X) networks. However, they only focus on improving communication performance, and ignore the requirement of platoon control on communications. Recently, few work have been conducted to study the problem of joint platoon control and communication. Considering a LTE-V2V network, in [8], joint resource allocation and control scheme is determined through allocating resources based on the tracking error rank. Model predictive control (MPC) is introduced in [9] to maintain desired spacing, while joint resource allocation and platoon control is considered under resource-constrained conditions. A joint platoon parition and resouce allocation method is proposed in [10] to yield a larger vehicle-to-infrastructure capacity. However, the control requirement on resources were not clearly modeled and considered in these work, which may lead to resource wasted or under-allocated. Besides, their control performance are limited by under-utilized resources with only conventional orthogonal multiple access (OMA) technologies applied.

To address the aforementioned issues, in this work, we study the problem of joint resource allocation for NOMA-V2V communications and platoon control. Considering a NOMA-V2V system, radio resources such as communication time slots are periodically allocated to different vehicles according to their control demands. We propose a mechanism
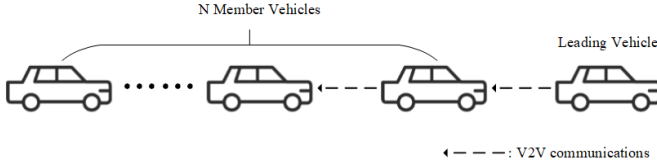
Fig. 1. Platoon description

to determine ones' control demand based on its spacing error, error bound and error correction ability. Besides, NOMA is applied to support multiple users sharing one time slot, which improves the resource utilization. Basing periodical information sharing via V2V communication, a distributed control policy is adapted at individual vehicle to reduce its tracking error, based on the estimation of desired state according to resource allocation scheme. Then, we formulate an optimization problem to minimize total power consumption, which is solved in two stage. In the first stage, the user scheduling scheme is determined according to control demand. Power allocation scheme is solved in the second stage based on the NOMA decoding order. Finally, experiments are conducted to evaluate the performance of our proposed method in terms of both communication aspects and control aspects. The result demonstrated that our proposed method is efficient in utilizing network resources to achieve effective platoon control and outperforms other existing methods.

The paper is organized as follows. Section II presents the system model and problem formulation. In Section III, the two-staged resource allocation method is proposed. Section IV gives the performance analysis of the proposed algorithm. Finally, the conclusion of this paper is presented in Section V.

II. SYSTEM MODEL

We consider a platoon consisting of 1 leading vehicle (LV) and N member vehicles (MVs) as shown in Fig. 1. The vehicles are homogeneous and of the same length l. The platoon is assumed to run on a straight line. We focus on the longitudinal control of MVs to maintain the desired velocity and spacing. The desired velocity is the same as the velocity of the LV. Constant Spacing (CS) policy is adapted and the desired spacing is set as d. For this goal, MVs need to acquire information that helps them track the desired state. As illustrated in Fig.1, each MV is allowed to communicate with its predecessor to acquire information via direct V2V communications. The predecessor send its state information, e.g., its position and velocity, to the MV. Then, the MV can use the state information to derive its desired state and adjust its control input to track it. This also helps to guarantee the safe spacing to avoid collision. This system is assumed to work in continuous time slots, denoted as $[0, 1, 2, ..., t-1, t, t+1, ...]$. The duration of a time slot is Δt. A MV is allowed to communicate with its predecessor at a specific time slot. However, it is impracticable and infeasible to allocate proper resources for communication before every time slots. Hence, we group every successive T time slots into a scheduling period. For example, $[0, 1, 2, ..., t, ..T-1]$ is the first scheduling period. Then, before each scheduling period, a centralized manager, which could be the base station, road side unit, the LV and so on, will allocate proper resources

to the communications among the platoon and broadcast the resource allocation scheme to all MVs.

A. Vehicle Dynamics

We apply the following second-order kinematic model to describe vehicle's dynamics,

$$\dot{p}_i = v_i \tag{1}$$
$$\dot{v}_i = u_i \tag{2}$$

where p_i, v_i and u_i are the position, velocity and control input of vehicle i ($i = 0, 1, 2, ..., N$, $i = 0$ denotes the LV) respectively.

Then, we utilize a time-discrete state model to describe the vehicle dynamics in continuous time slots. Denote the state of vehicle i at the beginning of time slot t as $\{p_i^t, v_i^t, u_i^t\}$. As well, we can denote the tracking error of MV i at the beginning of time slot t as $e_i^t = [e_{i,v}^t, e_{i,p}^t]$, where $e_{i,v}^t$ and $e_{i,p}^t$ are the velocity error and position error with regarded to its predecessor respectively. We have,

$$e_{i,v}^t = v_i^t - v_{i-1}^t \tag{3}$$
$$e_{i,p}^t = p_{i-1}^t - p_i^t - d - l \tag{4}$$

The evolution of vehicle dynamics can be expressed using following equations,

$$v_i^{t+1} = v_i^t + u_i^t * \Delta t \tag{5}$$
$$p_i^{t+1} = p_i^t + v_i^t * \Delta t + \frac{1}{2} u_i^t * (\Delta t)^2 \tag{6}$$

For the LV, its control input is commanded as given. For the MVs, their control inputs are generated according to our proposed control policy, which will be discussed lately.

B. NOMA-V2V Communications

In a scheduling period, each MV could be allocated to one or more time slots. At an allocated time slot, its predecessor send messages to the MV via a V2V link. However, available time slots in a scheduling period is limited, and may fail to satisfy the total control demand of a platoon. Hence, to further improve spectrum frequency, we introduce NOMA [11] for user multiplexing. With power-domain NOMA applied, multiple users are allowed to transmit simultaneously in the same time slot with different power level. Then, at the receiver side, using signal interference cancellation (SIC), one can decode the signal stronger than its own signal, and detect its own signal with the remain weaker signals as interference. With proper resource allocation, the number of allowed communications within a scheduling period could be improved to serve the platoon control demands.

We use a binary value o_i^t ($i = 1, 2, ..., N$) to denote the user scheduling scheme, where,

$$o_i^t = \begin{cases} 1 & \text{MV } i \text{ is scheduled at time slot } t \\ 0 & \text{otherwise} \end{cases} \tag{7}$$

Once MV i is scheduled at time t, it will receive the state information of its predecessor, in other words, $\{p_{i-1}^t, v_{i-1}^t, u_{i-1}^t\}$, at time t.

Due to the limitation of the hardware SIC design [6], we need to restrict the number of allowed users occupying the same time slot, which can be expressed as,

$$\sum_{i=1}^{N} o_i^t \leq o^{max} \tag{8}$$

In existing researches, the user scheduling scheme is mainly determined to improve communication performance. However, this neglects the impact of user scheduling on platoon control performance. The platoon control demand may not be well served. Indeed, for a MV with different level of error, it need different times of communications to satisfy its control demand. To model this relationship, we introduce f_i as the communication frequency of MV i during a scheduling period, which means how many time slots are allocated to MV i for its communications in a scheduling period. Then, we can derive f_i using following equations,

$$
f_i = \begin{cases} 0 & |e_{i,p}| \le e^{th} \\ min\{\frac{|e_{i,p}|}{\frac{1}{T} \cdot \frac{1}{2} u^{max}(T\Delta t)^2}, \frac{o^{max} \cdot T}{N}\} & |e_{i,p}| > e^{th} \end{cases}
$$

$$(9)$$

where e^{th} is the error bound and o^{max} is the maximal number of allowed users in a single time slot. MV i is considered to be stable if its spacing error $|e_{i,p}|$ at the beginning of a scheduling period is lower than the error bound. Otherwise, it needs to communicate with its predecessor to acquire information that helps it get stable. Then, f_i is determined according to the ratio between its spacing error and the error correction ability. The error correction ability is represented by the average gained (or reduced) distance under maximal control input with regarded to zero control input for a period in a single time slot. To guarantee user fairness, f_i is also limited to average allowed time slots allocated to a single MV in a period. In this way, proper time slots can be wisely allocated to each MV according to their control demands.

Then, the number of allocated time slots to MV i at time slot t should satisfy the following constraint,

$$
f_i = \sum_t^T o_i^t \tag{10}
$$

To fulfill the reliability requirement of a successful communication in a single time slot, proper power should be allocated to a NOMA-V2V link. Denote p_i^t as the power allocated to the V2V link between vehicle $i-1$ and MV i at time slot t. The signal-to-interference-plus-noise ratio (SINR) at the receiver side can be expressed as,

$$
\Gamma_i^t = \frac{o_i^t p_i^t h_{i,i-1}^t}{I_i^t + N_0} \tag{11}
$$

where N_0 denotes the Gaussian noise. $h_{i,i-1}^t$ is the channel gain from sender $i-1$ to MV i. Considering the high mobility of vehicles, the channel suffers from Rayleigh fading and path loss [6]. Besides, to improve resource utilization, it is assumed that the platoon share the channel with cellular users. Hence, I_i^t, the interference to MV i at time slots t, includes potential interference from both other MVs and cellular users occupying the same time slot.

To ensure that a V2V communication can be successfully completed in a time slot, the SINR for MV i should exceed the threshold R^{th}, which is expressed as,

$$
\Gamma_i^t \ge o_i^t R^{th} \tag{12}
$$

The power allocated to a V2V communication is also limited, which is expressed as,

$$
0 \le p_i^t \le p^{max} \tag{13}
$$

C. Distributed Control Policy

With received information from its predecessor, one MV can derive its desired state and generate control input to track it according to the control policy. Unlike [8] and [9], we apply the control policy in a distributed way. Each MV generate its control input individually based on its received information at each time slot. Then, the huge computation load on a single point can be released and the issue of single point failure can be alleviated.

Because one MV can not be scheduled at each time slot, we propose an estimation mechanism for it to estimate the state of its predecessor at each time slot based on the historical received information. Assume MV i receive the state information of its predecessor, $\{p_{i-1}^{t'}, v_{i-1}^{t'}, u_{i-1}^{t'}\}$, at time slot t'. MV i will assume that its predecessor keep its control input unchanged in the following time slots. Then, in following time slots that MV i receives no new information, it will estimate the state of its predecessor at a specific time slot t $(t \ge t')$ according to following equations,

$$
p_{i-1,est}^t = p_{i-1}^{t'} + v_{i-1}^{t'}(t - t')\Delta t + \tag{14}
$$
$$
\frac{1}{2}u_{i-1}^{t'}(t - t')^2\Delta t^2
$$
$$
v_{i-1,est}^t = v_{i-1}^{t'} + u_{i-1}^{t'}(t - t')\Delta t \tag{15}
$$

Then, MV i can estimate its tracking error $e_{i,est}^{t+1} = [e_{i,v,est}^{t+1}, e_{i,p,est}^{T+1}]$ at time slot $t + 1$, which is expressed as,

$$
e_{i,v,est}^{t+1} = p_{i-1,est}^{t+1} - p_i^t - v_i^t\Delta t - \tag{16}
$$
$$
\frac{1}{2}u_i^t\Delta t^2 - d - l
$$
$$
e_{i,p,est}^{t+1} = v_{i-1,est}^{t+1} - v_i^t - u_i^t\Delta t \tag{17}
$$

To minimize the estimated tracking error, u_i^t, the control input of MV i at time slot t can be generated through solving the following optimization problem,

$$
\min \quad e_{i,est}^{t+1} W e_{i,est}^{t+1\ T} \tag{18}
$$
$$
\text{s.t.} \quad u^{min} \le u_i^t \le u^{max} \tag{19}
$$

where W is a positive-diagonal weight matrix.

The problem (18) is equivalent to a standard form of quadratic programming with linear constraint. Hence, it can be effectively solved using many existing solvers [12], or using Lagrangian method with Karush-Kuhn-Tucker (KKT) conditions. For brevity, the solution is omitted here.

D. Problem Formulation

The resource allocation scheme, including user scheduling scheme O and power allocation scheme P, should be determined before each scheduling period. In this work, the goal is to effectively utilize network resources to maintain a stable platoon. Hence, The optimization problem is formulated to minimize total power consumption while guaranteeing both control-related communication constraints and communication quality constraints. It can be expressed as,

$$
\min_{\{O,P\}} \sum_t^T \sum_{i=1}^N o_i^t p_i^t \tag{20}
$$
$$
s.t. : (8), (10), (12), (13)
$$

III. TWO-STAGED RESOURCES ALLOCATION METHOD

A. User Scheduling

The communication frequency of one MV is already determined according to the control demand. Besides, the allocation order, i.e., which time slot should be allocated to one MV during a scheduling period, should also be determined according to the control demand. This is because the interval between two allocated time slots will also affect control performance. For example, a short interval between two adjacent communications for a MV will reduce the effectiveness of the first communication, and hence results in waste of network resources. A long interval will make the MV less sensitive to the changes in desired state, and hence results in unsatisfied control performance. As a result, it is essential to perform user scheduling at first according to control demand.

Assume that MV i is allocated to communicate every c_i time slots averagely in a scheduling period. Similar to f_i, c_i can be determined according to the ratio between the total error correction ability in a period and spacing error as below,

$$c_i = \begin{cases} 0 & |e_{i,p}| \leq e^{th} \\ \frac{\frac{1}{2}u^{max}(T\Delta t)^2}{|e_{i,p}|} & |e_{i,p}| > e^{th} \end{cases} \quad (21)$$

where the total error correction ability is represented by the total gained (or reduced) distance under maximal control input with regarded to zero control input in a control period. Then, for a receive message informing error as $|e_{i,p}|$, it is estimated that averagely after c_i time slots the error is eliminated and a new communication is needed to be allocated, so that MV i can update its desired state and track the new one. When $|e_{i,p}| > e^{th}$, $c_i = \frac{T}{f_i}$. Then we can acquire c_i when f_i is determined.

Then, assume that t_1 is the first time slot allocated to MV i in a scheduling period, the desired allocation array for it should be $[t_1, t_1 + c_i, t_1 + 2*c_i, \ldots, t_1 + (f_i - 1)*c_i]$. The selection of the first time slot to be allocated at this control period depends on the last allocated time slot of MV i in the previous scheduling periods. Assume the latest allocated time slot fo MV i in the previous scheduling periods as t_l. If $(t_l + c_i) \bmod T < T$, set t_1 as 1. Otherwise, set t_1 as $(t_l + c_i) \bmod T$.

However, due to the limitation of allowed user in a single time slot, we can't always allocate the desired time slot to MV i. In that case, we will tempt to find a candidate time slot for communication. Assume that MV i is already allocated to a time slots, we will determine the allocation of $a + 1$-th communication in the following steps.

1) Select $max\{t_a + c_i, T\}$ as the desired time slot to be allocated. If the number of allocated users in this time slot is less or equal to the maximal allowed number minus 1, we allocate MV i at the time slot.
2) Otherwise, we need to find candidate time slots for allocation. Denote the candidate time slot array as $[t_a+c_i-1, t_a+c_i+1, t_a+c_i-2, t_a+c_i+2, \ldots, t_a+1, T]$, which means we would like to search for candidate time slot arround the desired time slot in a "Z" shape. If a time slot can be allocated, we allocate MV i at this time slot.
3) If it reaches the required number of allocated time slots for MV i or it is at the end of the control period, exit. Otherwise, add the newly allocated time slot into allocated time slot array, and back to the (1).

In sum, the complete procedure of user scheduling is presented in Algorithm 1. To ensure effective information flow from front to end of the platoon, we determine the user scheduling scheme of each MV in the platoon according to Algorithm 1 one by one in an ascending order.

Algorithm 1 User Scheduling

Input: spacing error $|e_{i,p}|$, error bound e^{th}, last scheduled time slot t_l, length of a scheduling period T
Output: user scheduling scheme $\boldsymbol{O_i}$
1: **procedure** USER SCHEDULING OF MV i IN A SHCEDULING PERIOD
2:      Initialize user scheduling scheme $\boldsymbol{O_i} = \boldsymbol{0}$.
3:      **if** $|e_{i,p}| \leq e^{th}$
4:          Break.
5:      **else**
6:          Initialize allocated number $a = 0$, next desired
7:          time slot $t_n = 1$, f_i according to (9), $c_i = \frac{T}{f_i}$.
8:          **if** $(t_l + c_i) \bmod T > T$
9:              $t_n = (t_l + c_i) \bmod T$.
10:         **while** $a \leq f_i$ or $t_n \leq T$ **do**
11:             **if** t_n can be scheduled
12:                 $o_i^{t_n} = 1$.
13:                 $a = a + 1$.
14:                 $t_n = t_n + c_i$.
15:             **else**
16:                 Initialize candidate time slot array $\boldsymbol{C}$.
17:                 Update t_n as the first available time
18:                 slot in $\boldsymbol{C}$.
19:         **end do**
20: **end**

B. Power Allocation

With user scheduling scheme determined, the original problem (20) degrade and can be decoupled into T sub problems, as the power allocation of users in different time slots do not affect each other.

$$\sum_{t}^{T} \min_{\{\boldsymbol{P}\}} \sum_{i=1}^{N} p_i^t \quad (22)$$
$$s.t. : (12), (13)$$

To solve the power allocation problem of a NOMA-V2V network, it is essential to determine NOMA decoding order. According to NOMA principle [13], the optimal decoding order for maximizing system throughput in a down-link NOMA network is the ascending order in channel gain. However, this can not be directly applied in our NOMA-V2V network, where there are multiple unicast NOMA communications. Theorem 1 state the optimal decoding order for our case.

Theorem 1. *For a platoon-based NOMA-V2V network where there are only unicast communications between one vehicle and its predecessor, the optimal decoding order for NOMA is the ascending order in interference channel gain.*

To prove Theorem 1, we start from a case with only two users allocated at the same time slot to communicate with their predecessors. Assume the MVs allocated at the same time slots are MV j and MV k, $j < k$. The channel gains between MV j and its predecessor and that between MV k and its predecessor are $h_{j-1,j}$ and $h_{k-1,k}$, respectively. The

interference channel gain for MV j from MV k's predecessor is $h_{j,k-1}$, and the interference channel gain for MV k from MV j's predecessor is $h_{j-1,k}$. The common part of interference from other cellular users is omitted here. According to the channel characteristics [6], longer communication distance leads to smaller channel gain. As $d_{j,k-1} < d_{j-1,k}$, we can assume that $h_{j,k-1} > h_{j-1,k}$, which means the interference channel gain of MV j is larger than that of MV k.

Then, we consider two different decoding order, the first is in the ascending order of interference channel gain, and the second is in the decreasing order of interference channel gain. In the first choice, we have $p_j^1 < p_k^1$, and the total power consumption is,

$$p_{total}^1 = p_j^1 + p_k^1 = \frac{R^{th}N}{h_{j-1,j}} + \frac{R^{th}(p_j^1 h_{j-1,k} + N)}{h_{k-1,k}}$$

where to minimize the power consumption, we allocate corresponding power to each MV guaranteeing the achievable SINR just equals to the threshold.

In the second choice, we have $p_j^2 > p_k^2$, and similarly, the total power consumption is,

$$p_{total}^2 = p_j^2 + p_k^2 = \frac{R^{th}(p_k^2 h_{j,k-1} + N)}{h_{j-1,j}} + \frac{R^{th}N}{h_{k-1,k}}$$

Compare p_{total}^1 with p_{total}^2, we have,

$$p_{total}^1 - p_{total}^2 = (R^{th})^2 N \frac{h_{j-1,k} - h_{j,k-1}}{h_{j-1,j}h_{k-1,k}} < 0$$

Hence, lower power consumption is achieved with decoding order in ascending order of interference channel gain, which prove Theorem 1 under the case where only two users are scheduled at the same time slot. The proof under cases where there are more users allocated at the same time slot is similar. As in current literature, it is mostly considered that at most two users are allocated to share a resource block due to the complexity and cost in hardware design, we don't prove Theorem 1 for a general case at present.

With decoding order determined, it is then easy to solve problem (22). Assume we need to allocate power for M MVs that are allocated at the same time slot. Denote them as $\{1, 2, .., M\}$ sorted in descending order of interference channel gain. The power allocated to them can be greedy calculated as,

$$p_1 = \frac{R^{th}N}{h_1}$$
$$p_2 = \frac{R^{th}(p_1 h_{1,2} + N)}{h_2}$$
$$...$$

where each MV is allocated power to guarantee that its achievable SINR just equal to the threshold. As well, we will check whether the allocated power exceed p^{max}. If so, we set the allocated power to be p^{max} and this communication is considered to be failed.

IV. PERFORMANCE EVALUATION

In this section, we illustrate the performance of our proposed method using Python 3.8. We perform the simulation under a perturbation scenario [8]. A platoon is assumed to run on a highway at cruise velocity. Suddenly, it observes a slow moving vehicle ahead and need to decelerate to avoid collision. When it goes through the obstacle, it accelerates to its cruise velocity. To be specific, the simulation time window is $30s$. The LV decelerates from $20\ m/s$, which is the cruise velocity, to $15\ m/s$ during $[0s, 10s]$ with constant acceleration as $-1\ m/s$. Then, during $[15s, 25s]$, the LV accelerates to $20\ m/s$ with constant acceleration as $1\ m/s$. $[0s, 10s]$ and $[15s, 25s]$ are considered as the changing state when the desired state of all MVs changes. $(10s, 15s)$ and $(25s, 30s]$ are considered as the steady state when the desired state of all MVs keep unchanged and the whole platoon should remain stable. In this simulation, network resources such as time slots and power should be properly allocated to each MV to help them track the changing desired state and maintain a stable platoon. The other parameters are summarized in Table I.

TABLE I
PARAMETER SETTINGS

Parameter	Value
Length of time slot, Δt	$10\ ms$
Length of scheduling period, T	10
Channel bandwidth	$180\ KHz$
Noise	$-174\ dBm/Hz$
Maximum power, p^{max}	$35\ dBm$
SINR threshold, R^{th}	$10\ dB$
Maximum allowed users, o^{max}	2
Vehicle length, l	$5\ m$
Desired spacing, d	$10\ m$
Maximum control input, u^{max}	$2\ m/s^2$
Minimum control input, u^{min}	$-2\ m/s^2$

We conduct experiments to demonstrate the effectiveness of our method and compare it with other existing methods. We consider a large platoon whose size is 12. Error bound is set as 0.01. Our proposed method is compared with three existing methods: a) NOMA-NC, proposed in [7], maximizes total system transmission rate, but does not take platoon control into consideration. b) OMA-C, proposed in [8], allocates more network resources to the vehicle with larger tracking errors. However, it only adapts OMA technology. c) OMA-MC, proposed in [9], adapts an model predictive controller with the same allocation method with OMA-C. In this experiment, we measure the number of allocated communications, power consumption and successful communication rate to evaluate the resource utilization, and measure the average absolute spacing error to evaluate the platoon control performance. The results are presented in Fig. 2-4.

Fig. 2 presents the cumulative total allocated communications of the whole platoon during the simulation under different methods. Compared with the methods using OMA, our proposed method is able to allocate more communications to the platoon for control needs. Compared with the method using NOMA but no considering control, our proposed method is able to allocate communications according to control needs in different stages. Fig. 3 presents the cumulative total power consumption of the whole platoon during the simulation under different methods. Our proposed method achieves the lowest power consumption compared with the method using NOMA, which utilize more power to achieve higher transmission rate, and the methods using OMA, which allocate fixed power to each communication.

Fig. 4 presents the average absolute spacing error during the simulation under different methods, which reflects the
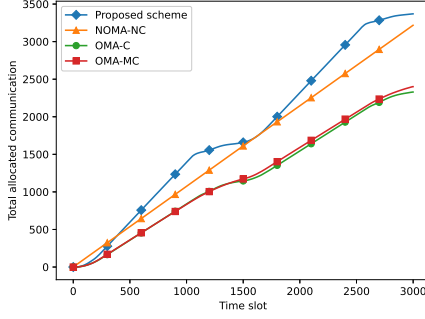
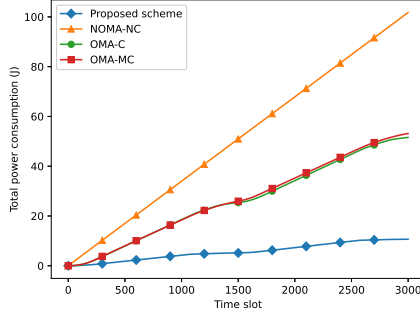Fig. 2. Total allocated communication under different methods

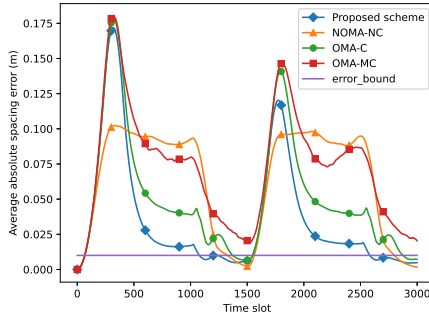Fig. 3. Total power consumption under different methods

Fig. 4. Average absolute spacing error under different methods

control performance of them. Compared with NOMA-NC, though the average spacing error under our proposed method reaches a higher peak at the beginning, it keeps at the much lower value at the rest time during the changing state. Besides, under our proposed method, the platoon converges to stable faster than that under NOMA-NC in steady state. Compared with OMA-C and OMA-MC, the average spacing error under our proposed method keeps lower in the whole simulation. Besides, under our proposed method, the platoon converges to stable much faster than those under OMA-C and OMA-MC in steady state. Hence, our proposed method outperforms than the comparing method in terms of control performance.

In sum, NOMA-NC utilize much more network resources, but the control performance does not improve accordingly as this method doesn't consider platoon control. Though OMA-C and OMA-NC consider the need of platoon control to allocate resources, they don't measure the control need exactly and only apply OMA technolgy. These make them

fail to effectively utilize network resources to achieve good control performance. Compared with these existing methods, our proposed method is showed to be able to utilize network resources much effectively to achieve better control performance.

V. CONCLUSIONS

In this paper, we have investigated the relationship between platoon control and network resource allocation. Then, we manage to allocate network resources to the platoon member exactly according to their control needs. Besides, NOMA is also applied to improve resource utilization. An optimization problem is formulated to minimize total power consumption to save network resources, and a two-stage algorithm is proposed to solve it. Finally, the experiments are conducted to evaluate the performance of our proposed method, compared with other existing methods. The result shows that our proposed method is effective in utilizing network resources to maintain a stable platoon.

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