Delay Optimization for URLLC in Software Defined Networks: A Case Study on Platooning

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***Abstract*—The autonomous driving in a platoon network requires reliable data transfer and strict latency on downlink traffic. These two requirements have been addressed in 5G under the Ultra-Reliable Low Latency Communication (URLLC) specification. In this study, we focus on this 5G service, and we design a novel Software-Defined Platoon Network (SDPN) to optimize the end-to-end Delay (e2eDelay). Our SDPN defines the e2eDelay in a closed-form expression that covers Data and Control planes. To optimize e2eDelay, we propose a Mixed Integer Linear Problem (MILP) that jointly considers the constraints in the vehicle to vehicle (V2V) and the vehicle to infrastructure (V2I) links. Due to the NP-hard characteristic of our MILP optimization and to reduce the computational complexity of the optimization at the same time, we propose a novel Centralized Set Cover algorithm that finds the optimum set cover of vehicles by building platoons. According to the results, our SDPN serves e2eDelay under 3.5 msecs with a 45% improvement over the conventional approach.**

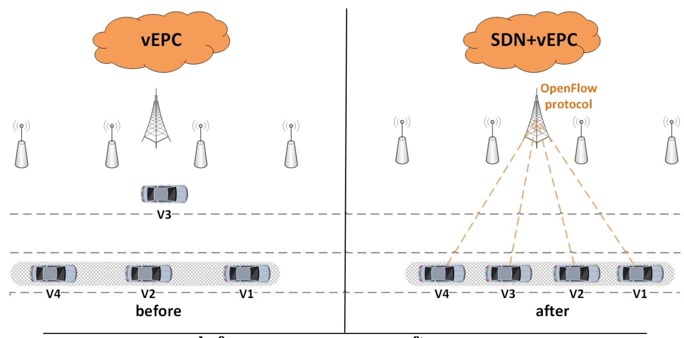
Keywords–SDN; URLLC; e2eDelay; Platooning; MILP.

I. Introduction

According to the European Commission, the carbon emission has been aimed to decrease the fuel-consumption in transportation by 60% level by 2050 [1]. To reduce it, ”eco-driving” is newly defined as avoiding aggressive acceleration, keeping optimal space, driving in steady-state speed according to road dynamics [2]. Therefore, this has led us to investigate a new Intelligent Transport Systems (ITS) with higher fuel efficiency in highways with an approach: *Platooning*.

In a platoon, there is one leader and there are also followers just behind it. Thanks tothe vehicle to infrastructure (V2I) link, a leader takes the dynamic rules for traffic flow control and accident data from the remote control center in virtual Evolved Packet Core (vEPC). By vehicle to vehicle (V2V) link, the leader forwards these rules to the following vehicles [2]-[4].Therefore,it decreases fuel consumption in different road dynamics enhances traffic efficiency and ensures safety by controlling the space between vehicles [2]. Such a fully automated driving in a platoon requires reliable data transfer and strict latency in downlink traffic flow during mobility. Here,this flow is called Ultra-Reliable Low Latency Communication (URLLC) in 5G services [3].

According to International Mobile Communications (IMT-2020), URLLC services require a radio-latency of 1 msec and an end-to-end Delay (e2eDelay) of a few msecs [4] [5]. E2eDelay is measured by the concatenation of V2V and V2I communications in the downlink URLLC service from a remote source to a vehicle. Therefore,by considering both edge and core in the platoon networks, we study e2eDelay into two parts as V2V and V2I.



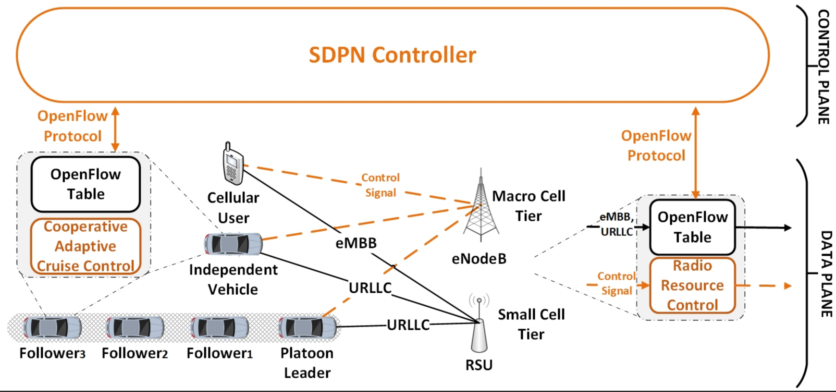
	before	after
Approach	AdHoc	Centralized
Comm. Tech.	DSRC, IEEE 802.11p	4G+5G, OpenFlow with SDN
Traffic Type	Reliable Data Transfer	URLLC

Figure 1. The Comparison of Vehicle Platooning Approaches.

A. Problem Definition

For V2V case, Figure 1 showstwo proposed approaches for platooning. Before,there has been an AdHoc approach that vehicles communicate with each other by Dedicated Short-Range Communication (DSRC) over IEEE 802.11p. A vehicle platoon has been built locally according to the vehicle-centric decision. There are many studies that try to build a platoon via an AdHoc approach [6] [7]. However,there have been such challenges as frequency reuse and interference between vehicles during the V2V communication and platoon building. Under extremely increased 5G background traffic [8], these challenges cause many packet retransmissions and this negatively affects the e2eDelay of URLLC service [9]. Therefore,the platoon should be built as long as possible by decreasing the number of independent vehicles exemplified as V3 in the figure. However,the size of the platoon cannot increase after a certain level because of depending AdHoc approach. To overcome these problems, the centralized orchestration of platooning and control of the vehicles are required.

Thanks to the global view of the centralized controller, an optimal platoon can be built that offers such advantages: The fuel efficiency is increased for the whole vehicular network. The frequencies per vehicle can be assigned to them previously from a centralized pool, and therefore,the data transfer would become reliable without any packet retransmission in a platoon [10]. Therefore,a centralized approach for the vehicle platooning is taken into consideration.



User Type	Application	5G Traffic	Velocity	Mobility Characteristic
Platoon Vehicle	Fully Automated Driving	URLLC	50-130 km/h	Fluid-Flow Direction
Independent Vehicle	Fully Automated Driving	URLLC	50-130 km/h	Fluid-Flow Direction
Cellular User	Video Content Apps	eMBB	0-2 km/h	Random Way Point

Figure 2. System Architecture and User Types in Proposed SDPN.

However,the centralized approach is only seen in 3% of the recent studies that try to solve such platooning challenges in the literature. The main reason for it is the lack of V2I technology investments in 5G [11]. Therefore,to keep the advantages of the centralized approach, we investigate also the V2I part of URLLC services in the platoon networks. In V2I part,the load in vEPC has increased because there is huge traffic intensity on core network [8] and the whole signaling of the platoon is now routed over V2I as mentioned in Figure 1. Therefore,the closed-form expression of e2eDelay is also proposed with a traffic load effect due to increasing the queuing and processing delay in the core devices.

B. Contributions

We propose a Software-Defined Platoon Networks (SDPN) that considers both Data and Control parts of URLLC services. It optimizes e2eDelay (D) with a Mixed Integer Linear Problem (MILP) for platoon networks by jointly considering V2V and V2I constraints. Thanks to the global view of SDPN, it builds an optimal platoon as long as possible. The decisions are embedded in each dummy devices without touching the physical plane with open source OpenFlow(OF) protocol. The whole contributions can be found below:

- A novel closed-form expression of e2eDelay (D) by covering Data and Control Planes,
- A MILP that jointly considers the constraints in both V2V and V2I links,
- A novel Centralized Set Cover for Platooning algorithm to optimize e2eDelay.

The rest of the paper is organized as follows: Section II gives the proposed system architecture of SDPN by considering the mathematical model of e2eDelay in terms of Data and Control Planes. Section III shows the comparison of proposed and conventional model in terms of e2eDelay (D). Finally, Section IV concludes the paper by giving summary.

II. Proposed System Architecture of SDPN

The system architecture of SDPN is shown in Figure 2. The Data and Control planes are separated from each other. Data plane includes two tiers. In small cells and macrocells, end-users are served over RSUs (5G) and eNodeBs (4G), respectively. There is a Dense-Urban (eMBB-UMx) [12] topology in Data Plane. It is based on four outdoor small cells per macrocells. The end-users have Control and Data signals to keep communications alive. Control signals, shown in dashed line,are routed over macrocells; whereas, Data signal shown in solid line, can be served over small cells.

A. Data Plane

In this paper, there are three user types named as platoon vehicle, independent vehicle and cellular user. A vehicle can be a platoon vehicle as either a platoon leader or follower in a platoon.The cooperative automation system in a platoon requires highly reliable service and ultra-low latency during this communication. Then,we assume predecessor-leader controller strategy in V2V communication. The leader communicates via V2I to take fully automated driving data over URLLC traffic type and also forwards it to the followers via V2V links in a platoon. Follower vehicle only communicates with the preceding one to know its relative position and to take road characteristics. For those vehicles, we only consider vehicle communication by ignoring end-user in a car who can generate multimedia traffic; i.e., eMBB.

In highways, the velocities are assumed as uniformly distributed between 50-130 km/h. In this study,we consider the speed limits in the German Autobahn road network (130 km/h). Then,the mobility characteristic is determined as Fluid-Flow direction. The reason for it is that the fuel-efficiency of platooning only makes sense in highways. According to Larsson et al. [1],the long and low-traffic roads are mostly suitable for platooning. Therefore, it is not preferred to use in the dynamic road characteristics with multi-lane scenarios. Moreover,the independent vehicle is a vehicle that communicates via V2I to take fully automated driving data over URLLC traffic. Here, it has no V2V communication around. Its velocity and mobilitycharacteristics are the same as platoon vehicles on highways. On the other hand,there are cellular users as background traffic in Core. They run video content applications over mobile-devices, which generates eMBB traffic. Due to being pedestrian, the velocity is assumed as uniformly distributed between 0-2 km/h. The mobility characteristic is determined as Randow WayPoint. The total number of the users is defined as N.

Each vehicle, macrocells, and small cells have also OpenFlow (OF) switch capability to communicate with Control plane via OF protocol. In the Data plane, each OF device has two main layers, such as Radio Resource Control (RRC) and OF table. Control signaling is performed via the RRC

TABLE I. AN EXAMPLE OPENFLOW SWITCH TABLE IN SDPN.

Match Fields				ACTION	STATISTICS
IN_PORT	IP_PROTO	IP_SRC	IP_DST	Output	TX Packets
port1	6 (URLLC)	10.0.0.1	10.0.0.3	port3	5260759
port2	17 (eMBB)	10.0.0.2	10.0.0.4	port4	34506

layer for assigning to radio resources. The resources for RSUs, eNodeBs, and vehicles are previously allocated from a resource pool. Especially in a platoon, it enables short inter-vehicle distance and low transmission power to enable spatial reuse of V2V links [13]. Moreover,the handover is only performed during inter-macrocell transitions.

URLLC and eMBB traffics are routed according to embedded rules in OF table as exemplified in Table I. The match fields of OF table include 44 components in OF basic class that can be matchable with the incoming packet header. This part is in OpenFlow Extensible Match (OXM) format, which is also defined as type-length-value (TLV) format and it has 5 to 259 bytes long [14]. In each OF table as exemplified in Table I, we consider statistics parts to take data periodically; such as user type, traffic load (ρ), current position and velocity. Firstly,the user type is defined according to the protocol type of the matched field which is directly mapped with URLLC and eMBB services. We differentiate the traffic flows according to the protocol number of IP packet (IP Proto=6 for TCP based URLLC, IP Proto=17 for UDP based eMBB). These flows should also match with such fields: Ethernet type (0x800 IP packet), different Ethernet source, destination, and different IPv4 source, the destination address in OF table. Secondly, the counter of TX packets is directly used to calculate traffic load (ρ) per OF switch. Thirdly, the current position of a mobile user is determined if the related flow is matched with specific OF switch (The static position of RSUs is already known). Finally, the velocity of end-user can be easily calculated by using periodically taken statistics, which will be used while building a platoon.

B. Control Plane

Control plane has centralized SDPN controller. It calculates proposed e2eDelay (D) per URLLC services and runs the proposed e2eDelay optimization algorithm by considering the whole topology thanks to the global view. It takes statistics via OpenFlow protocol 1.5.1 for each period of time. As a result; according to the output of SDPN decisions, OF rules are embedded to specific OF switches. The details of SDPN controller can be found into following subsections:

1) ***E2eDelay (D) Calculation:*** A novel e2eDelay(D) for SDPN is defined by considering two planes in the following equation:

$$\mathrm{D} = \overbrace{\sum P_{mm'} \cdot W_s}^{\text{Control Plane Delay}} + \overbrace{\sum P_j \cdot W_j}^{\text{Data Plane Delay}} \qquad \forall\ j \in (m, s) \tag{1}$$

where P_j is serving probability over OF_j, W_j is queuing and processing delay per macro or smallcells which are also OF switch. j is an index of macro (m) or smallcell (s). W_s is delay caused by SDPN Controller processing and is executed for each macrocell to macrocell transition ($P_{mm'}$=1) called handover procedure. Here,the propagation delay is ignored. It is calculated by using d/s equation where d is the distance in meters and s is the speed of light ($3\text{x}10^9$ m/sec) [15]. By considering 10 m distances between vehicles in a platoon, the delay becomes at most $3\text{x}10^{-8}$secs. This can be disregarded even if the length of the platoon may be increased too much ($\leq 10^5$ vehicles). Moreover,such an increase on platoon length is not realistic. It enables V2V communication in platoon simultaneously [11]. On the other hand, the propagation delay between eNB and a centralized SDN controller is taken as 1 msec. This propagation delay is calculated by the coverage of the SDN controller that is responsible for a highway. In this study,we assumed that 600 km long highway is orchestrated by a centralized controller. By using the speed of light and d/s equation, the propagation delay is measured as 1 msec [16]. Moreover, because of only controlling URLLC traffic which has a packet size equal to approximately one-tenth of the eMBB packets, the processing time can be kept under 5G requirements (1 sec response time).

a) ***Control Plane Delay:*** The control part of e2eDelay (D) is triggered when the macrocell to macrocell transition ($P_{mm'}$) occurs, which calls a handover procedure when the probability is 1. For the whole topology, the distribution function for the topology is calculated for all type of user such as Pedestrian, Platoon or Independent Vehicle as in the following equation:

$$P_{mm'} = \frac{\sum P_{mm'}(t < T)}{N} \tag{2}$$

where$N$ is the total number of usersand $P_{mm'}(t)$ is discrete probability of the handover execution between macrocells at simulation time t and T is the total period of time as follows:

$$P_{mm'}(t) = \begin{cases} 1, & \text{macrocell transition} \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

On the other hand,there is an extra delay (W_s) caused by the handover execution in centralized SDPN controller. The handover procedure is taken as 15 msecs for each requirement of inter macrocell transitions [15] [16]. Therefore,the $P_{mm'}$ per vehicle should be minimized by platooning them as long as possible. We mapped this part with Control part of e2eDelay.

b) ***Data Plane Delay:*** In Level 2 of the proposed equation, e2eDelay (D) is performed per URLLC flow by considering each packet process. To understand where the flow is performed at a specific time t, the match of OF_j table should be checked. If a flow is matched with OF_j table, that means it is served over this cell which can be either macrocell or small cell. This is mathematically formalized as in following discrete probability function:

$$P_j = \begin{cases} 1, & flow \text{ matches in } OF_j \text{ table} \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

On the other hand,in each OF switch, Data packets of end-user are directly affected by the load in Core due to queuing and processing delay (W (sec)). Wemodel each cell by queuing theory. In M/M/c/K Markov model, the probability density function (P_n) has a Poisson distribution for $0 \leq n < c$ and a Geometric distribution for $c \leq n \leq K$. As in general aspect, the summation of each probability (P_n) should be equal to 1. Here, the computation is nearly the same as the M/M/c (infinite queue) Markov model. However, both Poisson and Geometric series of M/M/c/K are finite; Therefore,in the computation, there is no constraint such that ρ defining as $\frac{\lambda}{c \cdot \mu}$ must be less than 1 [17]. Thanks to that, the waiting time in a queue while $1 \leq \rho$ can be also analytically calculated. While working on

$$
\mathrm{D} = \begin{cases} \sum_0^M P_{mm'} \cdot W_s + \\ \sum P_j \cdot \frac{r_j(1-\frac{(r_j)^K}{(c_j)^{(K-c_j)}c_j!}P_0)+\frac{P_0(r_j)^{(c_j)}\rho_j}{c_j!(1-\rho_j)^2}\cdot[1-(\rho_j)^{(K-c_j+1)}-(1-\rho_j)\cdot(K-c_j+1)(\rho_j)^{(K-c_j)})]}{\lambda_j(1-\frac{(r_j)^K}{c_j^{(K-c_j)}c_j!}P_0)} & ,(\forall j \in (m,s)),(\rho_j \neq 1) \\ \sum_0^M P_{mm'} \cdot W_s + \\ \sum P_j \cdot \frac{r_j(1-\frac{(r_j)^K}{(c_j)^{(K-c_j)}c_j!}P_0)+\frac{P_0(r_j)^{(c_j)}}{c_j!}\cdot\frac{(K-c_j)(K-c_j+1)}{2}}{\lambda_j(1-\frac{(r_j)^K}{(c_j)^{(K-c_j)}c_j!}P_0)} & ,(\forall j \in (m,s)),(\rho_j = 1) \end{cases} \tag{7}
$$

Dense Urban topology, this case should be also considered. Therefore,each macrocell and small cells are modeled with M/M/c/K Markov model. The probability density function of this model is given in (5) [17].

$$
P_n = \begin{cases} \frac{r^n}{n!} \cdot P_0 & ,0 \leq n < c \\ \frac{r^n}{c^{n-c} \cdot c!} \cdot P_0 & ,c \leq n \leq K \end{cases} \tag{5}
$$

where r is calculated as $\frac{\lambda}{\mu}$, c is channel number of small cell or macro cell and K-c is the length of the queue. With the help of $\sum P_n = 1$ general aspect, P_0 is calculated as in [17]. By implementing L'Hospital rule on $\sum n \cdot P_n$, the number of packets that are waiting in a queue (L_q) is calculated. Then,the number of packets in the whole system (L) is performed by using $L = Lq + r \cdot (1 - P_K)$ formula. $P_K$is the probability of being a drop from the queue. The total waiting time (W) in the whole M/M/c/K system is calculated as [17]:

$$
W = \frac{L}{\lambda \cdot (1 - P_K)} \tag{6}
$$

where λ is dynamically changed in the Data Plane, which also alters traffic load ($\sum \rho$) per cell. Therefore,e2eDelay (D) optimization should consider the traffic load in Core. We mapped the Data part of e2eDelay (D) analytical formula with Level 2. The whole formula of proposed D is shown in (7).

*2) **E2eDelay (D) Optimization**:* The e2eDelay optimization problem in SDPN is defined as follows:

$$
\begin{aligned} &\text{min e2eDelay (D):} && \text{(8a)} \\ &\text{s.t.} \quad |V_j| > 1, \quad V_j \in Platoon && \text{(8b)} \\ &\forall \ \ |V_j V_j'| < 20 \ \ m, \quad V_j \in Platoon && \text{(8c)} \\ &\sum W_j < 4 \ \ msecs, \forall j \in (m,s) && \text{(8d)} \end{aligned}
$$

The objective function is minimizing average D as in (7). It is calculated by considering all end-users in a platoon. Due to having both discrete and continues variables in the constraints, this problem is called a Mixed Integer Linear optimization problem (MILP). In the first constraint in (8b), the number of vehicles in a platoon should be higher than 1. Otherwise,a vehicle is called an independent vehicle because it cannot build a platoon alone. In the second constraint in (8c), the inter-vehicle spacing in a platoon should be under 20 m while considering optimal SINR values and path-loss models to keep V2V communication alive [13] [18] . In the third constraint in (8d), the data part of D should be under 4 msecs.

The optimal solution of this problem can be found by using the Branch and Bound algorithm, however, it is NP-hard. The spent time can reach up to 20 mins for German Autobahn as mentioned in [1]. In our scenario, the proposed optimization algorithm should be met by 5G requirements:

Require: Graph G
Ensure: Set of Platoons P and the size of it M
1: Initialize empty set for the platoons $P = \{\{\}\}$
2: **while** Platoon P is feasible **do** ▷ Check (8d)
3:     **while** Graph G is not empty **do**
4:         **for** Each Vehicle v in G **do**
5:             Find v' where |vv'| <20+penalty
6:             Add v' into the platoon of v in P
7:             Remove v from G
8:     M ←Calculate the size of P
9: **return** P, M

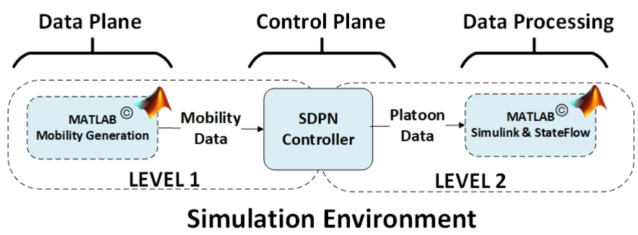
Figure 3. Centralized Set Cover for Platooning.

e2eDelay should be kept under a few msecs for URLLC traffic and SDPN controller should give dynamic decisions under 1 sec period [4] [19]. Therefore,we propose a greedy algorithm called Centralized Set Cover for Platooning that builds a platoon as long as possible. The pseudocode is given in Figure 3.

This algorithm finds minimum set cover in a graph G where all vehicles are platooned in a set P. However, the response time of the set cover is not acceptable because it exceeds 1 sec.. Therefore,we use the indirect constraint handling in e2eDelay(D) optimization. The static penalty function violates the constraint in (8c)enabling local search on infeasible solutions. In the proposed SDPN, these infeasible solutions would be feasible by dynamic alteration on velocities and positions of the vehicles in a platoon for the next period of the controller. It takes graph G including all vehicles in a highway as an input and returns the number of sets M and the minimum set covers as platoons P. After initializing empty set P, it checks the feasibility of the decision of the algorithm in terms of third constraint in (8d)in line 2. Between lines 3-7, there is a loop executing until there is no vehicle in a Graph G. Between lines 4-7, there is another loop for each vehicle v in dynamically reduced graph G. In line 5, the algorithm tries to find another vehicle v' of which euclidian distance to v is lower than 20+penalty. In this study, the penalty function is selected as 80 m and the performance evaluation is executed by using this value.If there is such v', it is added to the platoon of v in set P as in line 6 and the vehicle v is removed from graph G due to already being in a platoon as in line 7. Finally, the size of P is calculated as M in line 8 and the algorithm returns a greedy platoon P in line 9.

III. Performance Evaluation

The performance of the proposed SDPN is evaluated by a simulation environment shown in Figure 4. It is separated into two parts: Level 1 and Level 2. Firstly,in MATLAB©2018a, the Data Plane of SDPN is built by using uniformly random generation for mobility data according to Level 1 parameters in



(A). MOBILITY PARAMETERS.

LEVEL 1 Parameters	Values
Random Way Point	Pedestrains
Speed Interval	[0 2 km/h]
Pause Interval	[0 1 sec]
Walk Interval	[2.00 6.00 sec]
Direction Interval	[-180 180 degree]
Fluid Flow Direction	Vehicles
Highway Length	[0 24200 m]
Highway Exit Interval	2000 m
Speed of Vehicles	110 km/h
Cell Ranges	
Macrocell (R_m):	200 m
Smallcell (R_s)	100 m
Per macrocell	4 smallcells
Simulation Time	200 secs

(B). MARKOV PARAMETERS, AND THE DETAILS OF URLLC AND EMBB.

LEVEL 2 Parameters	Values
Spectrum, Bandwidth	
Macrocell:	4GHz, 200MHz
Smallcell:	30GHz, 1000MHz
V2V:	5.9GHz, 100 Mhz
Channels in Macro/Smallcell:	20, 7
Serving Rates	
of Macrocell $1/\mu_m$:	6,00E-005 secs/packet
of Smallcell $1/\mu_s$:	1,20E-005 secs/packet
Flow Parameters	
Packet generation	Poisson Traffic
λ per URLLC flow:	60 packets/sec
λ per eMBB flow:	1000 packets/sec
Total λ per macrocell:	33333 - 8333333 packets/sec
Queue size	10000

(C). TOTAL NUMBER OF URLLC AND EMBB WHEN TOPOLOGY UTILIZATION γ IS INCREASED.

γ	N	10 % URLLC	90 % eMBB	50%URLLC	50 % eMBB	90%URLLC	10 % eMBB
0.005	121	12	108	60	60	108	12
0.5	12100	1210	10890	6050	6050	10890	1210
1	24200	2420	21780	12100	12100	21780	2420
1.5	36300	3630	32670	18150	18150	32670	3630

Figure 4. Simulation Environment and Dense Urban (eMBB-UMx) [12] Topology Parameters in Platoon Network.

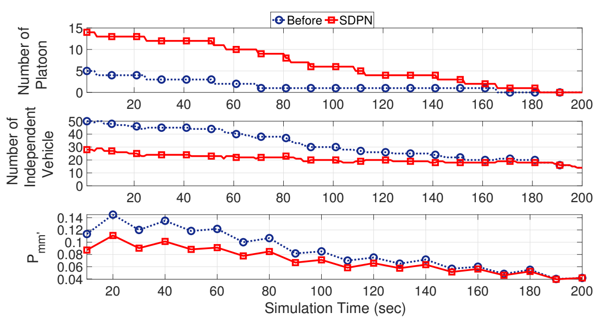


Figure 5. $P_{mm'}$ when $\gamma = 0.005$, 50% URLLC, and 50% eMBB Traffic.

sub-table 4a. Then,the mobility data is given to Control Plane which runs algorithm in Figure 3. These results are interpreted in the following Level 1 sub-section. Secondly,the data analysis is executed in Level 2 part by using Simulink and StateFlow libraries of MATLAB. The Level 2 parameters are given in sub-table 4b. The results are shown in the following Level 2 sub-section. Moreover,the traffic types during simulation are differentiated as given in sub-table 4c. Here, γ is the topology utilization changing by the total number of the users (N).

A. Level 1

In Level 1 of performance evaluation, two methods are compared: Before (conventional AdHoc platooning) and SDPN (proposed centralized platooning). In AdHoc platooning, each vehicle locally decides to enter or exit a platoon in terms of (8c). In Centralized platooning, SDPN executes Centralized Set Cover for Platooning algorithm in Figure 3 that globally tries to find minimum set cover of vehicles. In the Figure 5, the number of platoons and the effect on $P_{mm'}$ are shown by comparing Before and SDPN approaches. When the topology utilization is $\gamma = 0.005$, there is 50% URLLC and 50% eMBB, i.e., 60 URLLC (vehicles) and 60 eMBB (pedestrian). Initially, all vehicles are active in the highway, and after a randomly determined duration per vehicle, they leave the topology. In the first sub-graph, in Y-axis the number of platoons and in X-axis the simulation time are shown. Initially, SDPN builds 50% more platoons than Before. During the simulation, the number of leaving from the highways increase. Therefore,the number of platoons decreases. In the middle graph, there are further 20 independent vehicles in Before that create a handover request to SDPN controller per macrocell transition. It directly increase $P_{mm'}$. Thanks to SDPN, $P_{mm'}$ can be decreased by approximately 0.04 (33%) as given in third sub-graph. This directly decreases Control part of D, as in (1).

B. Level 2

In Level 2 of performance evaluation, the effect of Level 1 is studied on e2eDelay (D). As seen in Figure 6, e2eDelay (msec) is given according to different topology utilization (γ) during a first 15 seconds of the simulation. In each sub-graph,left one shows the results of the Before (conventional) and SDPN (proposed) approaches when $\gamma = 0.005$ and $\gamma = 0.5$, whereas,the right one shows the outputs when $\gamma = 1$ and $\gamma = 1.5$. Before performs AdHoc platooning, the SDPN executes proposed Centralized Set-Cover algorithm in Figure 3. In each case when $\gamma <= 0.5$, the SDPN can decrease

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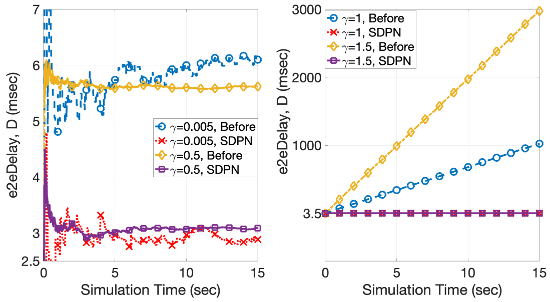
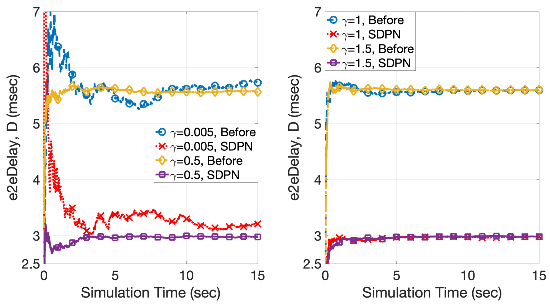
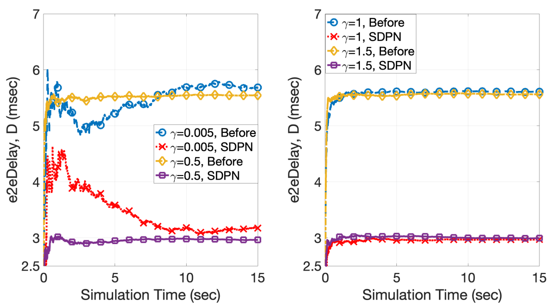


(a) 10% URLLC, 90% eMBB.



(b) 50% URLLC, 50% eMBB.



(c) 90% URLLC, 10% eMBB.

Figure 6. e2eDelay, D (sec) for different Topology Utilization γ.

e2eDelay nearly 2.5 msecs from 5.5 to 3. The fluctuationsare caused by the handover request during macrocell transition ($P_{mm'}$=0.3) to SDPN controller where W_s takes approximately 15 msecs as in (1). As the rate of eMBB services is increased from 10% to 90% in Figures 6a-6c, the URLLC service is further squeezed by the background traffic. In the right sub-graph of Figure 6a, Before cannot serve URLLC services and e2eDelay increases up to 3 secs,whereas the proposed one can keep it under 3.5 msecs. As a result,thanks to centralized view SDPN improves e2eDelay 45% by keeping it under 3.5 msecs even if the topology utilization is too high ($\gamma >> 1$).

IV. Conclusion and Future Work

In this paper, we proposed a Software-Defined Platoon Network (SDPN) dynamically optimizing e2eDelay of URLLC services. A closed-form expression of e2eDelay (D) was newly defined by considering Data and Control planes. This objective function was optimized via Mixed Integer Linear Programming (MILP) by jointly considering the constraints in V2V and V2I links of a platoon. Due to being NP-hard and to reduce the computational complexity of the optimization, we proposed a novel Centralized Set Cover for Platooning algorithm that built a platoon as long as possible. According to the performance evaluation, e2eDelay was improved by 45% by keeping it under 3.5 msecs even if the topology utilization was too high. As future work, the load effect of the core on platoon networks will be investigated due to the lack of V2I investments in 5G.

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