PAPER Special Section on Network Virtualization and Network Softwarization for Diverse 5G Services

A Deadline-Aware Scheduling Scheme for Connected Car Services Using Mobile Networks with Quality Fluctuation

Nobuhiko ITOH[†a)], **Motoki MORITA**[††], **Takanori IWAI**[†], **Kozo SATODA**[†], ***and*** **Ryogo KUBO**[†††], ***Members***

SUMMARY Traffic collision is an extremely serious issue in the world today. The World Health Organization (WHO) reported the number of road traffic deaths globally has plateaued at 1.25 million a year. In an attempt to decrease the occurrence of such traffic collisions, various driving systems for detecting pedestrians and vehicles have been proposed, but they are inadequate as they cannot detect vehicles and pedestrians in blind places such as sharp bends and blind intersections. Therefore, mobile networks such as long term evolution (LTE), LTE-Advanced, and 5G networks are attracting a great deal of attention as platforms for connected car services. Such platforms enable individual devices such as vehicles, drones, and sensors to exchange real-time information (e.g., location information) with each other. To guarantee effective connected car services, it is important to deliver a data block within a certain maximum tolerable delay (called a deadline in this work). The Third Generation Partnership Project (3GPP) stipulates that this deadline be 100 ms and that the arrival ratio within the deadline be 0.95. We investigated an intersection at which vehicle collisions often occur to evaluate a realistic environment and found that schedulers such as proportional fairness (PF) and payload-size and deadline-aware (PayDA) cannot satisfy the deadline and arrival ratio within the deadline, especially as network loads increase. They fail because they do not consider three key elements — radio quality, chunk size, and the deadline — when radio resources are allocated. In this paper, we propose a deadline-aware scheduling scheme that considers chunk size and the deadline in addition to radio quality and uses them to prioritize users in order to meet the deadline. The results of a simulation on ns-3 showed that the proposed method can achieve approximately four times the number of vehicles satisfying network requirements compared to PayDA.
key words: *IoT, resource control, 5G, LTE, connected car, V2X*

1. Introduction

Traffic collision is an extremely serious issue in the world today. The World Health Organization (WHO) reported the number of road traffic deaths globally has plateaued at 1.25 million a year [1]. In Japan, the number of fatalities is 4,000 a year, and 96% of traffic collisions are attributed to the driving error. Traffic collisions occurring in blind places, such as right-turn collisions and rear-end collisions, account for 74% of all accidents [2].

In an attempt to decrease the occurrence of traffic collisions, safety driving systems with sensors such as vehicle-mounted cameras and vehicle radar for detecting pedestrians and vehicles have been proposed. However, they cannot detect vehicles and pedestrians in blind places such as sharp bends and blind intersections. Installing surveillance cameras and sensors around such locations has been considered, but it is unrealistic to install them in all the places they are needed.

Therefore, mobile networks such as long term evolution (LTE), LTE-Advanced, and 5G networks are attracting a great deal of attention as platforms for connected car services. Such platforms enable individual devices such as vehicles, drones, and sensors to exchange real-time information (e.g., location information) with each other. As a result, individual devices can avoid collisions as they can detect each other.

Much work has been devoted to developing architecture and protocol for diverse 5G services to improve latency, the number of connected users, and throughput. Our research goal is to increase the number of connected users satisfying the quality of service (QoS). For connected car services, real-time application data such a location information and around-view camera images must be delivered within end-to-end deadline constraints. The end-to-end deadline is defined for each data block, which we call a chunk. For example, to ensure automobile collisions are avoided, vehicles need to periodically exchange a chunk such as an item of location information. The Third Generation Partnership Project (3GPP) stipulates that the information should be delivered within a certain time constraint (100 ms) to achieve this use case [3]. To support connected car services on the platform, the total amount of chunks that meet their deadline must be increased. Goodput [bps] is defined as the total amount of chunks that meet deadline constraints per second.

In LTE networks, a scheduler is implemented at the medium access control (MAC) layer of an evolved NodeB (eNB). This dynamically allocates radio resources to devices so that they can transmit and receive chunks. An enhanced scheduler is needed if we want to improve the goodput. Conventional MAC schedulers are categorized into two types: deadline-unaware and deadline-aware. Deadline-unaware schedulers have been proposed in [4]–[11], but these schedulers cannot guarantee the deadline. With proportional fair (PF) scheduler [4], chunks sometimes exceed the deadline because the same amount of bandwidth is assigned to all user equipment (UE) regardless of different deadlines and chunk sizes. In the case of maximum carrier-to-interference (Max C/I) scheduler [4], it assigns radio resources to UE on the

Manuscript received April 11, 2018.
Manuscript revised July 25, 2018.
Manuscript publicized September 20, 2018.
[†]The authors are with the System Platform Research Laboratories, NEC Corporation, Kawasaki-shi, 211-8666 Japan.
[††]The author is with the Smart Infrastructure Division, NEC Corporation, Kawasaki-shi, 211-8666 Japan.
[†††]The author is with the Department of Electronics and Electrical Engineering, Keio University, Yokohama-shi, 223-8522 Japan.
a) E-mail: n-itoh@az.jp.nec.com
DOI: 10.1587/transcom.2018NVP0002

basis of only radio quality, without considering chunk size or deadline. Some UEs that have bad radio quality cannot meet the deadline because Max C/I preferentially allocates radio resources to UEs with good radio quality. Therefore, these schedulers lead to a decrease in goodput. Deadline-aware schedulers have been proposed [12]–[21]. Earliest deadline first (EDF) [12] is very efficient on wired networks but slows down on mobile networks where the radio quality greatly fluctuates, such as LTE networks. Payload-size and deadline-aware (PayDA) takes deadlines and payload sizes into account [14], preferentially assigning radio resources to the flow in accordance with a priority calculated from the remaining time and the remaining data amount. However, it does not consider radio quality. Elsayed and Khattab proposed a scheduling discipline called channel dependent earliest deadline due (CD-EDD) [21]. This scheduling method also considers radio quality but not chunk size.

In this paper, we propose a deadline-aware scheduling scheme that guarantees the end-to-end deadline in cases where the chunk size, deadline, and radio quality heavily fluctuate. It identifies the emergency UE and then monitors the progress of data transmission and preferentially gives transmission rights to UEs after considering the radio quality of each UE, thus avoiding exceeding the deadline and degrading system throughput. It achieves higher goodput than the PayDA and the conventional PF, which is the most implemented scheduling scheme on eNB, and suppresses degradation of system throughput.

In Sect. 2 of this paper, we give a brief overview of the mobile system and describe the PayDA, one of the deadline-aware schedulers. Section 3 describes our proposed deadline-aware scheduling scheme for resolving degradation of the goodput. In Sect. 4, we evaluate our proposed deadline-aware scheduling method using a computer simulation and discuss the results. We conclude in Sect. 5 with a brief summary.

2. Mobile System and Payload-Size and Deadline-Aware Scheduler

2.1 Mobile System

User plane entity on current mobile systems such as LTE consists of UEs including vehicles and pedestrians, an eNB, a gateway (GW), and the application server. The current mobile system is shown in the upper part of Fig. 1, where UL and DL are uplink and downlink, respectively. The eNB decides how to allocate radio resources to UEs. The gateway, called the serving and packet data network gateway (S/P-GW) in the LTE system, terminates the tunnel for mobility and provides connectivity from the UE to the external packet data network. The application server provides connected car services to vehicles, which are considered UEs here. The application server collects location information and around-view camera images and then sends a control message to a UE. There is the potential for delay when connected car service is provided using the current mobile network without

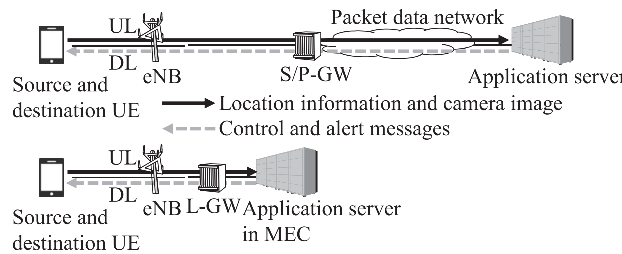

Fig. 1 Mobile system.

multi-access edge computing (MEC) because the application server is located beyond the packet data network.

MEC enables vehicles (i.e., UEs) to advertise location information and camera images to the application server with short delay compared to mobile systems without MEC because the application server is located nearby the eNB. The mobile system with MEC is shown in the bottom part of Fig. 1. The GW in the mobile system with MEC, called a local gateway (L-GW) that exists nearby the eNB, also terminates the tunnel for mobility. The system puts an application server out into MEC. However, MEC cannot decrease the delay between UE and eNB on a wireless section. Therefore, the system needs an enhanced scheduler in order to improve delay on the wireless section.

2.2 Payload-Size and Deadline-Aware Scheduler

PayDA is an enhancement of the common EDF algorithm and has been extended by considering the remaining data amount of each data flow [14]. In PayDA, a data stream with a close deadline and a small data amount tends to be prioritized over data streams with either large data amounts or a lot of time left before their deadlines. According to [14], PayDA is formulated as

$$\omega_i = \frac{1}{((\tau_i - D_{HOL,i}) \cdot \delta_{left,i})} \tag{1}$$

where ω_i is the weight of a metric used for user prioritization, τ_i is the deadline, $D_{HOL,i}$ is the head-of-line delay for the i-th user, and $\delta_{left,i}$ is the remaining data amount of the i-th user. The head-of-line delay $D_{HOL,i}$ marks the duration of stay of the first packet in a packet queue on the part of the transmitter since its generation.

PayDA causes degradation of goodput because it allocates radio resources without considering radio quality. System throughput (S_t) is formulated as

$$S_t = \frac{\sum_{k=1}^{N} C_k}{T} \tag{2}$$
$$\mathbb{A} = \{k \mid \text{id of received chunks within T}\}$$
$$|\mathbb{A}| = N$$

where T is observation time, C_k is size of k-th chunk, and N is the total number of received chunks. Goodput (S_g) is formulated as

$$S_g = \frac{\sum_{k'=1}^{N'} C_k}{T}, \mathbb{A}' \in \mathbb{A} \tag{3}$$

$$\mathbb{A}' = \{k' \mid \text{id of chunks received before deadline within T}\}$$
$$|\mathbb{A}| = N'$$

where N' is the total number of received chunks that meet the deadline constraint. The degradation of goodput is caused by that of the system throughput because goodput is a subset of system throughput as shown in (2) and (3). When radio resources are allocated without considering radio quality, system throughput is decreased.

3. Proposed Deadline-Aware Scheduling Scheme

In this section, we propose a deadline-aware scheduling method that delivers a chunk within a certain deadline constraint for connected car service with the LTE network. Our proposed method consists of UEs including vehicles and pedestrians, eNB, L-GW, MEC, and an application server that is co-located in MEC. The MEC has an uplink and downlink coordination function. This function adaptively assigns an uplink and downlink deadline to each link in accordance with the end-to-end deadline. The eNB has a priority calculation algorithm that considers radio quality, chunk size, and deadline along with a resource allocation function based on the priority.

We describe our architecture, its two functions, and LTE V2X applications in 3.1, 3.2, 3.3, and 3.4, respectively.

3.1 Architecture

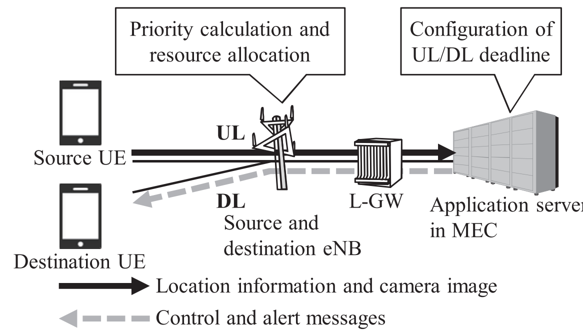

Fig. 2 Architecture for proposed method.

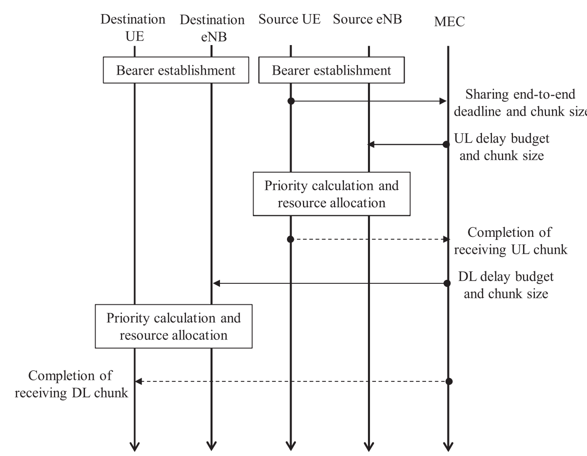

Fig. 3 Sequence of proposed method.

The architecture for our proposed method is shown in Fig. 2. It consists of the MEC, L-GW, the source and destination eNB, and the source and destination UEs. The source UE and destination UE may be the same UE, although they are shown as different UEs in the figure; similarly, the source eNB and destination eNB may be different eNBs. We chose to use MEC so that we could set an end-to-end deadline and achieve low delay compared with the delay between, for example, an application server on packet data networks and the UE. The MEC can terminate application layers above layer 2, which means it can measure the end-to-end delay and adaptively configure each direction deadline. This is in contrast to the eNB, which can measure only delay between UE and itself but not the end-to-end delay, since it terminates layer 2.

The network architecture in Fig. 2 can be applied to the use case of connected car services in 5G as well as LTE. Specifically, the proposed method can be applied to both LTE and 5G networks because the objective is to suppress end-to-end delay including application layers under the deadline in the use case of connected car services.

The sequence of our proposed method is shown in Fig. 3. The mobile system establishes a bearer between the source UE and the source eNB, and a bearer between the destination UE and the destination eNB. MEC couples these two bearers and decides the deadline and chunk size used in the source eNB and destination eNB. The QoS requirements are defined on the basis of each application and contain the end-to-end deadline and chunk size. MEC sends the requirements to eNBs when a new session is established or when the QoS requirements are changed in accordance with application mode switching, i.e., when a vehicle (one of the UEs) sends its real-time location information to avoid collisions in mode 1 and in-vehicle log data such as a remaining fuel and acceleration work for performing fuel saving drive to a driver in mode 2. The deadline of mode 1 is shorter than that of mode 2 since the urgency of mode 1 is higher. MEC advertises the changed deadline information to the eNBs. The source eNB calculates the priority of a chunk on the basis of the QoS requirements when it receives a communication request from a source UE. It then allocates radio resources in accordance with the priority.

The MEC calculates the delay budget for the downlink when it receives all packets consisting of a chunk. This budget is the remaining time to the end-to-end deadline. The MEC can distinguish each chunk because we assume that each chunk has a unique ID. The MEC sends the QoS requirements for downlink to the destination eNB, which then calculates priority on the basis of this requirement and allocates radio resources to the destination UE.

3.2 Update of DL Deadline on MEC

This function updates the DL deadline based on elapsed

Algorithm 1 Update of DL deadline

$$ULDeadline \Leftarrow \frac{Deadline - ComputationTime}{2}$$
$$DLDeadline \Leftarrow max(Deadline - ComputationTime - ElapsedTime, Th_1)$$

time, end-to-end deadline, and computation time of the MEC server. The proposed method needs to decide the DL deadline, considering the calculation time of this algorithm. Hence, the calculation time of the algorithm is defined as *ComputationTime*. Algorithm 1 is the pseudocode of the DL deadline update. MEC sets the UL deadline ($ULDeadline$) to $\frac{Deadline - ComputationTime}{2}$. When MEC receives all packets of the chunk from the source UE, it calculates the remaining time to the end-to-end deadline ($Deadline$) for the chunk from the end-to-end deadline ($Deadline$) and elapsed time ($ElapsedTime$) and sets $DLDeadline$ to a maximum value of remaining time ($Deadline - ComputationTime - ElapsedTime$) and Th_1. Th_1 is used to avoid $DLDeadline$ becoming a negative value. Then, MEC passes that value as the DL deadline to the eNB connected to the destination UE.

MEC first allocates 49.5 ms as $ULDeadline$, i.e., when $Deadline$, Th_1, and $ComputationTime$ are 100 ms, 1 ms, and 1 ms, respectively. $DLDeadline$ is updated to 69 ms, i.e., when $ElapsedTime$ is 30 ms. Then, MEC sends $DLDeadline$ to the destination eNB on the control plane, and also sends the stored chunk to the eNB.

3.3 Resource Scheduling Method on eNB

Our proposed method prioritizes each chunk in accordance with the radio quality between UE and eNB, the uplink and downlink delay budget, and the chunk size advertised by MEC and then delivers the chunk to a destination UE within the end-to-end deadline constraint. The source and destination eNB preferentially allocate radio resources to a high priority UE.

3.3.1 Priority Calculation Algorithm

Our proposed method locates emergency UEs by monitoring the progress of data transmission and preferentially gives transmission rights to the UE to avoid exceeding the deadline. The concept of our proposed method is depicted in Fig. 4.

Our proposed method judges whether a chunk is an emergency or not by comparing the target throughput and the requested throughput. Here, the target throughput is defined as chunk size divided by its deadline; that is, it is an unchanged value because it is independent of the progress of time. In contrast, the requested throughput is throughput needed to meet the deadline at a certain point in time, and as such we define the requested throughput as the remaining data amount divided by the remaining time to the deadline. The remaining data amount is calculated by subtracting the amount of data received from the chunk size. The remaining time is calculated by subtracting the elapsed time from the deadline. As time goes on, the requested throughput changes because the remaining data amount and the remaining time change.

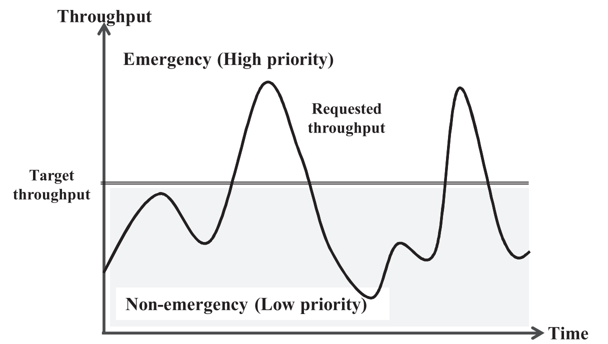

Fig. 4 Relation between chunk states and priority.

The pseudocode of the priority calculation is shown in Algorithm 2. Table 1 lists the parameters used for priority calculation. The priority calculation is executed each transmission time interval (TTI). Th_2 is used to avoid $RemainingTime(i,t)$ being equal to zero or negative value. When $RemainingTime(i,t)$ is zero, $RequestedThroughput(i,t)$ is indeterminate. $RequestedThroughput(i,t)$ is negative value when $RemainingTime(i,t)$ is negative value.

If the $RequestedThroughput(i,t)$ is higher than the $TargetThroughput(i)$, we set the chunk state as emergency because it is not likely to meet the deadline. Our proposed method also considers radio quality in addition to the emergency degree in order to efficiently use radio resources, which are finite resources. That is, the better the radio quality, the higher the priority. The modulation and coding scheme (MCS) is used as a radio quality index. If $RequestedThroughput(i,t)$ is lower than $TargetThroughput(i)$, we set the chunk state as non-emergency because the chunk is making good progress. Then, our proposed method decides the priority of the chunk by a $PFmetric$ that considers the fairness of the transmission right, since fairness is a significant index. $PFmetric$ is defined by a fraction of the average throughput and instant throughput.

3.3.2 Radio Resource Allocation

Here, we explain how to allocate radio resources to chunks. After calculating the priority of each chunk, our proposed method allocates radio resources to each chunk in accordance with its priority.

Radio resource allocation assigns radio resources to the UE that has the best radio quality among all the emergency UEs. By allocating to a good channel UE, the radio resource allocation can improve the goodput while suppressing degradation of throughput. If radio resources do not need to be allocated to emergency UEs, the radio resource allocation assigns them to non-emergency UEs in accordance with each priority $PFmetric$.

Algorithm 2 Priority calculation algorithm

if UL section **then**
  $SubDeadline(i) \Leftarrow ULDeadline(i)$
end if
if DL section **then**
  $SubDeadline(i) \Leftarrow DLDeadline(i)$
end if
$RemainingTime(i,t)$
$\Leftarrow max(SubDeadline(i) - SubElapsedTime(i,t), Th_2)$
$TargetThroughput(i) \Leftarrow \frac{ChunkSize(i)}{SubDeadline(i)}$
$RequestedThroughput(i,t) \Leftarrow \frac{RemainingChunkSize(i,t)}{RemainingTime(i,t)}$
$PFmetric(i,t) \Leftarrow \frac{InstantThroughput(i,t)}{AverageThroughput(i,t)}$
if $TargetThroughput(i,t) < RequestedThroughput(i,t)$ **then**
  $EmergencyFlag(i,t) \Leftarrow$ **true**
  $Priority(i,t) \Leftarrow MCSindex(i,t)$
else
  $EmergencyFlag(i,t) \Leftarrow$ **false**
  $Priority(i,t) \Leftarrow PFmetric(i,t)$
end if

Table 1 Algorithm parameters.

Parameters	Explanation
$TargetThroughput(i)$	Target throughput of chunk i
$ChunkSize(i)$	Size of chunk i
$SubDeadline(i)$	UL or DL deadline of chunk i
$SubElapsedTime(i)$	Elapsed time of chunk i on UL or DL section
$RequestedThroughput(i,t)$	Requested throughput of chunk i on t TTI
$RemainingChunkSize(i,t)$	Remaining chunk size of chunk i on t TTI
$RemainingTime(i,t)$	Remaining time to deadline of chunk i on t TTI
$PFmetric(i,t)$	Priority of chunk i that has no emergency flag on t TTI
$InstantThroughput(i,t)$	Instant throughput of UE that has chunk i on t TTI
$AverageThrouhput(i,t)$	Average throughput of UE that has chunk i on t TTI
$EmergencyFlag(i,t)$	Flag to show degree of urgency of chunk i on t TTI
$MCSindex(i,t)$	MCS index of UE that has chunk i on t TTI
$Priority(i,t)$	Priority of chunk i on t TTI
Th_2	Minimum value of remaining time

3.4 LTE V2X Applications

It is assumed that our proposed method can be applied to LTE V2X services with MEC that include vehicle-to-vehicle (V2V), vehicle-to-pedestrian (V2P), and vehicle-to-infrastructure (V2I). To take LTE V2V with MEC as an example, a source vehicle sends a chunk such as an item of location information to the MEC through an eNB, and MEC sends an alert message to the destination vehicle through an eNB based on the information. Our objective is to guarantee that the delay of the end-to-end (source vehicle to MEC to destination vehicle) is equal to or less than 100 ms.

Although the chunk size and deadline may change depending on the type of V2X, our proposed method should work well because it considers the chunk size and deadline when it decides the priority of each chunk.

4. Performance Evaluation

In this section, we compare our proposed method with the PF scheduler and PayDA. Our proposed method was implemented on ns-3, a general network simulation framework that is widely used in network research [22]. We define the UEs shown in Figs. 1 and 2 as vehicles and pedestrians. We investigated an intersection at which vehicle collisions often occur in order to evaluate our method in a realistic environment. The simulation of urban mobility (SUMO) [23], [24] was used to define the mobility model of vehicles and pedestrians. For practical use, the proposed method is evaluated under the assumption that the network architecture in Fig. 2 is LTE. In 5G, it is expected that the performance evaluation result of each method will be improved compared to LTE because the network latency of 5G will be smaller. However, the proposed method is expected to be also effective in 5G because the network may be congested depending on the number of connected cars, and radio quality will fluctuate.

4.1 Simulation Environment

We created a realistic environment on ns-3 to investigate an intersection at which vehicle collisions would be likely to occur. Results showed that most vehicle collisions are caused at intersections: right-turn collisions, rear-end collisions, and so on [2]. Right-turn collisions are particularly likely to occur at intersections that are bent sharply to the right, as shown in Fig. 5.

The performance evaluation was executed in the environment shown in Fig. 5. Simulation parameters of eNB are listed in Table 2. The cell formation was seven hexagonal cells, with one eNB allocated at the center of each cell. Road environment was allocated around the intersection on the center cell, which had one eNB and buildings for interference. The six neighboring cells were for interference. We measured performance on only the center cell. The UL/DL frequency and bandwidth were 2 GHz and 20 MHz used in LTE, respectively. Pedestrian A [25] was used as a fading model.

Table 3 lists the simulation parameters of the UE. We used mission critical UE (MC-UE) (which is delay sensitive) and best effort UE (BE-UE) (which is delay non-sensitive) as vehicle and pedestrian, respectively. The vehicle deadline was 100 ms and was shorter than that of the pedestrian deadline. The number of vehicles and pedestrians was 100 each. The first chunk of each vehicle or pedestrian was randomly generated between 0 and 100 ms of simulation time. Next chunks were generated at 100 ms intervals until the end of simulation. Th_1 and Th_2 were both 1 ms. To eval-

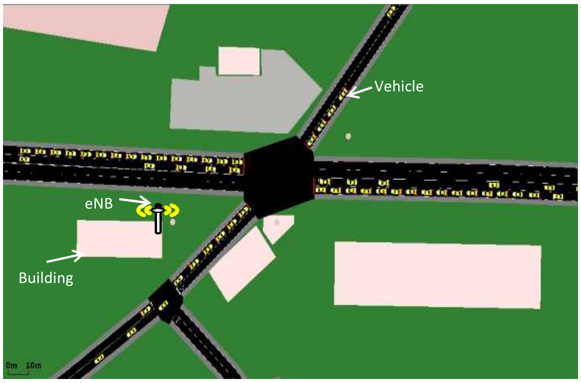

Fig. 5 Intersection used in the simulation.

Table 2 Simulation parameters for eNB.

Number of eNBs	7 (1 cell per eNB)
Radius	289 m (distance between eNBs: 500 m)
UL/DL frequency	2 GHz
Antenna height	32 m
UL/DL bandwidth	20 MHz (=100 resource blocks)
Fading	Pedestrian A

Table 3 Simulation parameters for UE.

Tx power	23 dBm
UL power control	Enable
Antenna height	1.5 m
Number of vehicles (as MC-UE)	100
Number of pedestrians (as BE-UE)	100
Traffic generation interval	100 ms
Deadline for vehicle	100 ms

uate the fundamental performance of our proposed method, *ComputationTime* that depends on the machine specs is set to 0 ms. Simulation time was 30 s and the number of simulations was five.

End-to-end flow consisted of a UL session and DL session, and sender and receiver were the same UE. It is assumed that a vehicle sends its own location information, and the MEC sends an alert message including location information of neighbor vehicles and pedestrians to the vehicle. Accordingly, when focusing on a certain vehicle, the sender and receiver are the same. Therefore, the proposed method is evaluated under the assumption that the sender and receiver are the same. The number of end-to-end flows of MC-UE and end-to-end flows of BE-UE were both 100. The user data protocol (UDP) was used as a transport protocol to exchange chunks, as 3GPP stipulates that vehicle-to-everything (V2X) such as connected car services use UDP [26].

4.2 Simulation Results of Basic Characteristics

Here, we present the simulation results for the environment described in 4.1. Each goodput of the methods was evaluated with the chunk size of the MC-UE changing as the information amount a vehicle sent or received became bigger. Figure 6 shows the goodput and application data rate, which is the rate of the amount of application data generated within the simulation time. When the goodput is equal to the application data rate, it means the scheduler is efficient.

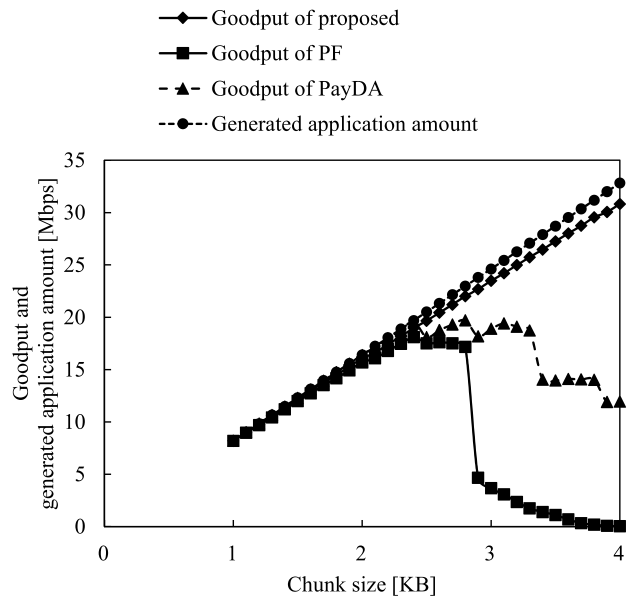

Fig. 6 Goodput.

As shown in Fig. 6, the proposed method was more efficient than PF and PayDA. One reason for this is that our proposed method preferentially allocates radio resources to chunks that are not likely to meet their deadlines in order to accelerate the transmission progress of the chunk. Therefore, these chunks can be delivered before their deadlines.

When the chunk size was larger than 3 KB, the performances of PF and PayDA degraded. The PF equally allocates radio resources to each UE without considering deadlines for chunks or chunk size, and such equable radio resource allocation has the potential to increase the number of UEs that fail to deliver a chunk within the deadline. In particular, the performance of PF suddenly degraded when the throughput needed to satisfy an end-to-end deadline constraint that was higher than the throughput equally allocated to each UE. The PayDA allocates radio resources to whichever UE has little remaining time and a small remaining data amount. The larger the chunk size, the larger the average remaining size. Therefore, the probability of exceeding the deadline increases in proportion to larger chunk size.

The ratio of goodput to throughput is formulated as

$$P_A = \frac{S_g}{S_t} \tag{4}$$

where S_t and S_g is defined in (2) and (3). Figure 7 shows P_A shown in (4), the ratio of goodput (S_g) to throughput (S_t), when using the proposed method, PF, and PayDA.

Degradation of P_A means that finite radio resources were used for chunks that did not meet the deadline even

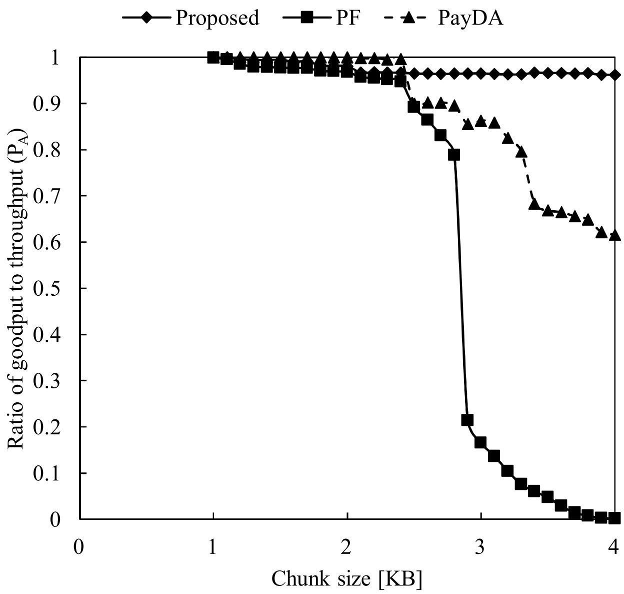

Fig. 7 Ratio of goodput to throughput.

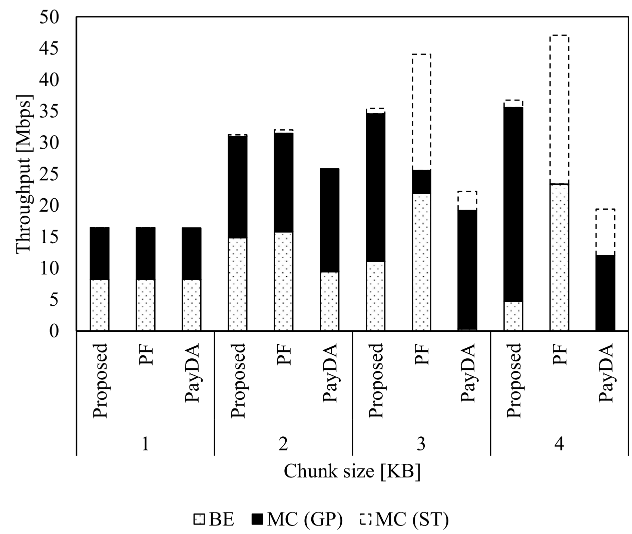

Fig. 8 System throughput.

though the scheduler allocated radio resources to MC-UEs, and inefficient transmission. When chunk size was equal to or less than 2.4 KB, each method achieved a high performance. The ratio of the proposed method is approximately equal to that of the PF because our proposed method decides each chunk's priority by using $PFmetric$ on a non-emergency state. In contrast, when the chunk size was larger than 2.4 KB, PF and PayDA exhibited performance degradation while our proposed method maintained a consistently high performance. This is because our proposed method assigns radio resources to monitor the emergency degree and suppress degradation of system throughput.

The system throughput of each method is shown in Fig. 8, where the system throughput is the sum of the total throughput of all MC-UEs and total throughput of all BE-UEs. The total throughput of all MC-UEs, the total throughput of all BE-UEs, and the total goodput are respectively expressed as MC (ST), BE, and MC (GP) in Fig. 8.

When chunk size was 1 or 2 KB, the system throughput of our proposed method was approximately equal to that of the PF, as our method prioritizes each chunk with $PFmetric$ in the non-emergency state. In contrast, the system throughput of PayDA was lower than the proposed method and PF. This is because PayDA has the risk of allocating radio resources with bad radio quality to UEs, as it does not consider radio quality.

The PF had the highest system throughput among all methods when chunk size was 3 or 4 KB. The system throughput of PayDA decreased since it does not consider the radio quality at all, while our proposed method obtained a higher system throughput than the PayDA because it allocates radio resources to UEs that have relatively better radio channel quality. Our proposed method obtained a higher sum of MC (GP) and BE than PF. PF consumes many radio resources due to chunks that do not meet the deadline, as shown in Fig. 8. With our proposed method, MC (GP) was approximately equal to MC (ST).

4.3 Use Case of Connected Car Services

The parameters for connected car services in terms of delay budget and arrival ratio within the delay budget have been presented in [3]. According to [3], in the case of urban intersections, the delay budget and the arrival ratio within the delay budget are 100 ms and 95%, respectively. We define these here as network requirements for safe driving.

In this subsection, we evaluate each method in terms of the number of vehicles satisfying the network requirements for safe driving. We set chunk size to 3 KB, a relatively large size, because we assume that vehicles will be sending camera image data in addition to location data and authentication data in the near future.

Figure 9 shows the ratio of the number of vehicles satisfying the network requirements to the total number of vehicles when chunk size was 3 KB. The ratio of the number of vehicles satisfying the network requirements to the total number of vehicles is formulated as

$$P_b = \frac{N_b}{N_a} \tag{5}$$

where N_a is 100 (the number of vehicles) and N_b is the number of vehicles satisfying the network requirements. Our proposed method achieved a higher ratio than the PF and PayDA. Specifically, the ratios with the proposed method and PayDA were approximately 0.9 and 0.2, respectively, while PF could not satisfy the network requirement for safe driving at all in the simulation environment.

Figure 10 shows the success ratio of the chunk of each UE. The success ratio is formulated as

$$P_c = \frac{M_b}{M_a} \cdot 100 \tag{6}$$

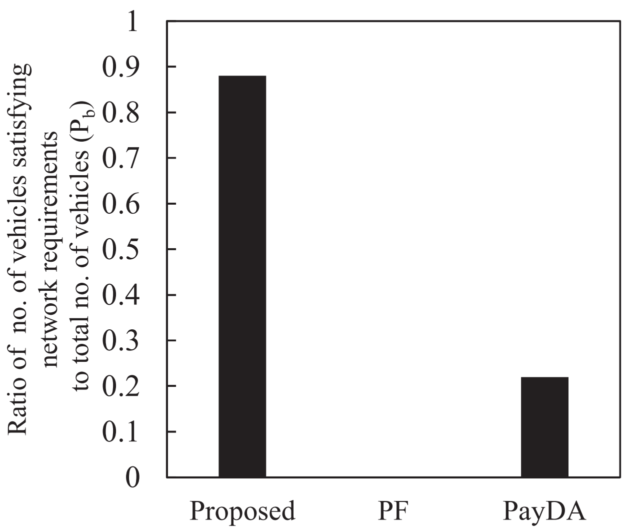

Fig. 9 Ratio of the number of vehicles satisfying network requirements to the total number of vehicles.

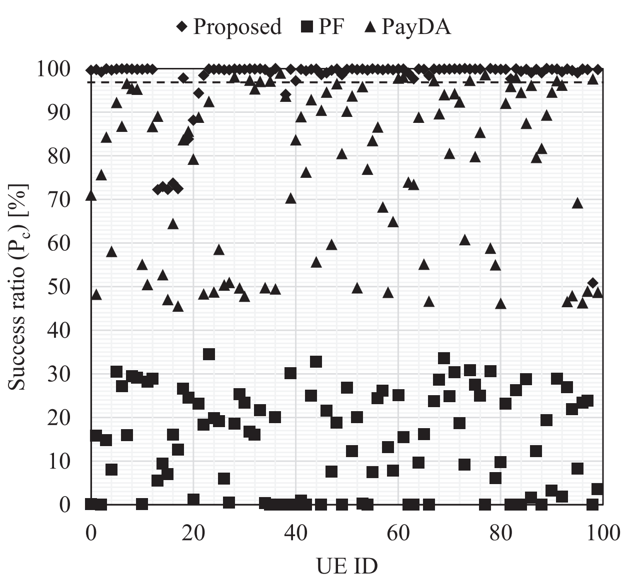

Fig. 10 Success ratio of each UE.

where M_a is the total number of chunks received within simulation time and M_b is the number of chunks received before deadline within simulation time. The number of MC-UE is 100 and the horizontal axis indicates UE ID in Fig. 10. As shown, the success ratio of most UEs was higher than 95% (i.e., the network requirement) with our proposed method. In contrast, with PF, the success ratio of each UE was distributed between 0% and 40%, and no UEs existed in the area higher than 95% because it does not consider the deadline. The success ratio of PayDA was higher than that of PF because PayDA considers the remaining time to the deadline and the remaining size. However, its success ratio was lower than that of the proposed method because it does not consider radio quality. When the scheduler assigns radio resources to UEs with bad radio quality, it leads to inefficient transmission. As a result, the success ratio of PayDA decreases.

Table 4 Average MCS of MC-UE with proposed method.

UEs (less than 95%)	UEs (more than 95%)
6.2	21.1

The reason our proposed method can obtain a higher success ratio than the conventional ones is that it considers radio quality in addition to chunk size and deadline when it allocates radio resources. Table 4 lists the average MCS of MC-UE with the proposed method in the simulation time. As shown, the average MCSs of the MC-UE that had a higher success ratio than 95% and that of the MC-UE that had a lower success ratio than 95% were 21.1 and 6.2, respectively. That means our proposed method can achieve efficient radio resource allocation because it allocates radio resources to UEs with good radio UE. The efficient radio resource allocation enables our proposed method to achieve a high success ratio compared to PF and PayDA.

5. Conclusion

In this paper, we discussed our deadline-aware scheduling scheme for connected car services to reduce traffic collisions and evaluated it with ns-3 in a simulation assuming an intersection at which traffic collisions often occur. We first evaluated the characteristics of chunk size to determine the basic performance when the amount of information that a vehicle sends and receives increases. Results showed that our proposed method achieved a higher goodput than conventional methods (PF and PayDA) and was especially efficient when chunk size was large. This indicates that our proposed method enables connected cars to send and receive rich contents to avoid traffic collision. We also evaluated our proposed method to see if it met the network requirements (maximum tolerable delay: 100 ms; arrival ratio within 100 ms: 0.95) and found that it could achieve approximately four times the number of vehicles satisfying these requirements than the best-performing conventional method.

Acknowledgments

This paper includes some of the results of "The research and development project for efficient and optimized use of radio resource in mobile networks with a variety of IoT devices" commissioned by the Ministry of Internal Affairs and Communications, Japan.

References

[1] Global status report on road safety 2015, World Health Organization, 2015.
[2] ITARDA, 'http://www.itarda.or.jp/english/
[3] 3GPP, "Study on lte support for vehicle to everything (v2x) services," Technical Report, TR 22.885, 2015.
[4] E. Dahlman, S. Parkvall, J. Skold, and P. Beming, 3G Evolution, Elsevier Science Publishing, 2008.
[5] R. Kwan, C. Leung, and J. Zhang, "Proportional fair multiuser

scheduling in LTE," IEEE Signal Process. Lett., vol.16, no.6, pp.461–464, June 2009.

[6] P. Kela, J. Puttonen, N. Kolehmainen, T. Ristaniemi, T. Henttonen, and M. Moisio, "Dynamic packet scheduling performance in UTRA long term evolution downlink," Proc. 2008 3rd International Symposium on Wireless Pervasive Computing, IEEE, May 2008.

[7] G. Monghal, K.I. Pedersen, I.Z. Kovacs, and P.E. Mogensen, "QoS oriented time and frequency domain packet schedulers for the UTRAN long term evolution," Proc. VTC Spring 2008 - IEEE Vehicular Technology Conference, IEEE, May 2008.

[8] Y. Lin and G. Yue, "Channel-adapted and buffer-aware packet scheduling in LTE wireless communication system," Proc. 2008 4th International Conference on Wireless Communications, Networking and Mobile Computing, IEEE, Oct. 2008.

[9] S. Sesia, M. Baker, and I. Toufik, LTE - The UMTS Long Term Evolution, Wiley John & Sons, 2011.

[10] S.B. Lee, I. Pefkianakis, A. Meyerson, S. Xu, and S. Lu, "Proportional fair frequency-domain packet scheduling for 3GPP LTE uplink," Proc. IEEE INFOCOM 2009 - The 28th Conference on Computer Communications, IEEE, April 2009.

[11] Y. Zaki, T. Weerawardane, C. Gorg, and A. Timm-Giel, "Multi-QoS-aware fair scheduling for LTE," Proc. 2011 IEEE 73rd Vehicular Technology Conference (VTC Spring), IEEE, May 2011.

[12] C.L. Liu and J.W. Layland, "Scheduling algorithms for multiprogramming in a hard-real-time environment," J. ACM, vol.20, no.1, pp.46–61, Jan. 1973.

[13] G. Piro, L.A. Grieco, G. Boggia, R. Fortuna, and P. Camarda, "Two-level downlink scheduling for real-time multimedia services in LTE networks," IEEE Trans. Multimedia, vol.13, no.5, pp.1052–1065, Oct. 2011.

[14] M. Haferkamp, B. Sliwa, C. Ide, and C. Wietfeld, "Payload-size and deadline-aware scheduling for time-critical cyber physical systems," Proc. 2017 Wireless Days, IEEE, March 2017.

[15] Y. Zhang, M. Wu, R. Zhang, P. Zhou, and S. Di, "Adaptive QoS-aware resource allocation for high-speed mobile LTE wireless systems," Proc. 2013 IEEE Globecom Workshops (GC Wkshps), IEEE, Dec. 2013.

[16] M.M. Hamed, S. Shukry, M.S. El-Mahallawy, and S.H. El-Ramly, "Modified earliest deadline first scheduling with channel quality indicator for downlink real-time traffic in LTE networks," Proc. The Third International Conference on e-Technologies and Networks for Development (ICeND2014), IEEE, April 2014.

[17] M.M. Andreozzi, G. Stea, A. Bacioccola, and R. Rossi, "Flexible scheduling for real-time services in high-speed packet access cellular networks," Proc. 2009 European Wireless Conference, IEEE, May 2009.

[18] N. Khan, M.G. Martini, and D. Staehle, "Opportunistic QoS-aware fair downlink scheduling for delay sensitive applications using fuzzy reactive and proactive controllers," Proc. 2013 IEEE 78th Vehicular Technology Conference (VTC Fall), IEEE, Sept. 2013.

[19] B. Liu, H. Tian, and L. Xu, "An efficient downlink packet scheduling algorithm for real time traffics in LTE systems," Proc. 2013 IEEE 10th Consumer Communications and Networking Conference (CCNC), IEEE, Jan. 2013.

[20] N. Afrin, J. Brown, and J.Y. Khan, "A packet age based LTE uplink packet scheduler for M2M traffic," Proc. 2013, 7th International Conference on Signal Processing and Communication Systems (ICSPCS), IEEE, Dec. 2013.

[21] K.M.F. Elsayed and A.K.F. Khattab, "Channel-aware earliest deadline due fair scheduling for wireless multimedia networks," Wireless Pers. Commun., vol.38, no.2, pp.233–252, June 2006.

[22] S. Siraj, A.K. Gupta, and Rinku-Badgujar, "Network simulation tools survey," International Journal of Advanced Research in Computer and Communication Engineering, vol.1, no.4, pp.201–210, June 2012.

[23] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, "SUMO — Simulation of urban mobility," Proc. The Third International Conference on Advances in System Simulation, 2011.

[24] M. Behrisch, D. Krajzewicz, and M. Weber, eds., Simulation of Urban Mobility, Springer Berlin Heidelberg, 2014.

[25] G. Piro, N. Baldo, and M. Miozzo, "An LTE module for the ns-3 network simulator," Proc. 4th International ICST Conference on Simulation Tools and Techniques, SIMUTools'11, ICST, Brussels, Belgium, Belgium, pp.415–422, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), 2011.

[26] 3GPP, "User equipment (ue) to v2x control function," Technical Reporit, TS 24.386, 2017.

Nobuhiko Itoh received his B.E. and M.E. degrees in electrical engineering from Kansai University, Japan, in 2006 and 2008. In 2008, he joined NEC Corporation, Japan. He is a senior researcher at System Platform Research Laboratories. He is currently pursuing his Ph.D. in integrated design engineering at Keio University. His research interests include system control, mobile networks, IoT service networks, and the evaluation of performance of these systems. He received Best Paper Award at the IEEE CQR Workshop 2017.

Motoki Morita received B.S. and M.S. degrees in physics from Keio University in 2000 and 2002. He joined NEC Corporation, Japan in 2002. He has been engaged in the research of radio resource management in mobile networks. He is now an assistant manager of the Smart Infrastructure Division.

Takanori Iwai received his B.E. and M.E. degrees in electrical and electronic engineering from Shinshu University, Japan, in 2002 and 2004. In 2004, he joined NEC Corporation, Japan, and is a Principal Researcher at System Platform Research Laboratories. He is currently pursuing his Ph.D. in integrated design engineering at Keio University. His research interests include system control, mobile and wireless networking, and IoT service networks. He received the Electrical Science and Engineering Award from the Promotion Foundation for Electrical Science and Engineering in 2016.

Kozo Satoda received his B.E. and M.E. degrees in electrical engineering from Kyoto University in 1991 and 1993. He joined NEC in 1993. He is a senior manager at System Platform Research Labs, NEC. He has received the best paper award at the IEEE CQR Workshop 2010, the best paper award at the IEEE CCNC 2017, an IEICE Communications Society Excellent Paper Award in 2016, an Information Network research award from IEICE, a Network System research award from IEICE, an Information Communication Management research award, 63rd Electrical Science and Engineering Promotion Awards, and the 2016 IPSJ Industrial Achievement Award. His research interests include multimedia communication, streaming, and mobile traffic management. He is a member of IEEE and IEICE.

Ryogo Kugo received his B.E. degree in system design engineering and his M.E. and Ph.D. degrees in integrated design engineering from Keio University, Japan, in 2005, 2007 and 2009. In 2007, he joined NTT Access Network Service Systems Laboratories, NTT Corporation, Japan. Since 2010, he has been with Keio University, Japan, where he is currently an Associate Professor at the Department of Electronics and Electrical Engineering. His research interests include system control, optical communications, networking, and cyber-physical systems. He received the Best Paper Award from the IEICE Communications Society in 2011, the IEEE International Conference on Communications (ICC'12) Best Paper Award in 2012, and the Leonard G. Abraham Prize from the IEEE Communications Society in 2013.