Location Based Data Delivery Schedulers for Vehicle Telematics Applications

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***Abstract*—This paper proposes four schedulers using location information and side information in telematics applications for vehicular networks. The scheduler algorithms consider peak traffic and link reliability, achieving savings of channel resources and reducing the number of retransmissions. A key feature of the proposed schedulers is the use side information in the form of a coverage map, which provides a map of link quality for the area covered by the radio access networks. In this paper, the total offered load and average excess delay are considered as two metrics for measuring the proposed schedulers, which are evaluated by simulation results. The performance of schedulers is reported and compared.**

Keywords-scheduling; data delivery; telematics; vehicular networks

I. INTRODUCTION

Vehicular networking has drawn significant attention recently as the automotive and communication industries announce plans to bring ubiquitous broadband Internet connectivity to moving vehicles. Envisioned applications include road safety, driver assistance, infotainment, and vehicle telematics utilizing a range of wireless communication methods based on Wi-Fi, dedicated short range radios (DSRC), or 3G/4G radios such as Mobile WiMAX and long term evolution (LTE). Infrastructure-based vehicular networks, also referring to vehicle-to-infrastructure (V2I) networks or vehicle-to-roadside (V2R) networks, employ statically deployed access points (APs) or base station (BSs) to connect moving cars. Despite the higher costs to deploy and maintain the AP/BS infrastructure, industries and transportation authorities are paying high attention to infrastructure-based networks due to their higher reliability and constant availability where such infrastructure exists. Recent studies have measured the performance of infrastructure-based vehicular networks analytically and practically, verifying the feasibility and performance characteristics [1-3].

Numerous studies have explored scheduling schemes for data delivery in mobile wireless networks [4-8]. In [4], a link-layer scheduling mechanism for non-real-time, non-safety data transmission in V2I systems is proposed for 802.11e standard, attempting to deliver as much information per flow as possible considering both constrained radio coverage of road segment and vehicle speed. In [5], a scheduling scheme in the downlink of a cellular network is proposed, consisting of joint Knopp and Humblet/round robin (K&H/RR) scheduling and reference channel (RC) scheduling, to achieve capacity gains and minimize the channel usage while satisfying users' quality of service (QoS) constraints. In [6], a physical-layer scheduling and resource allocation mechanism is proposed for the downlink in a CDMA system, maximizing the weighted sum throughput. In [7], a scheduling mechanism is proposed for the downlink of a cellular OFDM system, with considerations including integer carrier allocations, different sub-channelization schemes, and self-noises due to imperfect channel estimates or phase noise. Most of these scheduling schemes have not sufficiently considered the characteristics of applications in vehicular networks, and also depends on the specific low-layer technologies of radio access network (RAN). However, few works are focused on the scheduling for the applications in vehicular networks. In [8], an application-layer service scheduling of vehicle-roadside data access is proposed, considering service deadline, data size, and broadcasting.

This paper is focused on scheduling schemes for telematics service in vehicular networks. Specifically, the schedulers are implemented at the server side for navigation system, such as iPhone, Google Navi, and Android Navi, to achieve high efficient data delivery for mobiles, regardless of specific RAN technology. The objective of proposed schedulers is to save the resources (bandwidth) on the wireless channels, resulting in reducing the cost for application providers, while satisfying the requirements for mobile users at the same time. Section II introduces the background and preliminaries for the navigation systems and schedulers. Section III describes the details of the four proposed schedulers. Section IV analyzes the performance of the proposed schedulers. The paper concludes in Section V.

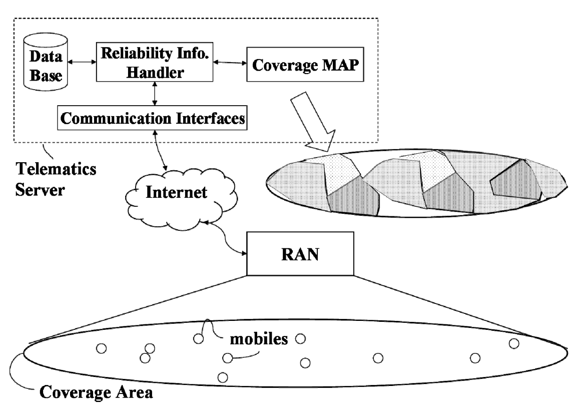


Figure 1. System structure.

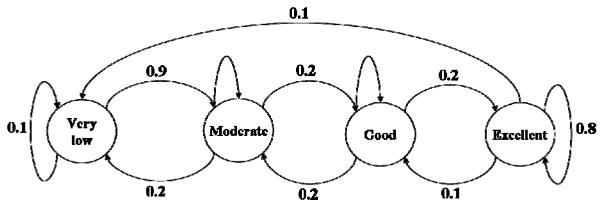


Figure 2. Markov chain of link state.

II. BACKGROUND AND PRELIMINARIES

This section first introduces the structure of navigation system for telematics in vehicular networks. Second, the model of link reliability is proposed. Third, the assumption of single packet type is addressed. Last, two performance metrics and two constraints are defined.

A. System Structure

Fig. 1 shows a diagram of the location based data (LBS) delivery. The telematics server is responsible for delivering data to mobiles as shown in Fig. 1. Mobiles are in the coverage area of RAN, and the link capacity is assumed to be known and dependents on access network technology (LTE, WiMAX, WiFi, etc). The *coverage map* is assumed to be known perfectly. The server decides the delivery timing for each mobile and the packets are delivered going through Internet and RAN, to each mobile based on information stored in the coverage map, accomplishing high efficient LBS data delivery.

The main application functions are carried out on a telematics server, which is responsible for collecting information from vehicles within the coverage area, including current position, desired destination, and recent drive times/road conditions. In addition, the telematics server provides information to vehicles in the form of navigation updates and location based services such as points of interest messages. The telematics server consists of a database, a reliability information handler, a coverage map, and various communication interfaces. The database contains information pertaining to points of interest and the locations of client vehicles. The reliability information handler manages the tasks of transmitting route update information and other messages to vehicles, as well as receiving position updates, telematic data, and service requests from the vehicles. A key feature of the telematics server is the use of the coverage map, which provides a map of link quality for the area covered by the RAN. The reliability information handler uses the MAP data to conduct tasks such as scheduling packet transmission to the vehicles based on their positions and the corresponding link quality stored in the coverage map at that position.

B. Model of link reliability

A Markov-chain model, of which the states are based on distinct transmission rates determined by signal-to-noise ratio (SNR) and modulation rates, was proposed in [9]. In this paper, the coverage map is assumed to be quantized into four states, which are very low, moderate, good and excellent, with probability of successful transmission 0.2, 0.4, 0.7 and 0.9, respectively. To model changes in the wireless channel as mobiles move through the service area, each mobile is assumed to see the state of its link follow a Markov chain which is shown in Fig. 2. According to the Markov chain in Fig. 2, the stationary distribution of link states {very low, moderate, good, excellent} is {0.1127, 0.3803, 0.2535, 0.2535}.

C. Single packet type

At the server, the arrival process of each packet for any mobile is assumed to follow the Poisson distribution, with the arrival rate λ. In this paper, the total number of mobiles connect to the server is set as 1000, and the range of λ is considered as [0.001, 0.006] packets/minute/vehicle.

D. Performance Metrics and Constraints

In general, it is desirable that the scheduler in the telematics server attempts to minimize the overall amount of traffic that is sent over the RAN. As noted in Section II.A the scheduler has access to the coverage map and also has knowledge of each mobile's location in the service area (or has an estimate of the mobile location from previous driving histories, location updates or navigation routes the mobile is following). Thus a simple approach to minimize the total traffic is simply waiting until the mobile is in a location in which the coverage map indicates there is a high probability of reception. Then the scheduler will transmit any packets destined to that mobile. This approach, however, does not take into account the delay incurred by waiting for favorable channel conditions. One may also consider that information destined to each mobile needs to be delivered in a timely fashion.

To achieve this goal of minimizing transmission and delay we have considered constraining the scheduling of packets according to two metrics. The two metrics are the total offered load and average excess delay. The total offered load is the total number of transmissions including the initial transmissions and retransmissions. The average excess delay is the time a packet must wait if it is not scheduled for transmission at the instant at which it arrives at the telematics server. The scheduler is assumed to operate in a slotted fashion. That is during each slot the scheduler examines pending packets and decides whether to transmit the packet in the current slot or delay transmission to a subsequent slot. Also, the time required to transmit a packet is assumed to be short compared with a scheduling slot so that packet transmission time along with all necessary retransmissions occurs within a slot duration. In the simulations 1 minute is taken as the slot duration and the average excess delay means the average amount of time a packet waits for transmission in terms of slot ignoring the packet length.

Two schedulers constraints are considered in this paper: a peak constraint and a threshold of link reliability. The peak constraint is the maximum number of transmissions allowed in one slot. Setting a peak constraint saves bandwidth and avoiding excessive utilization of RAN resources. Secondly, a threshold of link reliability is a threshold on the probability of successful transmission. Packets are only transmitted if the probability of successful transmission in current slot is above the threshold. Thus the reliability threshold limits transmissions to periods of high link quality, reducing the number of retransmissions.

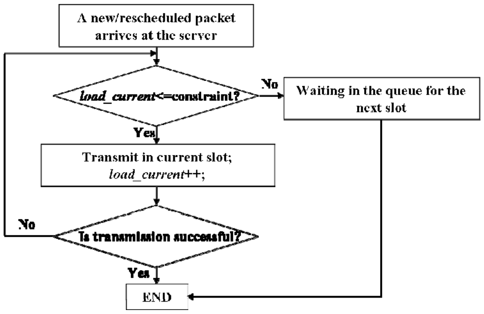


Figure 3. FCFS with peak constraint.

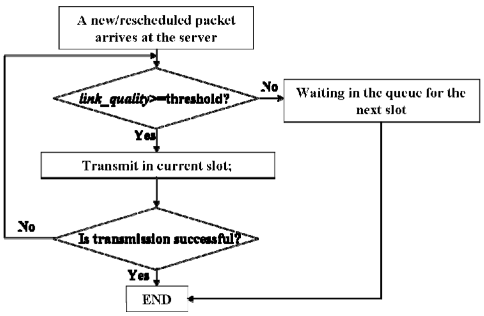


Figure 4. FCFS with link reliability.

III. The Proposed Scheduling Schemes

In this section, four schemes of LBS data delivery schedulers are proposed, considering peak traffic constraint and link reliability for the telematics server. These four schemes are (1) First Come First Serve (FCFS) with peak constraint; (2) FCFS with link reliability; (3) FCFS with peak constraint and link reliability; (4) FCFS with peak constraint and partial link reliability.

Fig. 3 shows a block diagram of FCFS with peak constraint. This scheduler sets a peak constraint and only transmit/retransmit the packet if the offered load in current slot has not exceeded the peak constraint. At the beginning a new/rescheduled packet arrives at the server. The server makes a decision by checking the offered load in current slot, *load_current* with peak constraint. If yes, this packet is scheduled to be transmitted in current slot and *load_current* increases by one; if no, the packet is delayed until the next scheduling slot. After transmission, the server checks the success of transmission for this packet. If this transmission is successful, the procedure goes to END; and if the transmission fails, the procedure goes back to make a decision for retransmitting or rescheduling.

The scheduling procedure described in Fig. 3 only considers the peak constraint and does not make use of the coverage map in determining the scheduling slot. Thus a packet destined for a mobile that is currently in a region with poor coverage can be retransmitted many times within the scheduling slot. This will cause packets destined to other mobiles to be unnecessarily delayed. That is if the scheduler had chosen to deliver packets to only mobiles in good to excellent coverage area then more packets destined to different mobiles could have been delivered. This case is considered next.

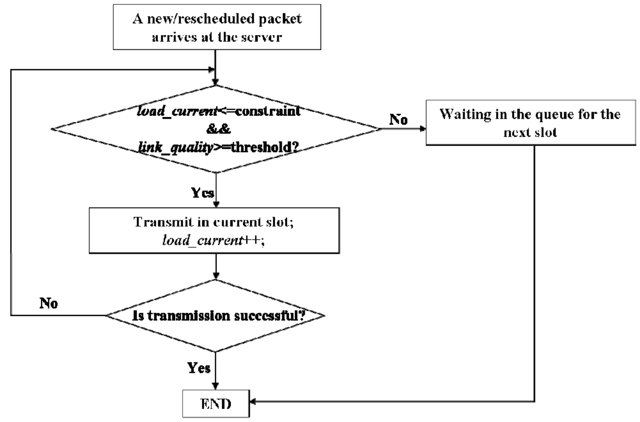


Figure 5. FCFS with peak constraint and link reliability.

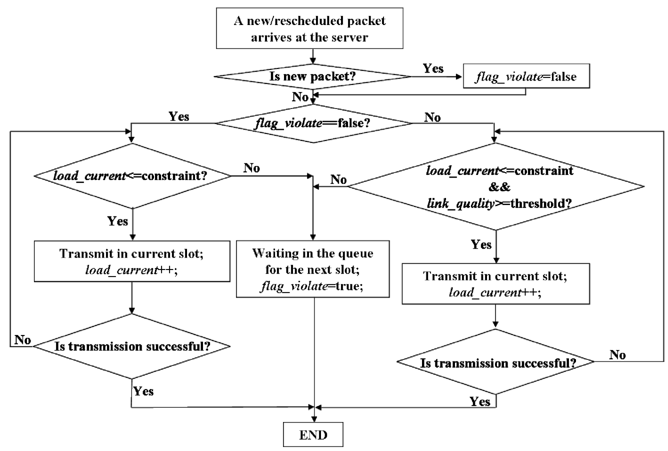


Figure 6. FCFS with peak constraint and partial link reliability.

Fig. 4 shows a block diagram of FCFS with link reliability. This scheduler is designed to schedule the packets during times of high link quality to reduce retransmissions, resulting in a reduction in the total offered load. At the beginning a new/rescheduled packet arrives at the server. The server makes a decision by first checking the destination mobile's link quality to insure that the value, *link_quality*, is above a given threshold of link reliability. If yes, this packet is scheduled to be transmitted in current slot; if no, it is waiting in the queue for the next slot. After transmission, the server checks the success of transmission for this packet. If this transmission is successful, the procedure goes to END; and if fails, the procedure goes back to make a decision for retransmitting or rescheduling.

This process ensures that only mobiles in areas where the link quality is above the scheduler's threshold are served. It does not guarantee any peak traffic constraint however since the scheduler will transmit all of the packets for which the mobiles have reasonably good link quality. The features of the two algorithms above are combined for the next scheduler to consider both peak traffic constraint and link quality.

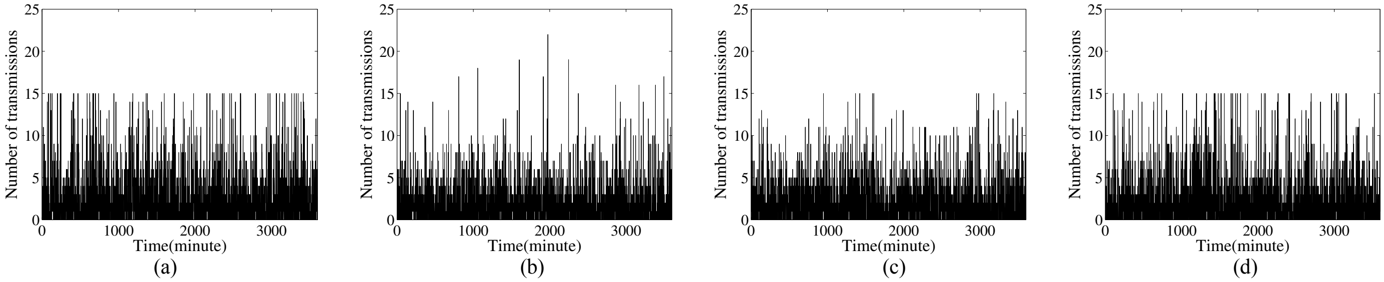


Figure 7. The number of transmissions versus time. (a) Scheduler (1). (b) Scheduler (2). (c) Scheduler (3). (d) Scheduler (4).

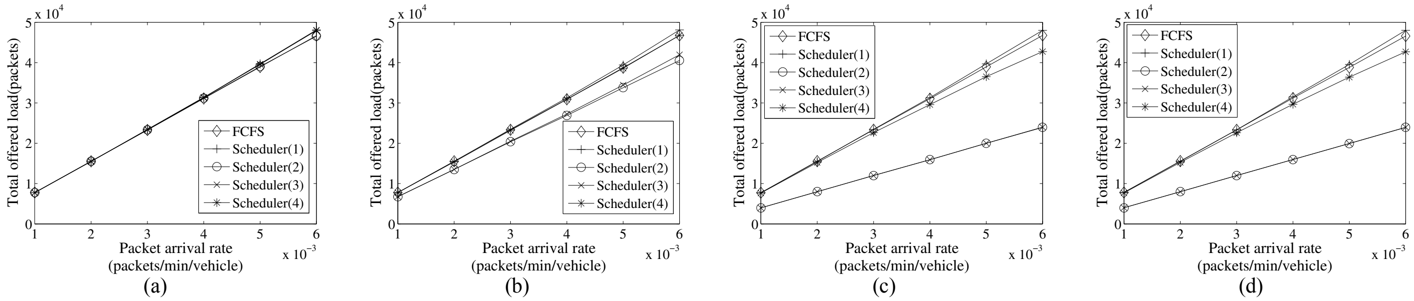


Figure 8. The total traffic load versus packet arrival rate when reliability threshold is (a) 0.2, (b) 0.4, (c) 0.7, and (d) 0.9.

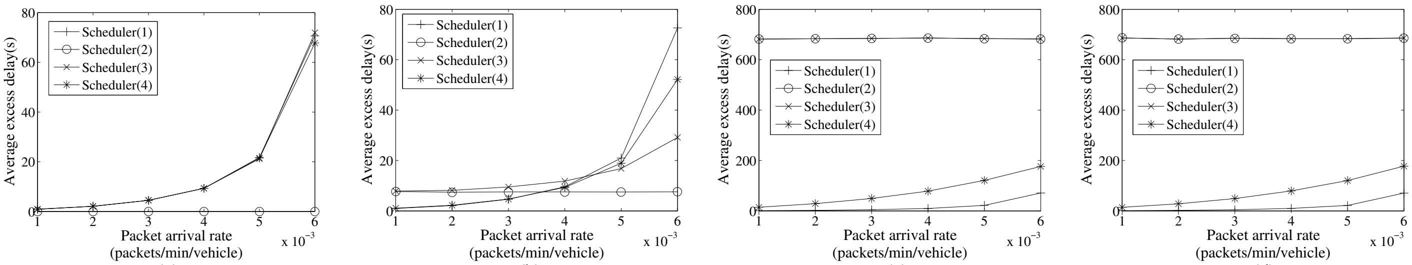
Fig. 5 shows a block diagram of FCFS with both peak and link reliability constraints. This scheduler avoids exceeding a peak constraint but also uses the coverage map to schedule the transmissions during times of high link quality. At the beginning a new/rescheduled packet arrives at the server. The server makes a decision by checking *load_current* against the peak constraint and checking *link_quality* with the reliability threshold. If load current is less then the peak constraint and the link reliability is greater than the reliability threshold, this packet is scheduled to be transmitted in current slot and *load_current* increases by one; if no, it is delayed until the next scheduling slot. After transmission, the server checks for successful reception of the packet. If this transmission is successful, the procedure goes to END; and if the transmission fails, the procedure goes back to make a decision for retransmitting or rescheduling.

Thus only packets that are destined for mobiles in regions of high link quality are transmitted as long as the total number of transmission attempts has not exceeded the peak constraint. This scheduling algorithm will reduce the offered load presented to the RAN since the number of retransmission will be limited by the link quality threshold. In addition, the scheduler imposes a limit on the total number of transmission attempts by enforcing the peak constraint. Due to the persistent checking of link quality at the scheduler the delay incurred by some packets may be quite significant, since some mobiles may be in regions of poor coverage. These mobiles will not have any packets scheduled for delivery until they move into better coverage areas. Thus some relaxation of the link quality constraints is allowed for the next scheduler in order to attempt the delivery of packets even when the link quality is known to be below the threshold. This has the effect of reducing the excess delay incurred by the scheduler at the expense of some increase in the offered load.

Fig. 6 shows a block diagram of FCFS with peak constraint and partial link reliability. This scheduler considers peak constraint for scheduling all the packets, and considers both peak constraint and reliability threshold only for those packets, which violate the peak constraint, in the following transmissions until success. At the beginning a new/rescheduled packet arrives at the server. The server first checks whether this packet is a newly arrived packet or a rescheduled packet. If it is a rescheduled packet the procedure directly goes to make a decision by checking the value of the flag for violating the peak constraint for this particular packet *flag_violate*. If this packet is a newly arrived packet the server sets *flag_violate* as false. If the decision for *flag_violate* is yes the server makes a decision by only checking *load_current* with peak constraint; if no the server makes a decision by checking both *load_current* with peak constraint and *link_quality* with the reliability threshold. After making a decision for *load_current* or *load_current*/*link_quality*, the following procedures are similar. If the decision is yes this packet is scheduled to be transmitted in current slot and *load_current* increases by one; if no, it is delayed until the next slot, and the server sets *flag_violate* as true. After transmitting in current slot, the server checks the success of transmission for this packet. If this transmission is successful, the procedure goes to END; and in the case of a transmission failure, the procedure goes back to make a decision for retransmitting or rescheduling.

IV. PERFORMANCE ANALYSIS

In this section, the performance of the four proposed schedulers is analyzed. The simulations were done using Matlab. The peak constraint was set to 15 and four reliability thresholds (0.2, 0.4, 0.7 and 0.9) are considered in this section. For simplicity, the name Scheduler (1), (2), (3), and (4) are used to represent FCFS with peak constraint, FCFS with link reliability, FCFS with peak constraint and link reliability, and FCFS with peak constraint and partial link reliability, respectively.



(a) (b) (c) (d)

Figure 9. The average excess delay versus packet arrival rate when reliability threshold is (a) 0.2, (b) 0.4, (c) 0.7, and (d) 0.9.

Fig. 7(a), (b), (c), and (d) show the number of transmissions versus time for the four schedulers (the threshold is 0.4). As expected, the total number of transmissions for each slot is limited by the peak constraint shown in Fig. 7(a), (c) and (d). In Fig. 7(b) and (c), the total number of transmissions is less than that in Fig. 7(a) and (d), because of the persistent checking of link quality.

Fig. 8(a), (b), (c), and (d) show the total offered load versus packet arrival rate when the reliability threshold is 0.2, 0.4, 0.7, and 0.9, respectively. Fig. 8(a) shows that the total offered loads of all four schedulers are close to that of FCFS with no constraints (peak or reliability), this is due to the reliability threshold setting of 0.2 (state "very low") the probability of rescheduling the transmissions due to bad link quality is 0.1127 according to the stationary distribution of the Markov chain. In Fig. 8(b), (c), and (d), the effect of the reliability threshold is apparent and reduction of the offered load is observed. Intuitively, this is because higher reliability thresholds are applied. Scheduler (2) and Scheduler (3) are the best two schedulers when reliability threshold is 0.4, 0.7, and 0.9, while Scheduler (4) is falls between (1) and (3); Scheduler (1) is the worst, e.g. the best two are better than the latter two by 80% and 100% approximately when packet arrival rate is 0.006 and reliability threshold is 0.7 in Fig. 8(c).

Fig. 9(a), (b), (c) and (d) show the average excess delay versus packet arrival rate when reliability threshold is 0.2, 0.4, 0.7, and 0.9, respectively. Fig. 9(a) shows that the average excess delay of Scheduler (1), Scheduler (3), and Scheduler (4) is close to each other when reliability threshold is 0.2, while the delay of Scheduler (2) is the lowest due to the low reliability threshold has negligible effects on the delay compared to that caused by peak constraint. From Fig. 9(b), when reliability threshold is 0.4 it is indicated that the delay of Scheduler (1) and Scheduler (4) is lower than the other two if the traffic load is not heavy, e.g. the packet arrival rate is below 0.003 packets/min; Scheduler (2) performs stable and flat as the packet arrival rate increases; the delay by Scheduler (1), Scheduler (4), and Scheduler (3) is significantly increased as the traffic load increases, e.g. exceed the delay of Scheduler (2) by 859.78%, 589.58%, and 285.1%, respectively, when packet arrival rate is 0.006 in Fig. 9(b). The performance of delay is similar for reliability threshold is 0.7 and 0.9 shown in Fig. 9(c) and (d), which indicates that the delay is not affected apparently by the increase of threshold once the packets are only allowed when relatively "good" link quality or higher. From Fig. 9(c) and (d), Scheduler (3), and Scheduler (2) are the worst two cases, while the Scheduler (1) performs best and Scheduler (4) is medium.

Combining Fig. 8 and 9, it is indicated there exists a tradeoff between achieving minimum total offered load and minimum average excess delay. Actually such tradeoff comes from the setting of peak constraint and reliability threshold. The choice for type of scheduler and reliability threshold at the server depends on the tolerance for offered load and excess delay by specific applications. The proposed schedulers emphasize allocation for slot-based arrived packets; an analytical model and discussion of the optimal solution considering the tradeoff will be considered in the future work.

V. CONCLUSION

Four schedulers of data delivery for telematics in vehicular networks are proposed in this paper. Peak constraint and threshold of link reliability are considered as two constraints for designing schedulers to avoid peak traffic and reduce the retransmission, respectively. The selection for type of scheduler and reliability threshold is based on the tradeoff between total offered load and delay, depending on performance requirements by specific applications.

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