VECADS: VEhicular Context-Aware Downstream Scheduling for Drive-thru Internet

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***Abstract*— We study the downlink scheduling performance of an IEEE 802.11-based roadside Access Point(AP) serving a number of moving vehicles. For determining the scheduling order, *Throughput* and *Fairness* are two important considerations. If *System Throughput Maximization* is the sole consideration, some vehicles can always get resource from the AP whereas some are starved. On the other hand, if *Fairness* is the sole consideration, resource should be allocated among all the contending vehicles regardless of individual vehicle's channel conditions and the system utilization should not be affected greatly. In this paper[1], we propose a novel scheduling algorithm called VEhicular Context-Aware Downstream Scheduling(*VECADS*). By exploiting the real-time vehicular context including the position, speed and cumulative data received by each vehicle, the scheduler can get up-to-date information to determine an appropriate scheduling order. The design objective of *VECADS* is to strike a better balance between *System Throughput* and *Fairness* among heterogeneous drive-thru vehicles. The performance of *VECADS* is evaluated via extensive ns2 simulations using real-world vehicular traffic traces. We show that *VECADS* outperforms *MV-MAX*, the state-of-the-art scheduling scheme for Drive-thru networks, in terms of system throughput, by 7 % while eliminating the bandwidth starvation problem of "weak" vehicles under *MV-MAX* for a Jain's Index of 0.895 vs. 0.727.**

I. INTRODUCTION

Drive-thru Internet Systems describe the systems in which vehicles can access to the Internet via roadside Access Points(APs) when they are moving along the roads. The APs are operated in IEEE 802.11 and they provide free Internet access services for vehicular users as usual. These systems can be applied to streets in cities or highways between towns. Traffic flows on the roads in these systems can be huge. Contention for AP's resource is likely to happen when multiple vehicles are within the AP's coverage.

Some experimental measurements on Drive-thru Internet Systems have been done like [7], [8], [13], [14], [16], [20]. They are related to *Throughput* measurements. In particular, David Hadaller et al. in [7] have given a detailed analysis on the factors affecting downlink performance when a moving vehicle passing an AP's coverage. Some researchers have focused on improving *Throughput* by means of leveraging association process using GPS-coded signal history information [9], shortening initialization time [10] and minimizing disruptions during a connection by exploiting basestations diversity [15]. Besides, some researchers have found the optimal solution on maximizing *Throughput* via correct placements of the APs [11] and correct selection of the AP to associate with from a number of APs [12].

Our work is different from the previous work. We consider high-density deployment scenario where resource contention is likely to happen as opposed to sparse, single-vehicle drive-thru. We also consider the heterogeneity in signal profiles experienced by the vehicles. There are different types of vehicles. Normal vehicles mean the cumulative bytes received(per vehicle per drive-thru) is roughly equal to the expectation resulted from having normal speed and having normal-gain antennas. "Strong" vehicles mean having the cumulative bytes received much more than the normal expectation resulted from their slow-moving behavior and/or having high-gain antennas. "Weak" vehicles mean having the cumulative bytes received much lower than the normal expectation resulted from their fast-moving behavior and/or having low-gain antennas. We want to maintain *High System Throughput* while achieving *Fairness* in the AP's downlink scheduling under the consideration of the AP's resource contention by different vehicles.

We design a novel algorithm called VEhicular Context-Aware Downstream Scheduling(*VECADS*). Our work is targeted for the Drive-thru Internet Systems on highways with unidirectional vehicular traffic flows. Specifically, a number of moving vehicles contend for resource from an IEEE 802.11-based roadside AP. The situation is illustrated in Figure 1.

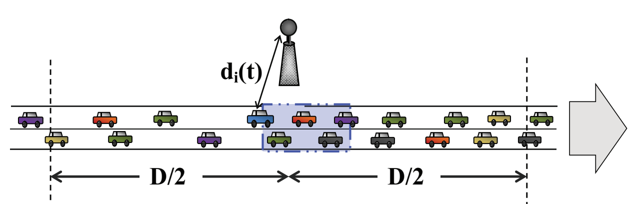

Fig. 1. Highway Scenario for Drive-thru Internet

VECADS exploits the vehicular feedback context information like vehicles' speeds, locations, signal strengths and

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cumulative bytes received to improve *System Throughput*. Moreover, an AP under *VECADS* will adjust the scheduling order to help "weak" vehicles if needed in order to avoid starvation and as a result improve *Fairness*. We implement *VECADS* in NS2 and conduct extensive simulations using real-life vehicular traffic traces to evaluate its performance.

The organization of this paper is as follows: Related work is included in Section II. The design and implementation of *VECADS* scheme are included in Section III. Performance evaluation of *VECADS* is performed in Section IV. Conclusion and discussion are given in Section V.

II. Related Work

A scheduler in the IEEE 802.11-based AP [2], [4], [5], [7] uses round-robin scheduling to deliver packets to clients. However, it does not consider any vehicular context like the vehicles' positions in the scheduling decision which eventually leads to poor *System Throughput* and is not suitable for the Drive-thru Internet scenarios. *MV-MAX* has been proposed in [3] which always serves the vehicle that experience the *best* Signal-to-Noise Ratio (SNR). Although *High System Throughput* can be achieved, *MV-MAX* starves some vehicles and causes unfairness in serving. [17] and [18] are related to the scheduling using *CDMA - HDR* for Internet data access in cellular networks. By choosing the client who has the highest instantaneous value of the instantaneous requested data rate over average data rate, proportional fairness can be achieved. Since the average data rate takes some time to converge and *CDMA - HDR* does not make use of the vehicular context information, the scheduling decision fails to take advantage of the more predictable variations in channel conditions caused by the vehicle trajectory in a drive-thru internet system. *BGFS-EBA* has been proposed in [19] which makes use of the excess bandwidth to serve clients who get less cumulative bytes received with the goal of achieving *Outcome Fairness*. Note that *BGFS-EBA* does not primarily focus on vehicular scenarios and it is less adaptive by stopping each flow from getting more resourceres from the AP when the vehicle's throughput exceeds certain threshold.

The authors have proposed a new rate adaptation algorithm called *CARS* in [2] which makes use of the vehicular context, i.e. the distance between the sender and the receiver and the vehicle's speed, to determine the next MAC data rate. The introduction of the use of vehicular context for the rate adaptation process is innovative. However, as [2] considers *Throughput Improvement* in turn of rate adaptation but not scheduling, it ignores the consideration of any unfairness issue resulted from the heterogeneities of vehicles. *RAM* has been proposed in [21] which is receiver-based and SNR-triggered rate adaptation algorithm. It changes the transmit rates of ACK frames wisely to indicate to the sender that suitable transmit rates should be sent to the receiver. The whole design is implementable in reality. But same as *CARS*, *RAM* does not address any fairness issue. *WARP* is a customized cross-layer rate adaptation platform proposed in [22]. It uses trained SNR values based on the coherence time of the environment.

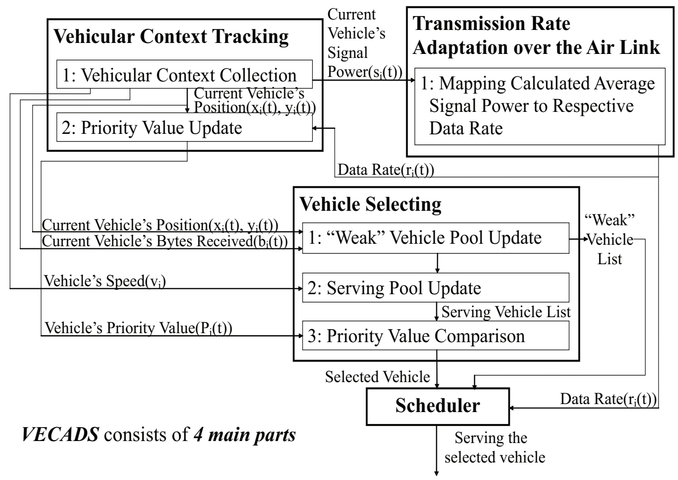

Fig. 2. Overall System Architecture of *VECADS*

Yet, the real-time training adds additional overheads for the rate adaptation process. Same as the previous rate-adaptation algorithms, *WARP* does not address the fairness issue.

III. Design and Implementation of *VECADS*

In this section, we describe the design and implementation of *VECADS* scheme. *VECADS* consists of 4 parts, the vehicular context tracking, the transmission rate adaptation over the air link, the vehicle selector and the scheduler. Figure 2 shows the overall system architecture of *VECADS*. For our design, a vehicle will send an ACK to the AP whenever it receives any unicast data frame or Beacon frame. The ACK contains vehicular context information which includes vehicle's received signal power, position, speed and cumulative bytes received. Therefore, for the vehicular context tracking in *VECADS*, it gathers the vehicular context information from the vehicles inside the AP's coverage and then it can perform priority update using the signal and proximity parameters. For the transmission rate adaptation over the air link, it maps the signal power to a respective data rate for next transmission. For the vehicle selector, there are 3 modules. The first module checks whether there are "weak" vehicles in the *"Weak" Vehicle Pool*. If yes, it will past them to the scheduler to serve in a round-robin manner. If no, it will proceed to second module and to construct the *Serving Pool* determined by the vehicles' speeds. The aim of this module is to penalize slow-moving vehicles. After this, the *Serving Vehicle List* can be obtained. By comparing the priority values of the vehicles in the third module, the module selects the highest one and pass it to the scheduler. The scheduler will serve the chosen vehicle with respective data rate.

The design objective of *VECADS* is to strike a balance between (A) System Throughput Maximization, and (B) Fairness with Starvation Avoidance. For (A), we have one idea: 1) Using Vehicular Context to Help Scheduling. For (B), we have two ideas: 1) Penalizing Slow-moving Vehicles in the Coverage and (2) Round-Robin Scheduling for "Weak"

Vehicles in the *Sweet Zone*. We describe them in details as follows.

A. Using Vehicular Context to Help Scheduling

VECADS makes use of vehicular context information. For the basic setting, Transmission Data Rate($r_i(t)$) by the AP to vehicle i at time t and the distance between the AP and the vehicle $i(d_i(t))$ at time t are chosen as the context. The reason for using both of them is to make the scheduling decision more reliable. In order to have a better evaluation of the scheduling priority for each vehicle quantitatively, we calculate the priority value of each vehicle by including both the channel quality's parameter $r_i(t)$ and the distance's parameter $d_i(t)$ in the calculation. The priority value is a function of $r_i(t)$ and $d_i(t)$ and the expression is:

$$P_i(t) = f(r_i(t), d_i(t))$$

Since we want to do priority comparison for different vehicles, it is better to normalize $r_i(t)$ and $d_i(t)$ in the calculation. For $r_i(t)$, it is normalized by the Nominal Data Rate $R(t)$ of the vehicles in the AP's coverage range within a period of time up to time t. The expression is:

$$\hat{r}_i(t) = \frac{r_i(t)}{R(t)}$$

For $d_i(t)$, we denote a new normalized proximity parameter for vehicle i at time t as $\hat{c}_i(t)$. $\hat{c}_i(t)$ should be inversely proportional to $d_i(t)$, i.e. $\hat{c}_i(t) \propto \frac{1}{d_i(t)}$. The reason for creating such variable is to assign a high priority value in calculation when vehicle i comes close to the AP. We make use of the standard AP's Coverage Radius $\frac{D}{2}$(see Figure 1) for the normalization. Specifically, the distance between the AP and the vehicle $i(d_i(t))$ at time t is subtracted from $\frac{D}{2}$ and the difference is further divided by $\frac{D}{2}$. The expression is:

$$\hat{c}_i(t) = \frac{\frac{D}{2} - d_i(t)}{\frac{D}{2}}$$

Therefore, for priority value assignment, it is a function of the normalized data rate($\hat{r}_i(t)$) and the normalized proximity parameter($\hat{c}_i(t)$) and the expression is:

$$P_i(t) = f(\hat{r}_i(t), \hat{c}_i(t))$$

In particular, we take $f(\cdot)$ as the minimum function, i.e. taking $P_i(t) = \min[\hat{r}_i(t), \hat{c}_i(t)]$ so that the AP will only serve vehicles that have higher data rates and they are geographically located near the AP's position. As such, the performance degradation problems caused by serving low-data-rate vehicles at the fringe area can be eliminated [6]. Also, vehicles that have extra high-gain antennas but are far away from the AP are penalized. This can reduce their share of time in getting AP's resource. One drawback of this approach is that for those vehicles which are close to the AP but experience poor channel conditions (i.e. lower data rates) will be suffered. Still, we use this method as the primary priority assignment scheme because the goal of this part is to increase accuracy in selecting vehicles to serve and achieve effectiveness of utilizing the AP's resource. In Subsection III-C, we will introduce an additional idea to help those "weak" vehicles. We have also considered an alternative version of the normalized proximity parameter, denoted by $\tilde{c}_i(t)$ which maps $d_i(t)$ to another discrete value via a stepwise function called $Stepwise\ Distance()$ based on the calculation of received power thresholds on different data rates using Free Space Model.

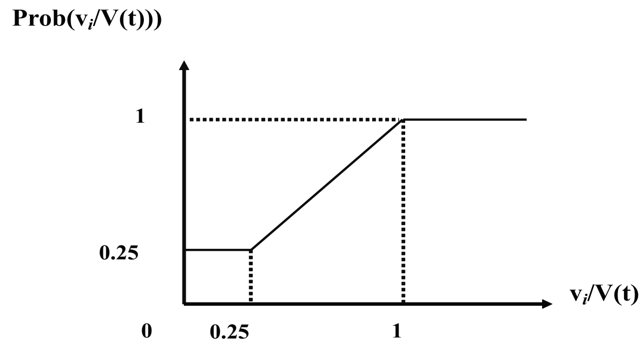

Fig. 3. Probability Model on Penalizing Slow-moving Vehicles

B. Penalizing Slow Vehicles in the Coverage

Normally, for a slow-moving vehicle, it has more time and more chance to interact with the AP. It is expected that the vehicle can get more resource from the AP. For a fast-moving vehicle, the situation is opposite. In our study, we find that if there are plenty of fast-moving vehicles inside the coverage, giving absolute priority for those fast-moving vehicles to get the AP's resource will starve those slow-moving vehicles.

Therefore, we propose to use a probability model to penalize the slow-moving vehicles. It is implemented in the AP's scheduling process. First, we define a pool of vehicles called the *Serving Pool*. The *Serving Pool* is to store potential candidates to receive services from the AP. When a vehicle i has a normal speed or a higher speed v_i compared with the Nominal Speed $V(t)$ of the vehicles in the coverage within a period of time up to time t, vehicle i can always be admitted into the *Serving Pool*. When a vehicle's speed is lower than $V(t)$, its probability of being admitted into the *Serving Pool* is reduced. The related probability is linearly proportional to the speed of the slow-moving vehicle its own and is represented by $\frac{v_i}{V(t)}$. There is a minimum threshold $Prob_{min}$ on the probability function. We guarantee that all the slow-moving vehicles have opportunity to be admitted into the *Serving Pool*. We set this threshold to be 0.25. Figure 3 shows the details of the probability function. The AP determines the probabilities of all the clients and pushes the successful candidates into the *Serving Pool* in each round of scheduling. Then, the AP can choose one candidate in the *Pool* to serve according to the idea in Subsection III-A.

Parameters	Values
Simulation time	2100sec
Number of vehicles	1000
Vehicles' speeds	{8.94, 13.41, 17.88}m/s
AP's carrier sensing range	200m
AP's transmission thresholds	{4.13e-09, 2.13e-09, 1.72e-09, 9.60e-10}W [1]
Data traffic protocols	CBR/UDP/IP/MAC 802.11b
MAC	IEEE 802.11b(RTS/CTS turned off)
MAC bit rate	{11, 5.5, 2, 1}Mbps
CBR packet size	1000bytes
AP's Beacon interval	100ms
Transmission power	100mW
Transmission frequency	2.437GHz(channel 6)
Antenna Gain	G_T=G_R; AP=1, Vehicles={0.5, 1, 1.5}
Antenna Type	Omnidirectional
Propagation Model	Ricean and Two Ray Ground Reflection models
RiceanKdB	6
RiceanMaxVel	17.88m/s

TABLE I
NS2 SIMULATION PARAMETERS

C. Round-Robin Scheduling for "Weak" Vehicles in the "Sweet Zone"

Penalizing slow-moving vehicles using the idea in Subsection III-B is not enough for helping "weak" vehicles. The reason is that "strong" vehicles can still be admitted into the *Serving Pool* in each round of scheduling and they are always selected to serve under the idea in Subsection III-A due to stronger signal they received. Clearly, we need to help "weak" vehicles explicitly. In this part, we define a region called the *"Sweet Zone"* specifically for "weak" vehicles to get data as long as they get close to the AP. It is illustrated as the shadow region in Figure 1.

When vehicles enter the *"Sweet Zone"*, the AP will check their cumulative bytes received. Suppose vehicle i gets less throughput than half of the Nominal Cumulative Bytes Received $B(t)$ of the vehicles inside the AP's coverage at time t, i.e. $b_i(t) < \frac{B(t)}{2}$, the AP will put vehicle i into the *"Weak" Vehicle Pool*. Vehicle i will be served in this round of scheduling regardless of its priority value. In addition, if there is more than one vehicle in the *"Weak" Vehicle Pool*, the AP will serve them in a round-robin manner. This round-robin scheduling is different from that of typical IEEE 802.11 in a way that the served vehicles are close to the AP and they are achieving their maximum possible data rates. We emphasize that no matter a "strong" vehicle or a "weak" vehicle, when it is far away from the AP, the maximum achievable data rate is not high as power loss is proportional to the distance from the source. Therefore, we define the *"Sweet Zone"* to be a reasonable size. This is bounded by the area for which a normal vehicle can achieve its maximum data rate.

IV. SIMULATION RESULTS

To evaluate the downlink scheduling performance of a roadside AP under different scheduling schemes, we run extensive NS2 simulations. Simulation parameters are listed in Table I. The scenario is on a freeway. The simulation time is 2100sec with the traffic flow of 1800 vehicles passing a lane in an hour. A roadside AP is operated in the Infrastructure mode with RTS/CTS turned off. It is the sole major sender of packets and always sends data to vehicular clients. The AP uses CBR/UDP/IP/MAC as the transmission protocols. It uses IEEE 802.11b for the MAC layer. The data size is fixed as 1000bytes so it won't be fragmented in MAC layer for transmission. The AP and the vehicles have one antenna on their own and they use one channel for communications only. For the channel propagation model, we use the Two Ray Ground Reflection model as the large-scale path loss model and the Ricean Fading model be the small-scale fading model. Channel links between senders and receivers are assumed to be asymmetric. Vehicles keep their speeds throughout their journeys. When a vehicle receives a corrected Beacon frame, a series of connection establishment processes which involve requests and replies are kicked off. After that, the vehicle can always perform downloading. In order to produce heterogeneity in signal profiles received by the vehicles, we set 3 different types of antenna gains and 3 types of speeds. The antenna gains are classified as low-gain(0.5), normal-gain(1) and high-gain(1.5). The speeds are classified as slow-moving speed(8.94m/s $\approx$ 20mph), normal-moving speed(13.41m/s $\approx$ 30mph) and fast-moving speed(17.88m/s $\approx$ 40mph). The values of speeds are chosen from 16:00-16:59 of slow lane 4 of the real mobility traces of I-80 Highway [23].

A. Distribution of the Cumulative Bytes Received of all the Vehicles

Figure 4 shows the distribution of the cumulative bytes received by all the vehicles(per vehicle per drive-thru). For the *VECADS w/o SA* scheme, it does not include *Starvation Avoidance*, the scheduler only selects vehicle which has the highest priority value to serve and aims to achieve *System Throughput Maximization*. For the *VECADS w/ SA* scheme, it includes *Starvation Avoidance*, it makes use of different methods including the use of *Stepwise Distance()*, penalizing slow-moving vehicles and also applying the *"Sweet Zone"* to help "weak" vehicles. The goal is to achieve *Outcome Fairness* with *Starvation Avoidance* and to maintain *High System Throughput*.

From the graph, we can see that IEEE 802.11 Scheduler and MAC performs the worst with about 75% of clients receiving less than 0.1Mbytes cumulative bytes. All other scheduling schemes perform much better with nearly 98% clients receiving more than 0.1Mbytes in these schemes. For the *VECADS w/o SA* scheme, nearly 90% of clients get more bytes than *MV-MAX*. This implies that vehicular context information, other than just using noisy channel parameter, can leverage *High System Throughput* in the scheduling process. For the remaining 10%, as the AP applies a strict rule that only vehicles which are close to the AP and experience good channel conditions are selected to serve and others are ignored. For the *VECADS w/ SA* scheme, around 65% of "weak" and normal vehicles get much more throughputs than those vehicles in *MV-MAX* whereas the other 35% vehicles get less

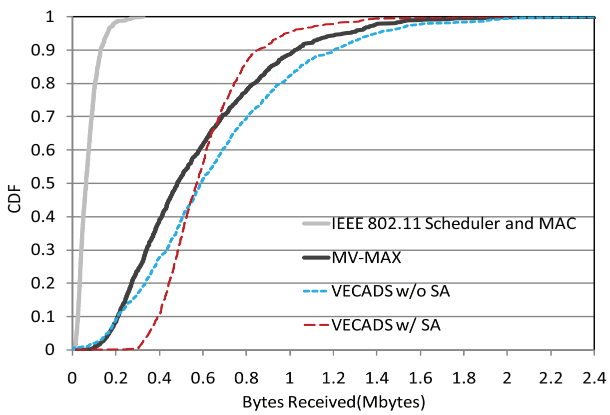

Fig. 4. Distribution of the Cumulative Bytes Received of all the Vehicles(bi(t))(per vehicle per drive-thru)

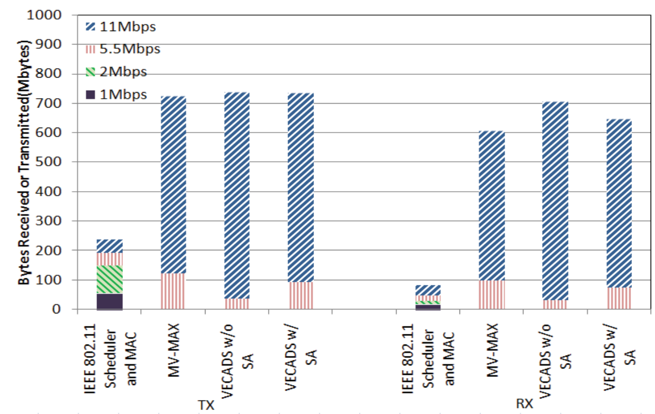

Fig. 6. Distribution of the Cumulative Bytes Received of all the Vehicles(bi(t))(per vehicle per drive-thru) including retransmissions

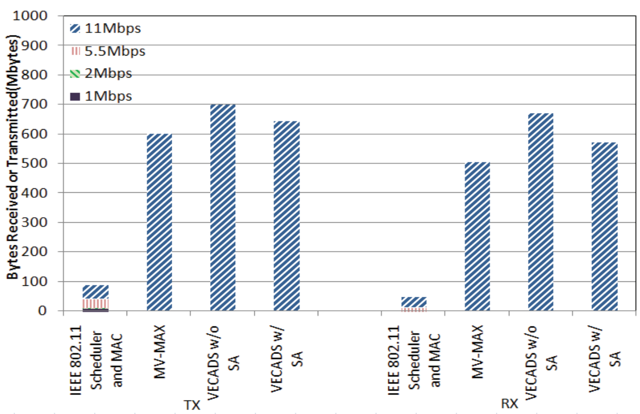

Fig. 5. Distribution of the Cumulative Bytes Received of all the Vehicles(bi(t))(per vehicle per drive-thru) excluding retransmissions

throughputs than those in *MV-MAX*. This is not surprising that "strong" vehicles receive less resource from the AP in the *VECADS w/ SA* scheme as we help "weak" vehicles explicitly by applying the *"Sweet Zone"* and even penalizing the slow-moving vehicles. Also, the use of *Stepwise Distance()* function can further equalize vehicles which have different properties.

B. Distribution of the MAC Bit rate transmitted and received

Figure 5 shows all the first transmission attempts excluding retransmissions made by the AP and received by the vehicles. Figure 6 shows all the transmission attempts including retransmissions made by the AP and received by the vehicles. For our designed rate adaptation algorithm, if the frame sent by the AP in the first attempt is fail, the frame will be retransmitted in one lower data rate with respect to the previous transmission data rate. For example, a frame is sent at 11Mbps, it will retransmitted in 5.5Mbps several time before giving up. Comparing the two figures, we find that there are many retries in lower data rates for IEEE 802.11 Scheduler and MAC. For *MV-MAX* scheme, which only uses noisy signal parameter to help scheduling process, there are more retries compared with our *VECADS w/o SA* scheme which makes use of both the signal and proximity parameters. For *VECADS w/o SA* scheme, there are less retries in lower data rate compared with *MV-MAX* and *VECADS w/ SA*. It further shows that vehicular context can help to choose "right" candidate to serve in first transmission attempts. For *VECADS w/ SA* scheme, as we apply the "Sweet Zone" and the use of the *Stepwise Distance()* function, it can influence the ultimate determination of the "suitable" vehicles chosen to be served. Therefore, there are more retries in our *VECADS w/ SA* scheme than our *VECADS w/o SA* scheme.

C. System Throughput Maximization and Fairness

Table II shows the average bytes received(per vehicle per drive-thru), normalized throughput, the 1-percentile of the cumulative bytes received and Jain's Index(fairness) of using different scheduling schemes. We use cumulative bytes received of all the vehicles by the end of simulation to do the calculations. To evaluate the normalized throughput, we normalize each average bytes received by the average value of *MV-MAX*. To evaluate the *Fairness* quantitatively, we calculate the Jain's Index [24].

From the column of the average bytes received, we see that IEEE 802.11 Scheduler and MAC performs the worst with the value of about 0.07Mbytes. From the column of normalized throughput, we further see that the average bytes received of IEEE 802.11 Scheduler and MAC is only about 13% of *MV-MAX*. It is suggested that IEEE 802.11's round-robin scheduler can't leverage *High System Throughput* in the scheduling process. We also observe from the column that *VECADS w/o SA* scheme gets the highest average bytes received of about 16% more that *MV-MAX*. For *VECADS w/ SA* scheme, it gets 7% more that *MV-MAX*. This again demonstrates that the use of additional vehicular context information can provide accuracy in the scheduling process and to achieve *High System Throughput*.

For the 1-percentile of the cumulative bytes received, IEEE 802.11 Scheduler and MAC performs the worst again with the

Scheme	Average Bytes Received (MBytes)	Normalized Throughput	1-percentile of the Cumulative Bytes Received (MBytes)	Jain's Index
A)	0.0712	0.125	0.01	0.695
B)	0.569	1	0.103	0.727
C)	0.663	1.16	0.045	0.730
D)	0.608	1.07	0.309	0.895

TABLE II

THROUGHPUT(PER VEHICLE PER DRIVE-THRU) COMPARISON ON DIFFERENT SCHEDULING SCHEMES, A)IEEE 802.11 SCHEDULER AND MAC, B)MV-MAX, C)VECADS W/O SA AND D)VECADS W/ SA

value of 0.01MBytes. *MV-MAX* has a value of 0.103MBytes that performs better than *VECADS w/o SA* scheme of the value of 0.045MBytes. *VECADS w/ SA* scheme performs the best with the value of 0.309MBytes. Since *VECADS w/o SA* scheme has a strict rule in selecting clients to serve, some of the vehicles cannot get enough throughput compared with *MV-MAX*. For the *VECADS w/ SA* scheme, as we have additional methods to help "weak" vehicles, most of them can get enough throughput from the AP.

For the *Fairness* issue, we need to see the column of *Jain's Index*. We find that the *Jain's Index* of *MV-MAX* is 0.727 which is less than those in *VECADS w/o SA* and *VECADS w/ SA* schemes. For the *VECADS w/ SA* scheme, its *Jain's Index* is 0.895. This is the highest *Jain's Index* among all the scheduling schemes. This demonstrates that the use of additional methods to help "weak" vehicles can equalize vehicles possessing different behaviors and to promote *Outcome Fairness* effectively.

V. CONCLUSION AND DISCUSSION

To conclude, we have proposed a new scheduling algorithm called *VECADS* for the Drive-thru Internet Systems. *VECADS* makes use of the vehicular context information like vehicles' positions and cumulated bytes received. From simulation results based on realistic traffic traces, we have demonstrated that *VECADS* is able to strike a better balance between system throughput maximization and fairness. In particular, *VECADS* manages to outperform *MV-MAX*, the state-of-the-art scheduling scheme for Drive-thru networks, in terms of system throughput while eliminating the bandwidth starvation problem of "weak" vehicles under *MV-MAX*,

VI. ACKNOWLEDGMENT

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