Reasoning about a Communication Protocol for Vehicular Cloud Computing Systems

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***Abstract*—Vehicular Clouds (VC) was inspired by the realization that the current vehicles are endowed with powerful sensing devices, storage, and computing resources and these resources are often underutilized. In this paper, we provide the reasoning for a communication protocol for vehicle-to-infrastructure (V2I) communications in Vehicular Cloud Computing systems. We first explain the structure of the proposed protocol in detail and then provide analytical predictions and simulation results to investigate the accuracy of our predictions.**

***Index Terms*—Vehicular Clouds, Internet of Vehicles, Internet of Things, Distributed Systems**

I. INTRODUCTION

Inspired by the success of the conventional Cloud Computing (CC) and the realization that the current vehicles are endowed with powerful compute and storage resources that are often underutilized, in 2010, a number of papers, [3] introduced the concept of Vehicular Cloud Computing (VCC) which is a non-trivial extension of the conventional CC paradigm. The unique power of the VC comes from the sensors that the vehicles carry, which along with the on-board computing resources make them ideal candidates for traffic management, urban surveillance applications and Content Delivery Networks (CDN) [7]. Vehicles are preloaded with Virtual Machine Monitors (VMM) and Virtual Machines (VMs) are used to set up unique environments and run processes or jobs without interfering with the hardware and physical resources on the vehicles. One of the key ways in which VC differs from conventional clouds is the dynamic nature of vehicles, which makes the assignment of jobs more challenging as the vehicles move, enter and leave the system. [4]–[6] This characteristic motivates the design of protocols and system architectures that are tailored to the needs of such unique systems. In [2] Ghazizadeh et al. have introduced a new system design for dynamic VCs and proposed a communication protocol for V2I communication which was inspired by a communication protocol that was designed in 1992 by Goes et. al [1]. This paper aims at providing a detailed reasoning about the communication protocol in [2].

II. FRAME CONFIGURATION

Figure 1, shows the frame structure which consists of multiple fields with fixed durations. The frame begins with a synchronization byte (SYNC) which is used for informing the vehicles that a new packet is arriving as well as synchronizing the receiver's clock with the transmitter's clock. Synchronization sequences are also used in between fields due to the dynamic characteristics of the vehicular environments. The start and the end of a frame are indicated by a start of frame delimiter (SFD) and an end of frame delimiter (EFD), respectively. The remaining of the fields are explained in detail in the next subsections.

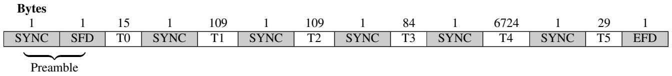

Fig. 1: Frame structure for V2I communication

A. *T0: Open communication period*

This field is used for broadcasting the access point (AP) identification number and the layout of the frame to all vehicles that are in the coverage area of the AP. Figure 2 shows the structure of T0. In this section, we explain in detail, the reasoning for the structure and size of each field in the T0 period. It is clear that the number of bits needed to represent a positive integer n is obtained by $\lfloor (\log_2 n + 1) \rfloor$.

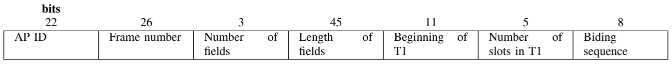

Fig. 2: Structure of T0

1) AP ID: The AP identification number consists of two components, the position of the AP along the highway and the highway number which is based on the current policy on numbering and designating US highways. For instance, 11-191 indicates an AP with a position of 11 miles along the US191 highway. Assuming that we have approximately 830 highways and the maximum length of a highway is 3365 miles, we can conclude that the size of this field should be 22 bits. Vehicles use this information to later construct a unique Vehicle identification number to communicate with the APs along the road. Figure 3 shows the structure of the AP ID.

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bits

12	10
Position of AP	**Highway number**
3237	191

Fig. 3: Structure of AP ID

2) Frame number: Vehicles that request to participate in the VC should be aware of the structure of the communication frame, therefore it is necessary that the AP broadcasts the basic information about the layout of the frame, such as the current frame number. To find the maximum number of frames f_{max} that one AP produces in a 24 hours period we should first find the length of a frame f_l in terms of seconds which can be calculated by dividing the frame length (T) by the available bandwidth (b) that is provided for Dedicated short-range communications (DSRC). f_l and f_{max} then can be calculated as follows:

$$f_l = \frac{T\ (bits)}{b\ (bps)} = \frac{56624}{27 \times 10^6} \approx 0.002\ s$$
$$f_{max} = \frac{24 \times 3600\ (s)}{f_l\ (s)} \approx 43200000$$

Therefore the maximum number of frames can be encoded using approximately 26 bits.

3) Number of fields: Vehicles should be aware of the number of fields in each frame. Since our frame consists of 6 fields, we can encode this information with approximately 3 bits.

4) Length of fields: Vehicles should be aware of the length of each field in bits so that they can calculate the beginning of each field and slot (Figure 4). Having the length of each period, the number of bits that we need to be able to encode the length of the fields (l_f) can be calculated using the following formula:

$l_f = \lfloor(\log_2(T1+T2)+1)\rfloor + \lfloor(\log_2 T3+1)\rfloor + \lfloor(\log_2 T4+1)\rfloor + \lfloor(\log_2 T5+1)\rfloor = \lfloor(\log_2 1744+1)\rfloor + \lfloor(\log_2 672+1)\rfloor + \lfloor(\log_2 53792+1)\rfloor + \lfloor(\log_2 232+1)\rfloor = 45\ bits$

bits

11	10	16	8
Size of T1 & T2 in bits	**Size of T3 in bits**	**Size of T4 in bits**	**Size of T5 in bits**
1744	672	53792	232

Fig. 4: Length of fields

5) Beginning of T1: Vehicles should be aware of the beginning of $T1$ period. Having this information as well as other information such as number of fields and length of fields, vehicles can then calculate the beginning of each period precisely which helps them to communicate reasonably with the AP. We allocate 11 bits to encode the beginning of $T1$.

6) Number of slots in T1: The number of slots that are available in each establishment periods $T1$ and $T2$ should be transmitted to the vehicles in the coverage area, in order for the vehicles to be able to randomly select a communication slot and compete with other vehicles to receive a communication slot. Since the number of slots in these two periods are the same, the AP only needs to send the information regarding one of the establishment periods. The number of slots is assumed to be 20 in each transmission period which can be encoded in 5 bits. The preferred number of slots in the establishment period depends on other factors such as the number of lanes, the average distance between two vehicles and the average length of the vehicle. In our system, we assume that we have 3 lanes, the average distance between two vehicles is 10 meters and the length of each car is on average 5 meters.

7) Bidding sequence: The bidding sequence is one byte information, which is an indicator of the bidding policy in the establishment period which should be revealed to the vehicles participating in the VC which will be discussed in detail in the next subsection.

B. T1 and T2: Establishment period

After receiving the initial signal and the frame layout from the AP, each vehicle that wants to communicate should compete for a slot based on the bidding sequence received in $T0$. There are two main bidding policies that are available to vehicles and one of these policies is selected based on the congestion level of the network. The probability of success for obtaining a slot for communication given that there are k other vehicles competing is defined as follows:

$$s(k)\text{: } \Pr(the\ vehicle\ obtains\ a\ slot\ for\ communication | \\ k\ other\ vehicles\ are\ competing\ for\ a\ slot)$$

a) Bidding policy 1: A vehicle that wants to communicate with the AP, selects a random slot number from 1 to M to transmit information in that slot in $T1$. If no other vehicle picks the same number then the vehicle can transfer information in that slot, otherwise, if another vehicle picks the same number then a collision occurs and neither of the vehicles that picked the same slot number can transmit in that slot. The vehicles get another chance to compete for a slot in $T2$. In this case, the probability of success is the probability that at least one of the two attempts to obtain a slot in one of the M slots in either recognition periods $T1$ or $T2$ is successful, which can be computed as:

$$s(k) : 1 - (1 - (1 - \tfrac{1}{M})^k)^2 = 2\left(1 - \tfrac{1}{M}\right)^k - \left(1 - \tfrac{1}{M}\right)^{2k} \quad (1)$$

b) Bidding policy 2: A vehicle that wants to communicate with the AP, gets only one chance per frame to select $T1$ or $T2$ randomly and then select a random slot number from 1 to M and transmits in that slot. Similar to the previous bidding policy, if another vehicle picks the same number then a collision occurs and neither of the vehicles that picked the same slot number can transmit in that slot. In this case, the probability of success can be computed as:

$$s(k) : \left(1 - \tfrac{1}{2M}\right)^k \quad (2)$$

The transmitted information in $T1$ and $T2$ differs based on the status of the vehicle and can be classified as follows:

(a) Initial request: A vehicle that contacts the AP for the first time to receive a job does not have an ID and therefore in $T1$ the vehicle transmits an estimated number of miles that it will be on the highway and the slot number that it will select in $T2$. In $T2$, the vehicle sends the estimated number of miles that it will be on the highway, and the slot number selected in $T1$. This will help the system to identify the vehicles that successfully obtained a slot in both transmission periods.

(b) Job download request: Vehicles that are requesting to download an assigned job should compete for a slot and therefore send the vehicle ID and a sequence indicating a request to download the job.

(c) Input data request: Vehicles that successfully downloaded the assigned job and need to download the intermediate input data send the vehicle ID and a sequence indicating a request to download the input data.

(d) Job submission and migration request: Vehicles that complete the assigned job and want to upload the results or want to migrate an incomplete job should send their vehicle ID, along with a sequence indicating the request.

Figure 5 shows the structure of T1 and T2.

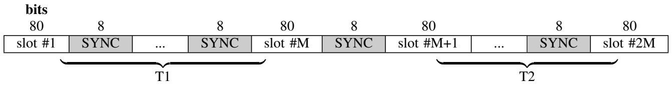

Fig. 5: Structure of T1 and T2

C. T3: ID and availability acknowledgment

This period has $2M + 1$ slots and the purpose of it is to send acknowledgments to the vehicles that successfully obtained a slot in the establishment period. As a general rule, each vehicle that obtained the slot number k in the establishment period should listen to the slot number k to in this period to receive the acknowledgment. Each acknowledgment is based on the messages that vehicles transmitted in the establishment period. The last slot contains information regarding the length of each slot and the number of vehicles that are guaranteed a slot in the transmission period. Figure 6 shows the structure of T3.

bits			
32	32		32
slot #1	slot #2	...	slot #M+1

Fig. 6: Structure of T3

D. T4 and T5: Transmission period and Transmission acknowledgment

In this period the acknowledged vehicles can transmit or receive information in the assigned slot. The number of slots in this period (N) and the size of each slot is adjusted based on the number of vehicles that were guaranteed a transmission slot. In $T5$, vehicles that received a message in $T4$ send the acknowledgments to the AP. Figure 7 shows the structure of T4 which is identical to the structure of T5.

slot #1	SYNC	...	SYNC	slot #N

Fig. 7: Structure of T4

III. PROBABILITY OF SUCCESSFUL SLOT ALLOCATION

In this section, we find the probability of successful slot allocation based on the arrival rate of the vehicles. We also evaluate the robustness of our predictions with simulations.

A. Bidding policy 1

1) Probability of successful slot allocation as a function of M and K: As described in the previous section, the probability of successful slot allocation as a function of M (number of available slots in the establishment period) and k (number of other vehicles in the coverage area that are competing for a slot), can be computed using equation 1. To evaluate the accuracy of this prediction we have simulated a similar condition. In our simulation, a vehicle randomly selects a slot from M slots and simultaneously k other vehicles each randomly select a slot from M slots, then the vehicles that picked unique slots are declared as successful vehicles in that period, however if multiple vehicles pick the same number then collision occurs and neither of the vehicles that picked the same slot is successful in that period. The vehicles again will repeat this process one more time and the ones that picked a unique slot number in first or second try will be declared as successful vehicles. Figure 8 shows our analytical predictions versus our simulation results which were averaged over 10^3 runs.

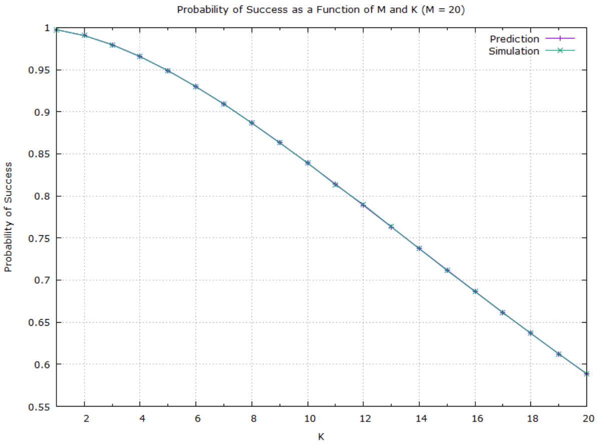

Fig. 8: Probability of successful slot allocation as a function of M and K for the first bidding policy.

2) Probability of successful slot allocation as a function of M and λ: We are interested in finding the probability of successful slot allocation based on the arrival rate of the vehicles at each AP. Vehicles arrive to the coverage area of the AP according to a Poisson process with a mean arrival rate λ. Let A be the event that our distinguished car is successful at receiving a communication slot at some access point A_n. We assume that once in the coverage area of A_n, each vehicle has a probability of $\alpha(n), n = 1, ..., N$ to attempt to connect. Let B_m be the event that m cars ($m \geq 0$) are in the coverage area of A_n.

$$\Pr[\bigcup_{m\geq 0} B_m] = 1 \tag{3}$$

We then obtain:

$$\begin{aligned} \Pr[A] &= \Pr[A \cap \bigcup_{m\geq 0} B_m] = \sum_{m\geq 0} \Pr[A \cap B_m] \\ &= \sum_{m\geq 0} \Pr[A \mid B_m] \Pr[B_m] \end{aligned} \tag{4}$$

The arrival rate of the vehicles to the coverage area is according to a Poisson process with a mean arrival rate λ, and t is the time in $seconds$ that a vehicle in under the coverage area of one AP, therefore we have:

$$\Pr[B_m] = e^{-\lambda t} \frac{(\lambda t)^m}{m!} \tag{5}$$

Thus:

$$\Pr[A] = \sum_{m\geq 0} \Pr[A \mid B_m] e^{-\lambda t} \frac{(\lambda t)^m}{m!} \tag{6}$$

Let $C_{m,k}$ be the event that k of the m vehicles in the coverage area of A_n attempt to communicate.

$$\Pr[\bigcup_{k=0}^{m} C_{m,k}] = 1 \tag{7}$$

Therefore:

$$\begin{aligned} \Pr[A \mid B_m] &= \Pr[A \cap (\bigcup_{k=0}^{m} C_{m,k}) \mid B_m] \\ = \Pr[\bigcup_{k=0}^{m} (A \cap C_{m,k}) \mid B_m] &= \sum_{k=0}^{m} \Pr[A \cap C_{m,k} \mid B_m] \end{aligned} \tag{8}$$

Lemma 3.1: Let X, Y and Z be random variables independent of each other. Using the chain rule of probability we have:

$$\Pr[X \cap Y \mid Z] = \Pr[X \mid Y \cap Z] \Pr[Y \mid Z]$$

By applying lemma 3.1 to 8, we obtain:

$$\Pr[A \mid B_m] = \sum_{k=0}^{m} \Pr[A \mid C_{m,k} \cap B_m] \Pr[C_{m,k} \mid B_m] \tag{9}$$

Using the binomial distribution we have:

$$\Pr[C_{m,k} \mid B_m] = \binom{m}{k} \alpha(n)^k [1 - \alpha(n)]^{m-k} \tag{10}$$

As explained in the previous section, we have:

$$\Pr[A \mid C_{m,k} \cap B_m] = 2(1 - \frac{1}{M})^k - (1 - \frac{1}{M})^{2k} \tag{11}$$

Therefore:

$$\begin{aligned} \Pr[A \mid B_m] = \sum_{k=0}^{m} \binom{m}{k} \alpha(n)^k [1 - \alpha(n)]^{m-k} \\ [2(1 - \frac{1}{M})^k - (1 - \frac{1}{M})^{2k}] \end{aligned} \tag{12}$$

We then get:

$$\begin{aligned} \Pr[A \mid B_m] = 2 \sum_{k=0}^{m} \binom{m}{k} [(1 - \frac{1}{M})\alpha(n)]^k [1 - \alpha(n)]^{m-k} \\ - \sum_{k=0}^{m} \binom{m}{k} [(1 - \frac{1}{M})^2 \alpha(n)]^k [1 - \alpha(n)]^{m-k} \end{aligned} \tag{13}$$

Theorem 3.2 (Newton's Binomial Theorem): Let α be a real (or even complex) number. Suppose $0 \leq |x| < |y|$. Then:

$$(x + y)^\alpha = \sum_{k=0}^{\infty} \binom{\alpha}{k} x^k y^{\alpha - k} \tag{14}$$

Applying 3.2 to 13, we obtain:

$$\Pr[A \mid B_m] = 2[1 - \frac{\alpha(n)}{M}]^m - [1 - \frac{\alpha(n)}{M}(2 - \frac{1}{M})]^m \tag{15}$$

By using 15, 6 can be rewritten as:

$$\Pr[A] = \sum_{m\geq 0} [2[1 - \frac{\alpha(n)}{M}]^m - [1 - \frac{\alpha(n)}{M}(2 - \frac{1}{M})]^m] e^{-\lambda t} \frac{(\lambda t)^m}{m!} \tag{16}$$

After algebraic manipulations we get:

$$\begin{aligned} \Pr[A] = 2e^{-\lambda t} \sum_{m\geq 0} \frac{[\lambda t(1 - \frac{\alpha(n)}{M})]^m}{m!} - \\ e^{-\lambda t} \sum_{m\geq 0} \frac{[\lambda t(1 - \frac{\alpha(n)}{M}(2 - \frac{1}{M}))]^m}{m!} \end{aligned} \tag{17}$$

Theorem 3.3 (Taylor Series): The Taylor series expansion for the function e^x is given by

$$e^x = 1 + x + \frac{x^2}{2} + \frac{x^3}{6} + \cdots = \sum_{n\geq 0} \frac{x^n}{n!} \tag{18}$$

After applying 18 to 17, we obtain:

$$\Pr[A] = 2e^{\frac{-\lambda t \alpha(n)}{M}} - e^{\frac{-\lambda t \alpha(n)}{M}(2 - \frac{1}{M})} \tag{19}$$

The equation 19 shows the probability that a distinguished car is successful in receiving a communication slot at some access point A_n. We have simulated a highway with access points installed along the road. The distance between each two consecutive AP is r_d, with a coverage area of r. Vehicles arrive to the coverage area of the AP, according to a Poisson process with a mean arrival rate λ, and continuously receive frames, while still in the coverage area. During the $T1$ period, a vehicle will select a unique slot number from 1 to M. If no other vehicle selects the same number then the vehicle receives that slot. This process is repeated in $T2$. This experiment is repeated 10^3 times and we record the number of successful slot allocations. The success probability obtained from our simulations and the predicted values are shown in Figure 9.

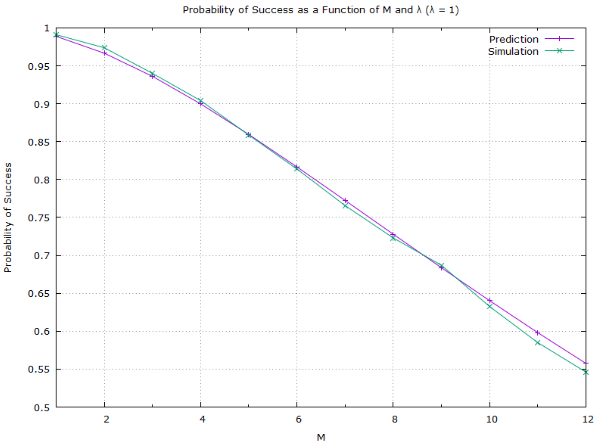

Fig. 9: Probability of successful slot allocation as a function of M and λ for the first bidding policy.

B. Bidding policy 2

1) Probability of successful slot allocation as a function of M and K: As described in the previous section, the probability of successful slot allocation as a function of M and k can be computed using equation 2. To evaluate the accuracy of our predictions we have simulated a similar condition. In our simulation, a vehicle randomly selects wether it wants to compete in $T1$ or $T2$. It then selects a slot from M slots and simultaneously k other vehicles each randomly select $T1$ or $T2$ and then select a slot from M slots, then the vehicles that picked a unique slot are declared as successful vehicles in that period. Figure 10 shows our analytical predictions versus our simulation results which were averaged over 10^3 runs.

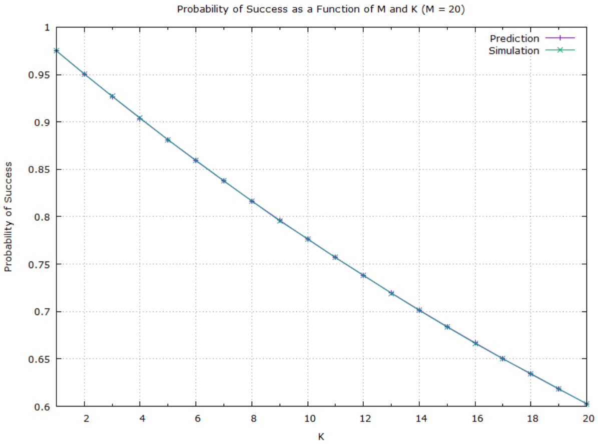

Fig. 10: Probability of successful slot allocation as a function of M and K for the second bidding policy.

2) Probability of successful slot allocation as a function of M and λ: We are interested in finding the probability of successful slot allocation based on the arrival rate of the vehicles at each AP. In this section we refrain from explaining the redundant notations that are similar to, (or were clarified in) the previous sections. Let $D_{k,k1}$ be the event that k_1 out of the k vehicles that attempt to communicate with A_n compete in $T1$, clearly:

$$\Pr[\bigcup_{k_1=0}^{k} D_{k,k_1}] = 1 \tag{20}$$

We evaluate $\Pr[A \mid C_{m,k} \cap B_m]$ as follows:

$$\begin{aligned}\Pr[A \mid C_{m,k} \cap B_m] = \Pr[A \cap \bigcup_{k_1=0}^{k} D_{k,k_1} \mid C_{m,k} \cap B_m] &= \\ \Pr[\bigcup_{k_1=0}^{k} (A \cap D_{k,k_1}) \mid C_{m,k} \cap B_m] &= \\ \sum_{k_1=0}^{k} \Pr[A \cap D_{k,k_1} \mid C_{m,k} \cap B_m] &= \\ \sum_{k_1=0}^{k} \Pr[A \mid D_{k,k_1} \cap C_{m,k} \cap B_m] \Pr[D_{k,k_1} \mid C_{m,k} \cap B_m] &=\end{aligned} \tag{21}$$

Using the binomial distribution we have:

$$\begin{aligned}\Pr[D_{k,k_1} \mid C_{m,k} \cap B_m] = \binom{k}{k_1}(\frac{1}{2})^{k_1}(1-\frac{1}{2})^{k-k_1} &= \\ \binom{k}{k_1}(\frac{1}{2})^{k}\end{aligned} \tag{22}$$

21 and 22 yield:

$$\begin{aligned}\Pr[A \mid C_{m,k} \cap B_m] = \sum_{k_1=0}^{k} \binom{k}{k_1}(\frac{1}{2})^{k} \\ \Pr[A \mid D_{k,k_1} \cap C_{m,k} \cap B_m]\end{aligned} \tag{23}$$

Further let $T1$ and $T2$ be the events that our distinguished car will compete in $T1$ and $T2$. We assume that $\Pr[T1] = Pr[T2] = \frac{1}{2}$. Therefore:

$$\begin{aligned}\Pr[A \mid D_{k,k_1} \cap C_{m,k} \cap B_m] &= \\ \Pr[A \cap (T1 \cup T2) \mid D_{k,k_1} \cap C_{m,k} \cap B_m] &= \\ \Pr[A \cap T1 \mid D_{k,k_1} \cap C_{m,k} \cap B_m] &+ \\ \Pr[A \cap T2 \mid D_{k,k_1} \cap C_{m,k} \cap B_m] &= \\ \Pr[A \mid T1 \cap D_{k,k_1} \cap C_{m,k} \cap B_m] \Pr[T1 \mid D_{k,k_1} \cap C_{m,k} \cap B_m] &+ \\ \Pr[A \mid T1 \cap D_{k,k_1} \cap C_{m,k} \cap B_m] \Pr[T1 \mid D_{k,k_1} \cap C_{m,k} \cap B_m]\end{aligned} \tag{24}$$

Let $\Pr[T1 \mid D_{k,k_1} \cap C_{m,k} \cap B_m] = \frac{1}{2}$. $\Pr[A \mid T1 \cap D_{k,k_1} \cap C_{m,k} \cap B_m]$ is the conditional probability of success that a specific vehicle competes in $T1$ along with k_1 other vehicles selected from the m vehicles that happen to be under the coverage area of A_n.

$$\begin{aligned}\Pr[A \mid T1 \cap D_{k,k_1} \cap C_{m,k} \cap B_m] &= \\ \binom{M}{1}\frac{1}{M}(1-\frac{1}{M})^{k_1} = (1-\frac{1}{M})^{k_1}\end{aligned} \tag{25}$$

Similarly:

$$\Pr[A \mid T2 \cap D_{k,k_1} \cap C_{m,k} \cap B_m] = (1 - \frac{1}{M})^{k-k_1} \tag{26}$$

It follows that:

$$\begin{gathered}\Pr[A \mid D_{k,k_1} \cap C_{m,k} \cap B_m] = \\ \frac{1}{2}(1 - \frac{1}{M})^{k_1} + \frac{1}{2}(1 - \frac{1}{M})^{k-k_1}\end{gathered} \tag{27}$$

23 and 27 yield:

$$\begin{aligned}&\Pr[A \mid C_{m,k} \cap B_m] = \\ &\sum_{k_1=0}^{k} \binom{k}{k_1} (\frac{1}{2})^k [\frac{1}{2}((1 - \frac{1}{M})^{k_1} + (1 - \frac{1}{M})^{k-k_1})] = \\ &\frac{1}{2^{k+1}} [\sum_{k_1=0}^{k} \binom{k}{k_1} (1 - \frac{1}{M})^{k_1} + \sum_{k_1=0}^{k} \binom{k}{k_1} (1 - \frac{1}{M})^{k-k_1}] = \\ &\frac{1}{2^{k+1}} [(1 + 1 - \frac{1}{M})^k + (1 + 1 - \frac{1}{M})^k] = (1 - \frac{1}{2M})^k\end{aligned} \tag{28}$$

Next, we replace $\Pr[A \mid C_{m,k} \cap B_m]$ with 28.

$$\begin{aligned}\Pr[A \mid B_m] &= \sum_{k=0}^{m} \binom{m}{k} \alpha(n)^k [1 - \alpha(n)]^{m-k} (1 - \frac{1}{2M})^k = \\ &\sum_{k=0}^{m} \binom{m}{k} [\alpha(n)(1 - \frac{1}{2M})]^k [1 - \alpha(n)]^{m-k} = \\ &[\alpha(n)(1 - \frac{1}{2M}) + 1 - \alpha(n)]^m = (1 - \frac{\alpha(n)}{2M})^m\end{aligned} \tag{29}$$

Finally, we replace $\Pr[A \mid B_m]$ from 29 back into 6.

$$\begin{aligned}\Pr[A] &= \sum_{m \geq 0} (1 - \frac{\alpha(n)}{2M})^m e^{-\lambda t} \frac{(\lambda t)^m}{m!} = \\ &e^{-\lambda t} \sum_{m \geq 0} \frac{[\lambda t(1 - \frac{\alpha(n)}{2M})]^m}{m!} = \\ &e^{-\lambda t} e^{\lambda t - \frac{\lambda t \alpha(n)}{2M}} = e^{\frac{-\lambda t \alpha(n)}{2M}}\end{aligned} \tag{30}$$

The equation 30 shows the probability that a distinguished car is successful in receiving a communication slot at some access point A_n. The simulation model is similar to the model explained in the previous section with the exception of using the second bidding policy instead of the first bidding policy. The success probability obtained from our simulations and the predicted values are shown in Figure 11.

IV. CONCLUSION AND FUTURE DIRECTIONS

In this paper we provided the reasoning for a communication protocol that can be used for V2I communications in dynamic Vehicular Cloud Computing systems implemented on top of moving vehicles on roads and highways. This protocol is an essential tool in utilizing resources provided by vehicles in VCs that can solve many problems which travelers and pedestrians face every day. In our future work, we will look into the feasibility of the proposed system by analyzing and measuring the job completion time and other important parameters that determine the reliability of the system.

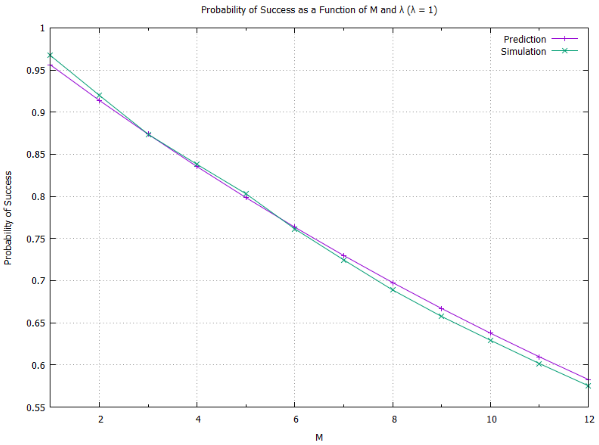

Fig. 11: Probability of successful slot allocation as a function of M and λ for the second bidding policy.

TABLE I: Parameters

Symbol and Description	Value
f_l (length of a frame)	0.002 s
f_{max} (maximum number of frames produces by an AP in 24 hours)	41203900
v (vehicle's average speed)	70 mi/h
l (number of lanes)	3
r_d (distance between two consecutive access points)	2 km
b (available bandwidth)	27 Mbps
T (one frame length)	56624 bits
$T0$ (open communication period)	119 bits
$T1 + T2$ (recognition period)	1744 bits
$T3$ (ID and availability acknowledgment period)	672 bits
$T4$ (transmission period)	53792 bits
$T5$ (transmission acknowledgment period)	231 bits
M (number of slots in T1 and T2)	20
λ (arrival rate of vehicles)	1 (vehicle/s)
r (access point coverage range)	100 m

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