

Research on Performance of Vehicular Ad hoc Networks*

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Abstract - VANET has emerged as a promising field of research. As one of the most important applications, location-aware service plays a key role on its advancement. Different related service protocols have been proposed. The performance, however, is evaluated through the simulation which limits the accurate assessment and their improvement. In the paper, the Extended Stochastic Petri Nets (ESPN) is presented to construct the formal performance model which reflects its actual operation process. Furthermore, the moment generating function approach is also presented to analyze the model, and the functional relation expression is obtained that facilitates the performance analysis and bottleneck identification. Finally, an example is also detailed to verify the efficiency and effectiveness.

Index Terms - Vehicular Ad hoc Networks; ESPN; Moment Generating Function; Performance.

1. Introduction

Vehicular Ad hoc Networks (VANET) is an open ad hoc network which is composed by communications between vehicles on road, and between vehicles and fixed access points roadside. It provides the self-organized, deployable, cheap and open-structured communication for vehicles [1-2].

VANET can play an important role on road safety, traffic information service, internet surfing and other applications, and has become a research focus. U.S. Federal Communications Commission allocated a specific frequency band for intervehicle communications. Since 2004, Mobicom holds a workshop on VANET each year. Furthermore, there are also a number of research projects or organization devoted to VANET such as Car2Car, Fleetnet, "Network on Wheels", "Association of Electronic Technology for Automobile Traffic and Driving", "Group Cooperative Driving", TrafficView, and so on[3-4].

Compared to other ad hoc networks, VANET has several own unique features[3]: Rapid topology changes, unreliable data transmission, more computation and energy resource and multiple information sources. Last, but not least, an important challenge is to provide two higher-level applications, road safety and driving comfort which are both based on location-aware service[4-6]. Different location-based discovery methods have been proposed, such as VITP, LocVSDP[5]. However, the formal performance evaluation methodology for location-aware services has not been proposed, and the simulation is usually conducted to estimate the metrics, such as response time, dropping rate that are insufficient or inaccurate to reflect the performance of the location-aware service of VANET.

In the paper, we propose efficient formal analysis model for location-aware service of VANET based on Extended Stochastic Petri Nets (ESPN) which includes both exponential and non-exponential distributions timed transitions. Furthermore, the moment generating function approach is presented to evaluate its performance, and the function relations for different parameters' impact on performance are also obtained. From these relations, the bottleneck of services can be easily identified.

The remaining of the paper is organized as follows. In Section 2, the ESPN and moment generating function analysis method are introduced. In Section 3, we give a short overview of the location-aware service model. Section 4 presents the key design concepts and modeling methods. Section 5 the performance evaluation method is presented with an example. Lastly, the conclusions are given in Section 6.

2. ESPN and Moment Generating Function Approach

A. ESPN

Definition 1: An ESPN is a seven-tuple $\langle P, T, I, O, H, m, F \rangle$, where [7]:

$P = \{p_1, p_2, \dots, p_n\}$, $n > 0$, and is a finite set of places;

$T = \{t_1, t_2, \dots, t_s\}$, $s > 0$, and is a finite set of transitions

with $P \cup T \neq \emptyset$, $P \cap T = \emptyset$;

$I: P \times T \rightarrow N$, and is an input function where $N = \{0, 1, 2, \dots\}$;

$O: P \times T \rightarrow N$, and is an output function;

$H: P \times T \rightarrow N$, and is an inhibitor function;

$m: P \rightarrow N$, and is a marking whose i th component is the number of token in the i th place. An initial marking is denoted by m_0 ;

$F: T \rightarrow R$, is a vector whose component is a firing time delay with an extended distribution function.

By extended distribution functions, the generalized distribution functions are allowed for noncurrent transitions which are not limited to exponential distribution.

B. Moment Generating Function Approach

Definition 2: Suppose x is a random variable, then the expectation of e^{sx} is the moment generating function of x , denoted as $M(s) = E(e^{sx})$ [8-9].

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Definition 3: Let $P(i,k)$ be a probability that transition t_k can fire. A transfer function is defined as the product $P(i,k)M(s)$, and is

$$W_k(s) = P(i,k)M(s) \quad (1)$$

For calculation of transfer function of PN, three reduction rules for three fundamental structures can be applied to reduce into a single transition: For t_1 with transfer function $W_1(s)$ and transition t_2 with transfer function $W_2(s)$, if they are sequence structure, then the equal transfer function $W_k(s) = W_1(s) \cdot W_2(s)$; if they are parallel, then the equal transfer function $W_k(s) = W_1(s) + W_2(s)$; if they are loop, then

$$W_k(s) = \frac{W_1(s)}{1 - W_2(s)}$$

The performance evaluation based moment generating function are as follows[7]:

- Construct the ESPN model;
- Build the reachability graph of PN;
- Transform into a state machine PN;
- Compute the transfer function of each transition;
- Apply reduced rules to obtain equivalent transfer function;
- Evaluate the performance.

3. Service Model

The usual scene of location-aware service is shown in Fig.1[4]. Vehicle1 wants to know the traffic status about road A, so it starts a service requests that return the average speed about at least three vehicles on road A; the request is passed to vehicles through intervehicle communication of VANET; After the request has reached a vehicle on road A, the service computation is started. Each vehicle calculates its own speed, and transfer the information to other ones on road until at least three vehicles has processed it or fails to satisfy the request and time is out; then the computation result is return to vehicle1 also by VANET.

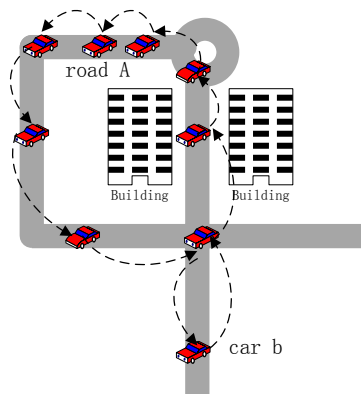


Fig.1 The caption

The service can be categorized as the following phases, which is detailed in Ref. [4]: At the service request phase, a

vehicle starts a location-aware service request; then, in the dispatch-request phase, the request is forwarded toward its target area through underlying VANET. When the request are transporting, an intermediary peer in VANET can search its own local database and may obtain the match information, and then return the results directly which can save much communication and computation resources; After the request arrive at the target area, it is the service-computation phase, a vehicle calculates its own speed, and then forward it to other vehicles in the target areas with the computation result; upon the return condition is satisfied, that is time out or service satisfaction, and then it is the dispatch-reply phase. During the phase, the service results are back to the original area based on the support of VANET; when the reply reaches the source area, it is the final phase service back. At this stage, the results are transmitted to the source vehicle by broadcasting.

4. Modeling based Petri Nets

According to the description of location-aware service model, the ESPN model is shown in Fig.2. The meanings of places and transitions are listed in Table 1 and 2. The type of transition I means immediate transition, E for exponential distribution, T for timed transition. When a service request is started, there is probability a that the service requirements can be satisfied through intermediary vehicles searching local database during the message transportation. The single hop transmission time is set to one unit time, and the computation

time is neglected. Thus, the firing rate of T4 is $\frac{1}{n}$ for n hops

transmission. Furthermore, during transmission, the intermediary vehicle may search its local database, and find needed information, then backward results to the source vehicle. Suppose the uniform distribution, the average hops for caching is $\frac{n}{2}$. Considering the forward and backward time, the

firing rate of T3 is $\frac{1}{n}$. The firing probability of T5 is b , which

represents the probability that the service can be met; and T6 is $1-b$, which is for the service request cannot be satisfied and lead to time out. The firing rate of T8 depends on the request information that how many vehicles' speeds are needed, thus it is $\frac{1}{m}$, and m means the number of service computation. T9 is

for the backward route whose firing rate is assumed as the same as the forward process, so it is $\frac{1}{n}$.

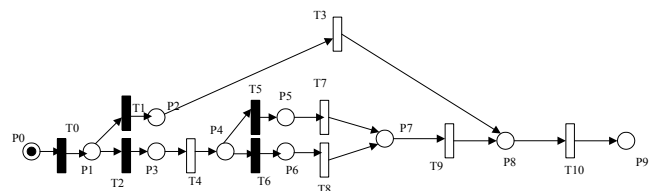


Fig. 2 PN model of location-aware service

TABLE 1 Meaning of places

Place	Meaning
P0	Start
P1	Service request
P2	Caching
P3	Ready for transportation by VANET
P4	Ready for Service computation
P5	computing
P6	Fail to satisfy
P7	Ready to return results
P8	Ready to broadcast
P9	Service end

TABLE 2 Transitions

Transition	Meaning	Type	Rate or Weight
T0	Request computation	I	1
T1	Ready to caching	I	a
T2	Ready to service computation	I	1-a
T3	Caching information return	E	1/n
T4	Transmission by VANET	T	1/n
T5	Satisfy request	I	b
T6	Prepare for time out	I	1-b
T7	Service computation in m vehicles	E	1/m
T8	Time out	T	300
T9	Results transmission	T	1/n
T10	Results broadcasting	E	1

To carry out the performance evaluation, the reachability graph is firstly constructed which is shown in Fig. 3, and markings are shown in table 3. From the reachability graph, the state machine PN is then built up which is shown in Fig. 4.

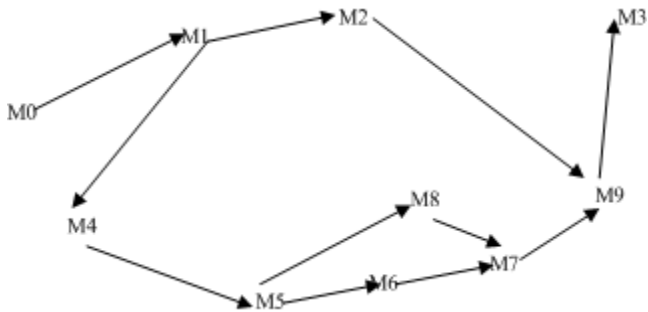


Fig. 3 Reachability graph

TABLE 3 Markings

M0	1000000000
M1	0100000000
M2	0010000000
M3	0000000001
M4	0001000000
M5	0000100000
M6	0000010000
M7	0000000100
M8	0000001000
M9	0000000010

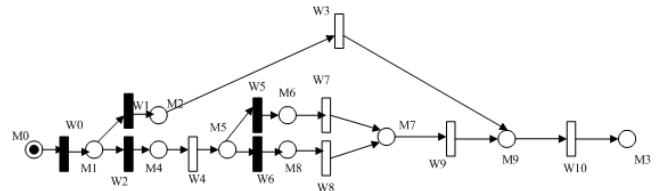


Fig. 4 The state machine Petri net

Next, the equivalent transfer function from M0 to M3 can be calculated using either the reduction rules introduced in Ref. [7] or Mason's rule as below:

$$W(E) = W_0(W_2W_4(W_5W_7 + W_6W_8)W_9 + W_1W_3)W_{10}$$

Where, $W_0 = 1$,

$$W_1 = a, W_2 = 1 - a, W_3 = \frac{1/n}{1/n - s} = \frac{1}{1 - ns}, W_4 = e^{ns},$$

$$W_5 = b, W_6 = 1 - b, W_7 = \frac{1/m}{1/m - s} = \frac{1}{1 - ms}, W_8 = e^{300s},$$

$$W_9 = e^{ns},$$

$$W_{10} = \frac{1}{1 - s},$$

$$\text{Thus, } W(E) = \left((1-a)e^{ns} \left(\frac{b}{1-ms} + (1-b)e^{300s} \right) e^{ns} + \frac{a}{1-ns} \right) \frac{1}{1-s},$$

The mean service cycle:

$$T = \frac{\partial}{\partial s} W_E(s) \Big|_{s=0} = (2-2a)n + (1-a)(bm + 300 - 300b) + an + 1 \quad (2)$$

5. Performance Evaluation

From the equation (2), we can easily obtain the time performance of location-aware service of VANET. Figure 5 plot the response time versus a and b values with the condition of $n = 10, m = 3$. With wireless medium an 802.11-compliant network with a transmission range of 250 meters, it

means about 2500 meters and request for the average speed of three vehicles. It can be shown in Figure 5 that the response time increases with the increases of a and decreases of b . Thus, we should design as much as caching function for high efficient location-aware service in VANET. Also, VANET is insufficient to support more accurate location service, for more service computation participants means more possibility of failure and time out.

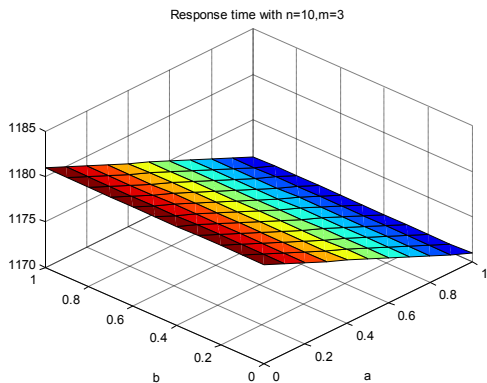


Fig.5 Response time with n=10,m=3

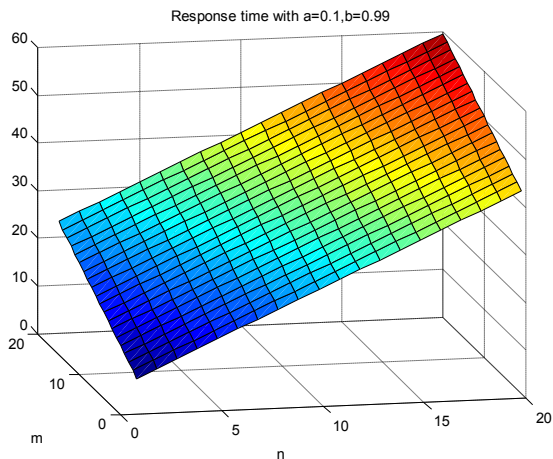


Fig.6. Response time with a=0.1, b=0.99

Figure 6 plots the response time versus the query distance with different number of vehicles. It can be shown that the

response time increases almost linearly with n and m which has been verified in Ref.[5] through NS2 simulation.

6. Conclusions

Location-aware service is one of the most important functions of VANET. Different service strategies have been proposed. Their performance is usually evaluated through simulation. In the paper, the ESPN model of location-aware service is constructed, which includes both exponential and non-exponential distribution transition. Therefore, the model can more accurately reflect the actual service capacity of VANET. Furthermore, the moment generating function approach is also utilized to evaluate the performance, and the function relations among different parameters are obtained. The performance variation is easier to know, and the bottleneck can also be identified. An analysis example is presented to verify the efficiency and effectiveness of the proposed method.

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