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Modeling and Performance Evaluation of Internet of Things based on Petri Nets and Behavior Expression

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Abstract: Modeling and performance evaluation plays an important role on the theoretical research and technology improvement of the Internet of Things (IoT). In the study, the modeling and performance evaluation method based on Petri Nets and behavior expression is presented. Firstly, according to the system information flow chart, the constraint relationship between places and transitions are identified and then graphic Extended Stochastic Petri Nets model is built up; next, the behavior expression method is adopted to obtain a variety of performance indicators. A case is also presented to verify the effectivity and efficiency.

Keywords: Behavior expression, performance evaluation, petri nets, the internet of things

INTRODUCTION

With the in-depth development of Internet technology, the expansion and extension based Internet form a new generation of network technology, that is the Internet of Things (IoT). The concept is first proposed at the International Conference on mobile computer and network in the United States, 1999. In Tunisia 2005, at the World Summit of Information Society, the International Telecommunications Union (ITU) released "ITU Internet reports 2005: the Internet of Things" which formally proposed the concept of IoT (Wang and Zhang, 2010).

IoT can be applied on a variety of areas, such as intelligent transportation, environmental protection, governmental administration, public security, industrial monitoring, elderly care, personal health and others. In 2009, the European IoT research project working group funded by the European Commission draw up IoT Strategy Research Roadmap , RFID and IoT Model and other submissions. In the same year, Japan also developed the i-Japan program (Feng and Ye, 2010).

Results of modeling and performance evaluation of IoT lay the basis for its design, planning and further improvement. Modeling of IoT is to abstractly construct the dynamic stochastic model of IoT in some manner, describe the relations between process elements and IoT performance and give the quantitative analysis results of system performance. Modeling and evaluation will be able to help to find out the network bottleneck, to further improve the overall network performance.

Petri Nets (PN) is a modeling and performance evaluation tool for discrete event dynamic system, especially for description of sequential, parallel, conflict and synchronization relations (Lin, 2001). Thus, the system modeling and evaluation technologies based on PN are widely proposed. Different types of PN (such as Object-Oriented PN, Colored PN, Stochastic PN and Changeable Structure PN) adapts to different system requirements respectively.

In the study, firstly, the modeling method for IoT is presented based on PN and then the performance evaluation method is also proposed based on behavior expression which can not only deal with PN with arbitrary time distribution transitions, but also conveniently obtain function relationship for evaluation. Furthermore, a case is presented and the evaluation results are also presented and discussed.

METHODOLOGY

Information flow model: IoT is based on the technologies of RFID and EPC (Electronic Product Code), which is combined with those of computer networks, database and middleware and so on. The global identification system determines each entity object a unique code, which builds a larger scale network than Internet composed of a large number of networking RFID readers and mobile tags (Xiao, 2009).

EPC middleware (Savant, also known as expert system) is responsible for filtering, integrate labels from readers or data flow from sensors.

ONS (Object Name Service system) can provide EPC lookup service, translate given EPC codes into one or more host URL addresses containing items of information to obtain more items related information on EPCIS servers.

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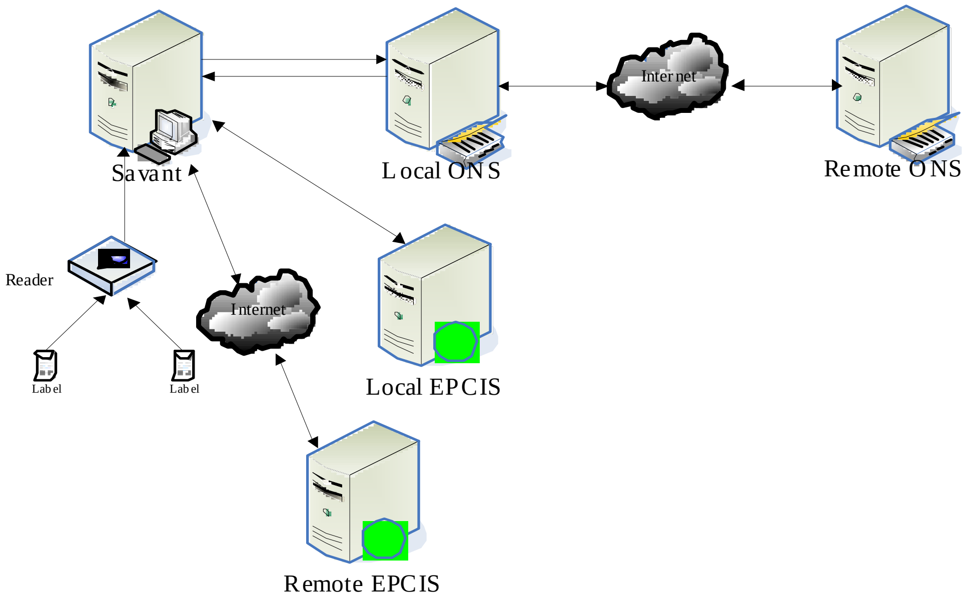

Fig. 1: Simplified information flow

EPC Information Service (EPCIS, formerly called PML service) keep all items related PML files produced by a lot of manufactures.

Information collection, integration and transmission play an important role on IoT. The information flow diagram is mainly composed of three parts: first, the RFID system transfers to EPC and then the local network processes EPC codes, finally, Internet returns the PML information of items (Jiao, 2007; Mohsen and Martin, 2008). The simplified information flow diagram is shown in Fig. 1.

Extended Stochastic Petri Nets (ESPN): An ESPN is a seven-tuple (P, T, I, O, H, m, F) (Guo *et al*., 1991), where

P = $\{p_1, p_2, ...p_n\}$, $n > 0$ and is a finite set of places;
T = $\{t_1, t_2, ...t_5\}$, $s > 0$ and is a finite set of transitions with $P \cup T \neq \Phi$, $P \cap T = \Phi$;
I: $P \times T \to N$ and is an input function where $N = \{0, 1, 2, ...\}$;
O: $P \times T \to N$ and is an output function;
H: $P \times T \to N$ and is an inhibitor function;
m: $P \times T \to N$ 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: $T \to R$, is a vector whose component is a firing time delay with an extended distribution function.

Analysis method based behavior expression: A behavior expression is compound or power series. It can depict the bounded PN, or some unbounded PN (with existence of expression). According to the expressions and by means of the following the following theorems, we can obtain the transfer function W of PN and then analysis method of moment generating function can be used to deal with the quality analysis of arbitrary distribution PN. The analysis method is based on the following three theorems (Jiang, 2000):

Theorem 1: Set α is a monomial, $\alpha = t_1, t_2, ...tq$, then

$$W_\alpha(s) = \prod_{i=1}^{q} W_{t_i}(s)$$

Theorem 2: Set α is a standard polynomial, $\alpha = \alpha_1 + \alpha_2 + ... + \alpha_n$, then

$$W_a(s) = \sum_{i=1}^{n} W_{\alpha_i}(s)$$

Theorem 3: Set $\alpha = (\alpha)^*$, then. $W_\alpha(s) = 1/1 - W_\alpha(s)$

The specific analysis steps are as follows:

- Generate the behavior expression of ESPN and convert the polynomial into the standard polynomial.
- Figure out firing probability and moment generating function according to the distribution parameter and the behavior expression structures. Next, base the transfer function definition, the transfer function of each event can be obtained.
- Remark the behavior expression to differentiate the same events with different transfer function in expressions according to the second step of the calculation results.

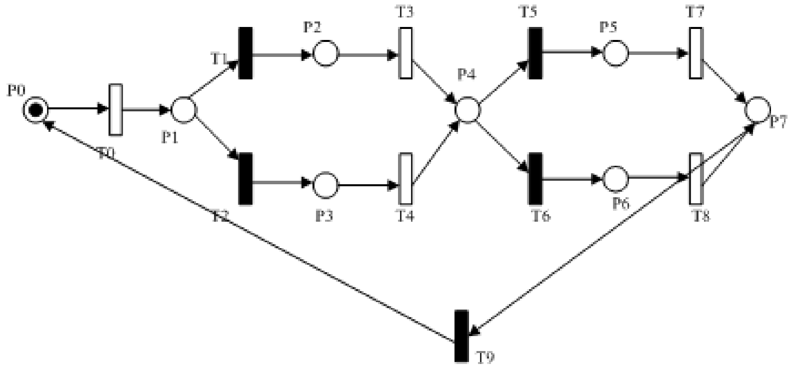

Fig. 2: Simplified ESPN model

- Compute the transfer function of remarked behavior expressions according to theorem 1 to 3.

Evaluate performance according to the above results and methods of moment generating function, obtain the quantitative analysis results.

RESULTS AND DISCUSSION

ESPN model: Readers access the EPC codes of labels and pass them to Savant in local servers. After information filtering by Savant, applications transfer Savant information to local ONS system, by which to get the host URL address about the other related information of corresponding items. After application software get the URL address, it can automatically link to local or remote EPCIS server, get all the information about the items. Simplified ESPN model is shown in Fig. 2.

The meanings of places are described in Table 1 and the firing rate or weight of transitions are listed in Table 2. These data in Table 2 are collected from statistical analysis of prototype system developed by us. T_0 is determined time transition with rate 1 ; T_3, T_4, T_7, and T_8 are exponential distribution with firing rate 5, 1, 4, 0 and 8 respectively. Random switches of immediate transitions T_1, T_2, T_5 and T_6 are also determined from statistical data.

Evaluation based behavior expression: We can obtain the behavior expression from Fig. 2:

$$\alpha = T_0\,(T_1\,T_3 + T_2\,T_4)(T_5\,T_7 + T_6\,T_8)\,T_9$$

and then figure out moment generating functions of each transition:

$$W_{T_0} = e^s, W_{T_1} = 0.8, W_{T_2}\ 0.2$$

$$W_{T_3} = \frac{\lambda_{T_3}}{\lambda_{T_3} - s} = \frac{5}{5-s}, W_{T_4} = \frac{\lambda_{T_4}}{\lambda_{T_4} - s} = \frac{1}{1-s}$$

Table 1: Meaning of places

Place	Meaning
P0	Ready to read tags
P1	EPC code into local server
P2	Prepare local ONS service
P3	Prepare remote ONS service
P4	Ready to obtain item information
P5	Prepare local EPCIS service
P6	Prepare remote EPCIS service
P7	Information acquisition end

Table 2: Rate or weight

Transition	Meaning	Rate or weight
T0	Car reader reading	1.0
T1	Local processing	0.8
T2	Remote processing	0.2
T3	Local access to URI	5.0
T4	Remote access to URI	1.0
T5	Local EPCIS	0.8
T6	Remote EPCIS	0.2
T7	Local access to the item information	4.0
T8	Remote access to the item information	0.8
T9	Service end	1.0

$$W_{T_5} = 0.8, W_{T_6} = 0.2, W_{T_7} = \frac{\lambda_{T_7}}{\lambda_{T_7} - s} = \frac{4}{4-s}$$

$$W_{T_8} = \frac{\lambda_{T_8}}{\lambda_{T_8} - s} = \frac{0.8}{0.8-s} W_{T_9} = 1$$

There is no need to remark α, for there not exist different transfer function of the same event for transitions. According to theorem 1-3, compute the transfer function of α:

$$W_\alpha(s) = e^5\left(0.8 \times \frac{5}{5-s} + 0.2 \times \frac{1}{1-s}\right)$$
$$\left(0.8 \times \frac{4}{4-s} + 0.2 \times \frac{0.8}{0.8-s}\right)$$

Then, the mean service time for IoT is:

$$T = \frac{\partial}{\partial s} W_\alpha(s)\Big|_{s=0} = 0.81$$

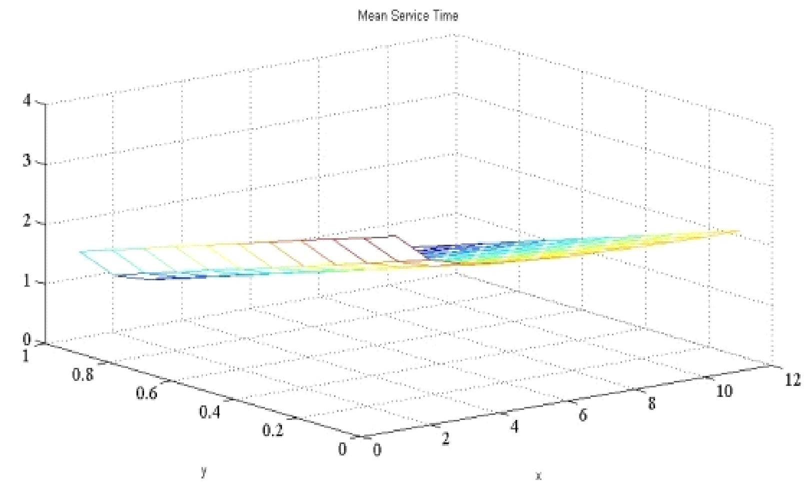

Fig. 3: Performance with changes of the time of reading tag and ratio of local processing

Let $s = 0$ in $W_i(s)$, where i is the transitions except for T_0 and now:

$T' = \frac{\partial}{\partial s} W_\alpha(s)\big|_{s=0} = 1$, thus the steady-state probability $P(M_0) = \frac{T'}{T} = \frac{1}{1.81} = 0.5524$, which shows that the system stays in the state of reading tag with the maximum probability and the card reader reading is the performance bottleneck. In our prototype system, the card reader access tags using serial mode, so it spend longer time for EPC code read into the local server. We need to optimize the tag access method to improve the whole system performance of prototype IoT.

Moreover, Let the firing rate of transition T_0 be x and the random switch of T_1, T_2, T_5, T_6 are y, 1-y, y, 1-y, respectively. It is to investigate the changes in system performance with the changes of the time of reading tag and ratio of local processing and remote processing. Then, the transfer function of behavior expression α is:

$$W_\alpha(s) = e^{s/x}\left(y \times \frac{5}{5-s} + (1-y) \times \frac{1}{1-s}\right)$$
$$\left(y \times \frac{4}{4-s} + (1-y) \times \frac{0.8}{0.8-s}\right)1$$

And the mean service time for IoT is:

$$T = \frac{\partial}{\partial s} W_\alpha(s)\big|_{s=0} \; 1/x-9/5*y+9/4$$

It is shown in Fig. 3 that both the time of reading tags and ratio of local processing play crucial roles on the performance of IoT. Except to reduce the time of reading tags, to improve the system performance, we should try to handle events in the local servers as far as possible.

CONCLUSION

The Internet of Things (IoT) is a new development opportunity for human being in the century, known as the top technology to change life. The modeling and performance evaluation of IoT lays the basis on theoretical analysis, technology improvement and its quantitative results can guide researchers to locate the performance bottleneck, lay the foundation for further improvement. In the study, the modeling and performance evaluation based PN and behavior expression is proposed which can deal with arbitrary distribution transitions. It is used to analyze the prototype system and the detailed analysis results are also presented. In the future, we will work on the modular modeling method for IoT based PN, which can help to build more complex PN model using the bottom-up approach.

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