JianHua Liu[1,2],WeiQin Tong[1]

School of Computer Engineering and Science Shanghai University(1),College of Mathematics Physics and Information Engineering Jiaxing University(2)

Device service networks maintenance scheme in the internet of things

Abstract. *Aiming at the failure of link and path problem in device service networks of internet of things, reliability of link and path was analyzed theoretically. Three service maintenance strategies were proposed. Firstly, idle service component joining in service network maintenance strategy, it reduces average hop counts for message delivery and service completion time between components and devices. Secondly, link-based maintenance strategy, it is local maintenance method, in case of failure of the components migration, checking its one-hop neighbors in order to quickly recover service. Finally, path reconfiguration strategy: the failure of the link is estimated theoretically according to the analysis of reconfiguration target. The establishment of the probability model for the path reconfiguration of the stability analysis is to minimize service recovery time.*

Streszczenie. *Przedstawiono analizę serwisu urządzęń sieci IOT biorąc pod uwagę awarie łącza internetowego. (**Schemat utrzymania usługi sieciowej dla łącza internetowego IOT - Internet of Things**)*

Keywords: internet of things,device service networks,service maintenance, path recovery,components migration
Słowa kluczowe: IOT - Internet of things, utrzymanie łączności

Introduction

With deployment of the internet of things (IOT) [1, 2], and infrastructure [3] as a service, intelligent device nodes can more easily access services, it is not the single function device, processing capacity evolves from single processor to multi-processor [4]. However, especially for those who require a higher real-time processing tasks, intelligent device nodes(e.g. sensor,mobile device etc.) are unable to meet the requirements of practical applications due to potentially catastrophic faults, therefore, device service networks(DSNs)maintenance is a challenging task in IOT. Intelligent service collaboration [5] have been studied.Zhang et al. [6] presented a protocol that utilizes symmetric cryptography to achieve security of routing path. Chakraborty et al. [7] presented service composition protocols based on distributed brokerage mechanisms. A QoS-based approach for services replacement in Web service composition was proposed [8] .A WSC_KUPB algorithm is proposed to solve the k-maximum utility path problem [9] .Inter-domain wireless device networks path and client sessions availability are very poor [10].A model-based approach is proposed to study service routing, service interference perceived by end users in order to minimize user-perceived interference routing in service composition [11] .Novel route maintenance algorithms are proposed for the Bluetooth ad hoc networks [12] . Sequential service composition solution has been proven to be the NP-hardness problem [13].Ad-hoc networks provide new challenges with respect to fault monitoring [14, 15].MDSCR heuristic algorithm [16] is designed to achieve minimum service disruptions for ad hoc network.But existing work has some disadvantages.This paper takes into account effect of path reconfiguration trigger time, link probability and reconfiguration probability on service maintenance in DSNs.

Idle component joining

C_i is idle in time t,it can join initial DSNs.Figure 1 shows c_3 joined to DSNs, service coordinator (SC)registers its information into router table. The hop number reduces to 2 from $c_1 \rightarrow c_2 \rightarrow c_4 \rightarrow c_5$ to $c_1 \rightarrow c_3 \rightarrow c_5$ by $ConnectingBinding(c_1, c_3)$ and $ConnectingBinding(c_3, c_5)$.

Link-based maintenance

Link-based services component maintenance strategy detects the one-hop neighbors. Maintenance process is as follows:(1) Initialize the existing path.(2)Figure 2 shows c_5 is weak component,$link(c_1, c_5)$ and $link(c_5, c_6)$ will be formed two weak links by $c_5.ic_1 = \{c_1, c_2\}$ and $oc_2 = \{c_6\}.sc$ finds c_2 links with its one-hop neighbor $c_8.c_8$ links with its one-hop neighbor c_6. $leaving\ service(c_5, sc)$,$ConnectService(c_1, c_2)$, $ConnectService(c_2, c_8)$,$ConnectService(c_8, c_6)$.Link-based services component maintenance path is $c_1 \rightarrow c_2 \rightarrow c_8 \rightarrow c_6$.

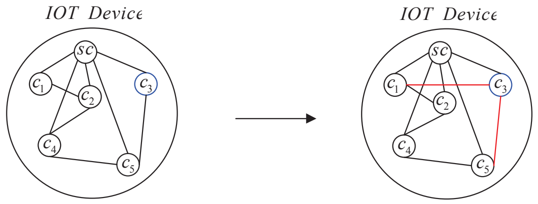

Fig. 1. Idle component joining DSNs

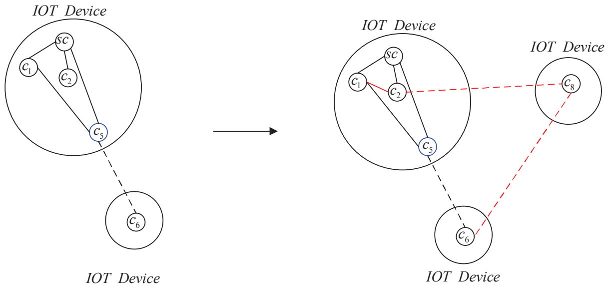

Fig. 2. Link-based services maintenance

Service path reconfiguration

0.1 Service path reconfiguration objective

A challenge of service path recovery and reconfiguration is time overhead of linking adjusting between service components, which allows users to use the service with minimum user-perceived network instability or even less than time to complete path reconfiguration.The relation reconfiguration of time and frequency and service completion is represented as by using function: $y_1 = \lambda_1 x^{\frac{3}{2}}$,$y_2 = \lambda_2 x^{\frac{1}{2}}$,$y_3 = \lambda_3 x$.$y_1$ indicates reconfiguration time exceed service lifetime,which makes user'service accessed become outdated.y_2 indicates reconfiguration frequency is too large,which makes the service can not complete within the deadline time.The third case y_3 is expected, the service path reconfiguration aims to make the first two close to the third case.

Proof: if $f(t_1^r, t_1^{fr}) = x^{\frac{3}{2}}$,$f(t_2^r, t_2^{fr}) = x^{\frac{1}{2}}$,$\frac{3}{2} \rightarrow 1, \frac{1}{2} \rightarrow 1$, $\lambda_1 = \lambda_2 = \lambda_3$,so $\frac{f(t_1^r, t_1^{fr})}{f(t_2^r, t_2^{fr})} = \frac{\lambda_1 x^{\frac{3}{2}}}{\lambda_2 x^{\frac{1}{2}}} =$

$\lambda_3 x = f(t_3^r, t_3^{fr})$.This shows that as long as the changing $x_1 = w_1 t_1^r + w_2 t_1^{fr}$ and $x_2 = w_1 t_2^r + w_2 t_2^{fr}$ close to x,reconfiguration service path optimal solution are obtained. In the first case, it is necessary to reduce the search for service components and adjust the time in order to avoid too long time. The second case, in order to avoid excessive reconfiguration frequency, we must find a device that has strong link, the greater link probability, the more stable, less link reconfigurations can reduce the reconfiguration frequency.Problem is transformed into:

(1)

$$Max\left\{\left(\beta_1 \cdot F_1 \quad \frac{f(t_1^r, t_1^{fr})}{f(t_2^r, t_2^{fr})}\right) - \beta_2 \cdot F_2(f(t_3^r, t_3^{fr}))\right), 0\right\}$$

Difference of F_1 and F_2 is smaller, there is the best path reconfiguration, completes the proof.

0.2 Service path link failure estimation

DSNs are deployed in a large square area, the side length is a_k,its diagonal length is $\sqrt{2}a_k$,it is the maximum distance of link between devices.Let $F_d(\xi)$ denote the distance distribution function between two devices [17] .$P(h_i)$ is probability of path with h_i hops number,the path with a large hops number has a large probability of failure,$P(h_i) = \int_{(h_i-1)r}^{h_i \cdot r} F_d(\zeta)\, d_x$.Let T_{Pf}^l denotes path reconfiguration trigger time,when a path failure rate exceeds a given threshold P_{th},path maintenance protocol will re-start find a new link for the path reconfiguration. Link failure probability of the path (LPFP) can be expressed as:

$$\begin{aligned} P_{th}^l &= LPFP(N, a_k, r, T_{pf}^l) \\ &= 1 - \sum_{h_i=1}^{H} P_{co}(l, T_{pf}^l)^i \cdot \int_{(h_i-1)r}^{h_i \cdot r} F_d(\zeta) \end{aligned} \tag{2}$$

Therefore, path reconfiguration trigger time can be attained by calculating LPFP.

0.3 Service Path Reconfigurability Analysis

There are several instability cases in IOT devices service networks. Firstly,a lack of device power causes service components of the QoS values decline, weak capacity link between devices and networks partition.Secondly,service component of the heavy load exceeds QoS threshold. Aiming at above cases, stability of IOT device service networks reconfiguration is analyzed. Let state of DSNs follow exponentially distributed, random variable is $Z(z \in (0, 1, 2, ..., m))$.

(3)

$$Prob[Z = z_c] = \begin{cases} \prod_{i=1}^{m} \exp(-\lambda_i \tau_i^{SN}) & , z_c = 0 \\ (1 - \exp(-\lambda_{z_c} \tau_{z_c})) \prod_{i=1, i \neq z_c}^{m} \exp(-\lambda_i \tau_i) & , otherwise \end{cases}$$

if $z_c = 0$,so,DSNs have not component or link failure,otherwise,$z_c = c_i^v (1 \leq i \leq m, 1 \leq v \leq m)$,so,DSNs have component or link failure.Let η denote the probability of service components failure,let L denotes the probability of link failure between devices.SN denotes DSNs.Its reconfigurability is represented as $S.S_0(\eta, L, SN, Ts)$ denotes that DSNs is stability and not failure.$S^{z_c}(\eta, L, SN, Ts)$ denotes $z_c - th$ service component or link failure.So $S^{z_c}(\eta, L, SN, Ts)$ includes two types of reconfiguration: (1)service component path reconfiguration $S_C^{z_c}(\eta, L, SN, Ts)$.(2)link reconfiguration between devices in DSNs $S_{Link}^{z_c}(\eta, L, SN, Ts)$. Therefore, paths service reconfiguration can be calculated as follows:

$$\begin{aligned} &S_{C+Link}^{z_c}(\eta, L, SN, Ts) = \\ &\quad S_C^{z_c}(\eta, L, SN, Ts) \times S_{Link}^{z_c}(\eta, L, SN, Ts) \end{aligned} \tag{4}$$

Let t_{ij} denote service component i execution time in device j.$f_{ij} = 1$ indicates that component i is not failure.$f_{ij} = 0$ indicates that component is failed.Figure 3 shows c_{41}has failure.SC searches same function c_{51} and c_{91} component to replace it. In the case of no-fault, there are three component service paths in device:$c_{11} \to c_{21} \to c_{31} \to c_{41} \to c_{61}$,$c_{11} \to c_{21} \to c_{31} \to c_{51} \to c_{61}$,$c_{11} \to c_{21} \to c_{31} \to c_{91} \to c_{61}$.Its execution probability can be calculated as follows:

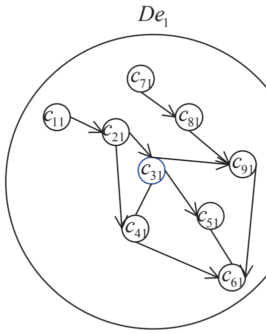

Fig. 3. Reconfiguration of component fault

(5)

$$\begin{aligned} S_0^C(\eta, SN, Ts) &= \prod_{j=1}^{m} \prod_{k=1}^{o} \prod_{i=1}^{n} \exp(-\lambda_k x_{ij} t_{ij}) \\ &= \exp(-\lambda_1(t_{11} + t_{21} + t_{31} + t_{41} + t_{61})) \\ &\times \exp(-\lambda_2(t_{11} + t_{21} + t_{31} + t_{51} + t_{61})) \\ &\times \exp(-\lambda_3(t_{11} + t_{21} + t_{31} + t_{91} + t_{61})) \end{aligned}$$

λ_k denotes the number of selecting path.j is the number of device, it equals currently 1. In the case of c_{41} fault,its reconfiguration probability can be calculated as follows:

$$\begin{aligned} &S_C^1(\eta, SN, Ts) = \\ &\quad \prod_{j=1}^{m} \prod_{k=1}^{o-1} \prod_{i=1, i \neq z_c}^{n} \exp[-\lambda_k t_{ij}(x_{ij} + y_{hi})] \end{aligned} \tag{6}$$

Link probability is directly characterized by message transmission between two devices.If message and data successfully transport,so,the state of link is normal.Messages are delivered by communication components between device De_i and De_j.Its set of message transmission is: $Me_{k1,k2} = \{(c_1, c_2) | e_{ij} > 0 \wedge x_{ik1} = 1 \wedge x_{ik2} = 1\}$,$1 \leq k1, k2 \leq m, 1 \leq i, j \leq n$.Where $e_{ij} > 0$ signifies that a message is sent from device De_{k1} to De_{k2} by using communication component c_{ik1} and c_{ik2}. $x_{ik1} = 1, x_{ik2} = 1$ means that the link fault do not occur between De_{k1} and De_{k2}.$t_{k1,k2}^d$ denotes message transmission time from De_{k1} to De_{k2}.$\mu_{k1,k2}$ is link failure probability. Its reconfiguration probability can be calculated as follows:

$$\begin{aligned} &S_{k1,k2}^0(M, SN, DN, Ts) = \\ &\quad \prod_{i=1}^{n} \prod_{j=1, j \neq i}^{n} \exp[-\mu_{k1,k2} x_{ik1} x_{ik2} (t_{k1,k2}^d e_{ij})] \end{aligned} \tag{7}$$

$$S_0^{Link}(M,SN,DN,Ts)=\prod_{k1=1}^{m}\prod_{k2=1,k2\neq k1}^{m}S_{k1,k2}(M,SN,DN,Ts) \tag{8}$$

$De_{k1}\rightarrow De_{k2}\rightarrow De_{k3}\rightarrow De_{k4}$ is a link sequence.De_{k3} and De_{k2} have link failure due to interfere or lack of battery energy in senor device.SC will search new link b to replace this weak link, its reconfiguration probability can be calculated as follows:

(9)

$$\begin{aligned}S_b^{k1,k4}(M,SN,DN,Ts)=&\prod_{i=1}^{n}\prod_{j=1,j\neq i}^{n}\exp[-\mu_{k1,k2}x_{ik1}x_{jk2}(t_{k1,k2}^{d}e_{ij})]\\&\times\left\{\prod_{i=1}^{n}\prod_{j=1,j\neq i}^{n}\exp[-\mu_{k2,b}x_{ik2}x_{jb}(t_{k2,b}^{d}e_{ij})]\right\}\\&\times\left\{\prod_{i=1}^{n}\prod_{j=1,j\neq i}^{n}\exp[-\mu_{b,k4}x_{ib}x_{jk4}(t_{b,k4}^{d}e_{ij})]\right\}\end{aligned}$$

All weak links are recovered, its reconfiguration probability can be calculated as follows:

(10)

$$S_{ki}^{Link}(M,SN,SN^R,DN,DN^R,Ts)=\prod_{\substack{k1=1,\\k1\neq ki}}^{m}\prod_{\substack{k4=1,\\k4\neq k1,\\k4\neq ki}}S_{ki}^{k1,k4}(M,SN,DN,SN^R,Ts)$$

Link and component failures as a random variable presented above section. However, sometimes, we need accurately to get the reconfiguration probability of link and component failure.Let x_c denote random variable of service component failure.Let y_l denote random variable of link failure between devices. There are two types of cases:(1)Service component failure, link stability.Its reconfiguration probability can be calculated as follows:

$$\begin{aligned}S_c(\eta,SN,Ts)&=Prob(Y=0|X=x_c)\\&=\tfrac{Prob(X=x_c,Y=0)}{Prob(X=x_c)}\end{aligned} \tag{11}$$

(12)

$$S_c(\eta,SN,Ts)=\frac{\sum_{j=1}^{m}\left\{\begin{aligned}&Prob(X=x_c)\times\\&\qquad\left[\prod_{k=1}^{o}\prod_{i=1,i\neq x_c}^{n}\exp[-\lambda_k t_{ij}(x_{ij}+y_{hi})]\right]\times\\&Prob(Y=0)\times\\&\qquad\left[\prod_{k2=1,k2\neq j}^{m}S_{j,k2}(M,SN,DN,Ts)\right]\end{aligned}\right\}}{\sum_{j=1}^{m}Prob(X=x_c)\times\left[\prod_{k=1}^{o}\prod_{i=1,i\neq x_c}^{n}\exp[-\lambda_k t_{ij}(x_{ij}+y_{hi})]\right]}$$

(2)Link disconnection, component stability.Its reconfiguration probability can be calculated as follows:

$$\begin{aligned}S_L(\eta,L,SN,DN,DN^R,Ts)&\\=Prob(Y=y_l|X=0)&\\=\tfrac{Prob(Y=y_l|X=0)}{Prob(Y=y_l)}&\end{aligned} \tag{13}$$

(14)

$$S_L(\eta,L,SN,DN,DN^R,Ts)=\frac{\sum_{ki=1}^{m}\sum_{j=1}^{m}\left\{\begin{aligned}&Prob(X=0)\times\\&\qquad\left[\prod_{k=1}^{o}\prod_{i=1}^{n}\exp(-\lambda_k x_{ij}t_{ij})\right]\times\\&Prob(Y=y_l)\times\\&\qquad\left[\prod_{\substack{k1=1\\k1\neq y_l}}^{m}\prod_{\substack{k4=1\\k4\neq k1\\k4\neq y_l}}^{m}\begin{aligned}S_{ki}^{k1,k4}(M,SN,SN^R,\\DN,DN^R,Ts)\end{aligned}\right]\end{aligned}\right\}}{\sum_{ki=1}^{m}\left\{Prob(Y=y_l)\times\left[\prod_{\substack{k1=1\\k1\neq y_l}}^{m}\prod_{\substack{k4=1\\k4\neq k1\\k4\neq y_l}}^{m}\begin{aligned}S_{ki}^{k1,k4}(M,SN,SN^R,\\DN,DN^R,Ts)\end{aligned}\right]\right\}}$$

Experiment analysis

0.4 Maintenance performance analysis

The performance analysis mainly include two aspects:(1)Idle components joining method, idle components joining makes DSNs reduce message transmission of hop number, experiment mainly compares dynamic component path maintenance method (DCP) with the static component service path maintenance method (SCP).(2)In the first case of path reconfiguration, in order to avoid too long time, it is necessary to reduce the time of searching for service components and adjusting service path.The second case, in order to avoid excessive frequency reconfiguration,SC must find a strong link probability device, the greater link probability,the more stable DSNs,which reduces reconfiguration time.Therefore,the experiment mainly verifies the impact of reconfiguration frequency on service completion time.

0.5 Performance metrics

(1)Average hop number(AHN): the average hop number is the key performance indicators in idle components joining method, the average number of hops of the new component services path reduce after idle components joined DSNs,which makes the service completion time reduce,saves equipment resources occupation,such as, reducing the device power consumption, CPU/MCU and communication links and storage occupancy.Figure 4 shows SCP and DCP performance comparison,when a new idle component joins to DSNs,DCP method has better results than the SCP method, with the number of joined components increasing,DCP method of the average number of hops message transmission between components continuously de-

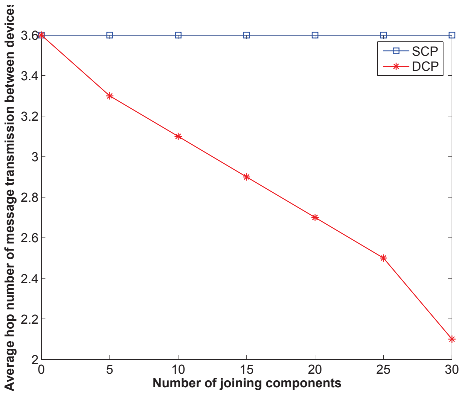

Fig. 4. Effect of idle components joining on average hop number

creases,while the SCP method has little effect.(2) Path reconfiguration frequency(PRF): it refers to the number of path reconfiguration.Figure 5 shows the relationship of the reconfiguration frequency, the number of service components and service completion time, when the total number of service components increases, the greater PRF value, the longer service completion time.

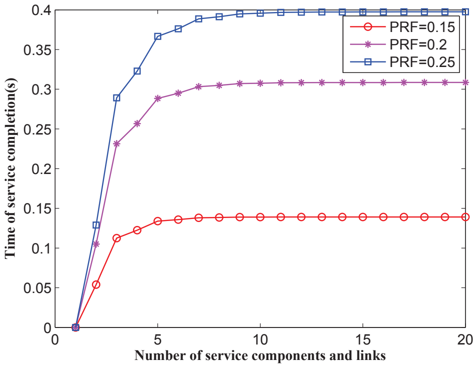

Fig. 5. Effect of reconfiguration frequency on service completion time

Effect of reconfiguration time and load of device link on the optimal solution of service path reconfiguration, that is, effect of link reconfiguration number (NLR) and the number of components to replace (NCR) on approximation of the optimal solution.We use MATLAB modeling tool to create a reconfiguration target optimal solution model.Because the value of device QoS reflects its link ability,therefore,trigger time and device QoS value as feedback network input and output make equation(1),$\beta_1 \cdot F_1\left(\frac{f(t_1^r, t_1^{fr})}{f(t_2^r, t_2^{fr})}\right)$ approximate to $\beta_2 \cdot F_2(f(t_3^r, t_3^{fr}))$.Figure 6 shows experiment result.When NLR+NCR=11, approximating to reconfiguration objective.

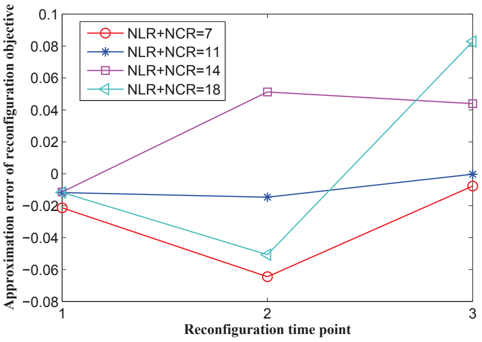

Fig. 6. approximation error of reconfiguration objective

Conclusion

This paper has presented three maintenance strategies for path reconfiguration in DSNs.The formula of path reconfiguration trigger time,link probability and reconfiguration probability are derived according to analysis of the process of path reconfiguration. In the three maintenance strategies, path maintenance strategy needs large network overhead,but also the other two maintenance strategies are ineffective,it is used to maintain DSNs.These three strategies are to maintain device service network to ensure stability and reduce service completion time and resource overhead,idle components joining can reduce the average number hops of service network to transport messages between components,which also means reduction of service completion time and saving resource.Three methods proposed have advantages and disadvantages to maintain services, different strategies are chosen according to requirement of maintenance the target and DSNs environment context.

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***Authors**: Ph.D. Jianhua Liu,School of Computer Engineering and Science,Shanghai University,Shanghai 200072,China,College of Mathematics Physics and Information Engineering,Jiaxing University,Jiaxing,Zhejiang 314001,China, email:ljh_541@163.com,Prof.Weiqin Tong,School of Computer Engineering and Science,Shanghai University,Shanghai 200072,China, email:wqtong@mail.shu.edu.cn*