Synergy-aware Selection Mechanism for High Quality and Sustainability of Ubiquitous Services

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***Abstract*—In ubiquitous stub environments, it is a critical challenge to select an optimal set of devices to accomplish a graph-based ubiquitous service and execute it continuously. The mobility of devices, the diverse access technologies and underlying path quality have a great influence on the user experience. Thus, we put forward a hierarchical model and a novel selection function considering the synergetic effect between devices. Then we elaborate a Synergy-aware Selection Mechanism (SSM) which includes three modules: service launch, device selection and service maintenance. We design a distributed core algorithm to integrate the devices and a dynamic updating weight method. The simulation results show that Synergy-aware Selection Mechanism can select a set of executive devices to ensure the service quality, continuity and smoothness. It improves the performance in the perceived experience and the number of service reelections.**

Keywords- ubiquitous service; synergy-aware; service quality; service sustainability

I. INTRODUCTION

With more intelligent terminals such as mobile handsets, sensors, robots and wearable devices accessing to the network, the ubiquitous networks and pervasive computing have a significant progress in recent years. The vision of ubiquitous computing is to create a smart space (e.g. a home, office, park or campus) called a ubiquitous stub environment where users can enjoy personalized ubiquitous services in the manner of "anytime, anywhere, on any device" with little user intervention. A ubiquitous service is regarded as a distributed application and is composed of a set of services that are deployed on networked multi-devices without fixed infrastructure such as MANETs.

Literatures focusing on the high quality of service composition, they cannot meet the graphic services and ubiquitous environments characterized by dynamic conditions resource heterogeneity and user mobility. To optimize the quality of a ubiquitous service, it is unreasonable only considering the QoS of each service in isolation without considering how these services are composed together[1]. In addition, the small quantity of papers on graph-based services ignore the synergetic effect. It is important to provide better perceived experience in such a volatile environment. In this paper, we mainly study the strategies by taking synergetic effect and the characteristics of the ubiquitous services.

Currently, device selection can be classified into two categories: centralized and distributed. The overhead and the consumption are too high to implement the centralized methods for limited resource devices. Su [2] proposed a distributed approach for high quality ubiquitous service. Through its QoS-driven utility function introduced mobility, it just selected the nodes with low mobility without considering synergy.

In such a dynamic network, a small quantity of researches take notice of the synergy [1,3]. However, Choudhury [3] just put forwards a framework without concrete implementation. And in [1], it mainly focuses on how to partition a composition service. It assumes that a node with rich resources could achieve many concrete services. So it selects an orchestrator to achieve several concrete services in one device. It does not make a utility value related to synergy.

This paper firstly sets up a hierarchical model to map a ubiquitous service to service layer and device layer. Secondly, we take the synergetic capability into account and design a novel selection function. Thirdly, we propose the synergy-aware selection mechanism. A distributed algorithm is designed in the mechanism called synergy-aware device selection algorithm (SDSA). The synergy-aware selection function and the maintenance module make the ubiquitous service more sustainable and better perceived experience.

II. STATEMENT OF THE UBIQUITOUS SERVICE-ORIENTED DEVICE SELECTION

A. Scenario Description

We abstract the problem into a hierarchical model shown in Fig.1. A ubiquitous service is composed of multiple concrete services in service layer. A concrete service is a self-contained atomic service which will be performed on an executive device selected from candidate devices in device layer. The scenario in Fig.1 illustrates an intelligent application of a location-aware spot display in a smart park. A mobile user wants to watch the spot overviews suiting his location and preferences by triggering this service.

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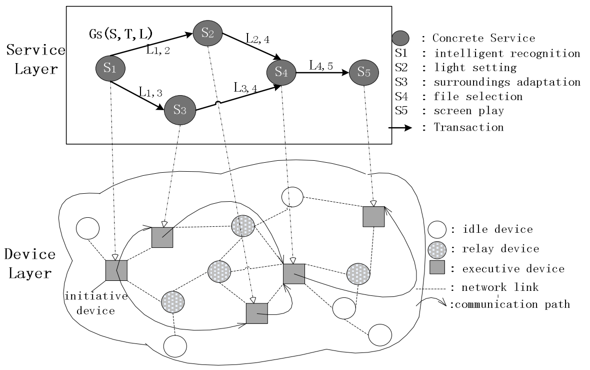


Fig.1 A ubiquitous scenario describing the hierarchical model

B. Hierarchical Model

In the service layer, we map the ubiquitous service to a weighted graph $G_S(S,T,L)$ as a composition service shown in Fig.1. As an example, where

- Concrete service set $S=\{S_1, S_2\dots S_n\}$ is the vertex set, where $|S|=n$.
- T is the transaction set of the ubiquitous service. A transaction denotes a data or control dependency between concrete services.
- L is the edge-weight set, where $L_{v,i}$ denotes the expected traffic load between S_i and its adjacent ancestor service S_v.
- SA_i is the set of adjacent ancestors of S_i, where $|SA_i|=sa_i$. In Fig.1, $SA_4=\{S_2, S_3\}$, $sa_4=2$.

In the device layer, different kinds of intelligent devices can cooperatively form a network without fixed infrastructure like MANETs. The topology $G_D(D,CP,Q)$ is composed of the sets of devices, communication path and quality. We define the device layer as follows:

- $d_{i,j}$ represents the candidate device that can perform the concrete service S_i. The executive device of S_i define as d_i. d_1 is the initiate device of the ubiquitous service.
- $da^a_{i,j}(a=1\cdots sa_i)$ is an adjacent-ancestor device set of $d_{i,j}$. The element devices in the set are the candidate devices of S_a which is in SA_i.
- $CP(ij,i'j')$ is the communication path between $d_{i,j}$ and $d_{i',j'}$.
- $STP(ij,i'j')$ is the stamp which records the information involved in the data or control flow of $d_{i,j}$ and $d_{i',j'}$ in order to realize the distributed calculation of the synergy and network performance between devices.
- The mobility characteristic of $d_{i,j}$ is defined as m_{ij} represented by a set of a quadruple (v_{ij}, b_{ij}, px_{ij}, py_{ij}), namely velocity, bearing, x and y-axis position of a device.

In this paper, we assume the path between any two devices at network level using existing methods can be figured out. Based on the route path between two devices beforehand, we should choose the executive devices with the consideration of synergy and the network performance.

Graphs $G_S(S,T,L)$ and $G_D(D, CP, Q)$ are the problem models for synergy-aware selection of a ubiquitous service. The problem is to find G_D*, a sub-graph of $G_D(D, CP, Q)$, that is isomorphic to $Gs(S,T,L)$ with the information of STP. And the device set in G_D* is the executive device set of the ubiquitous service requested by the user.

C. Selection Function

Based on the problem models, two main issues for selection are how to select an executive set and keep less interruption. Due to the mobility nature, some devices usually have limited resources and the network is volatile. It is critical to make an appropriate selection function for ubiquitous services.

Most researches choose the most fixed nodes when given mobility but take little attention on the synergetic effect which may provide higher quality as a whole. The heterogeneous composition devices that communicate with matched access technologies and move in the similar bearing and velocity provide higher reliability. In this paper, we mainly discuss the failure caused by mobility. The utility value of a candidate device is defined as the contribution to the ubiquitous service quality if it is selected to be the executive device. We define the perceived quality utility value of a candidate device as $\varphi_{i,j}$. It concludes the individual information and the synergetic information between devices.

1) Individual Capability: We define the quality of the available resource on device $d_{i,j}$ as $\rho_k^{IC}(d_{i,j})$ which must satisfy condition (i). The integrated individual capability of $d_{i,j}$ is calculate as (1):

$$o_k(s_i) \le \rho_k^{IC}(d_{i,j}) \ \ \forall k \qquad \text{(i)}$$

$$\rho^{IC}(d_{i,j}) = \begin{cases} \sum_{k=1}^{K} \frac{1}{k} \times \frac{o_k(s_i)}{\rho_k^{IC}(d_{i,j})} & \text{cost index} \\ \sum_{k=1}^{K} \frac{1}{k} \times (1-\frac{o_k(s_i)}{\rho_k^{IC}(d_{i,j})}) & \text{benefit index} \end{cases} \qquad (1)$$

Here, $o_k(s_i)$ is the requirement of S_i for the k-th resource.

2) Path Quality: We define the network link quality on path between d_{k1} and d_{k2} as $P(i_h j_h, i_{h+1} j_{h+1})$. The link quality is influenced by factors like the transmission distance and channel noise. In [5] channel noise is often regarded as the equivalent transmission distance. And many literatures have proved that the transmission distance is regarded as transmission time in link quality. Therefore, the transmission time is adopted to represent the link quality in this paper. And the path quality $\rho^{PC}(d_{k1}, d_{k2})$ is formulated as (2):

$$\rho^{PC}(d_{k1}, d_{k2}) = 1 - \sum_{h=1}^{hop} P(i_h j_h, i_{h+1} j_{h+1}) \Big/ P_{req} \qquad (2)$$

Here, P_{req} is the transmission time with maximum range.

3) Synergetic Capability: Taken the access technologies of heterogeneous devices and mobility similarity into consideration, we define a novel criterion as $\rho^{SC}(d_{k1}, d_{k2})$ to evaluate the synergetic performance between devices d_{k1} and d_{k2} in formula (3). $\alpha(d_{k1}, d_{k2})$ and $\sigma^{SC}(d_{k1}, d_{k2})$ represents the access cost and the relative mobility between d_{k1} and d_{k2}. The devices with the similar mobility will keep the sustainability of service and provide better mobility experience to the user. With the mobility characteristic m_{ij}(a quadruple (v_{ij}, b_{ij}, px_{ij}, py_{ij}) of $d_{i,j}$), we define the quality of relative mobility in (4) referring [1,3]:

$$\rho^{SC}(d_{k1},d_{k2}) = \alpha(d_{k1},d_{k2}) \times \sigma^{SC}(d_{k1},d_{k2}) \quad (3)$$

$$\sigma^{SC}(d_{k1},d_{k2}) = 1 - \frac{\sqrt{v_{k1}^2+v_{k2}^2-2v_{k1}\cdot v_{k2}\cdot\cos(b_{k1}-b_{k2})}}{2V_{\max}} \cdot \frac{|d_{k1},d_{k2}|}{CR} \quad (4)$$

Here, $|d_{k1},d_{k2}|$ is the distance of two devices and CR is the communication range in this network.

In this paper, based on the $G_S(S,T,L)$, we adopt the widely-accepted linear method in multi-attribute theory and conclude the utility value of $d_{i,j}$ as (5):

$$\varphi_{i,j} = \omega_1^0 \cdot \rho^{IC}(d_{i,j}) + \omega_2^0 \cdot \sum_{k=1}^{sa_i} \rho^{SC}(d_{i,j}, d_{SA_i[k]}) + \omega_3^0 \cdot \sum_{k=1}^{sa_i} \frac{L_{k,i}}{L_i} \cdot \rho^{PC}(d_{i,j}, d_{SA_i[k]}) \quad (5)$$

where $L_i = \sum_{t=SA_i[1]}^{SA_i[sa_i]} L_{t,i}$, ω_m^0 ($\sum_{m=1}^{3} \omega_m^0 = 1,\ 0 \le \omega_m^0 \le 1$) is the initial weight of the *m*-th factor.

To select the executive devices from candidate devices with the utility value $\varphi_{i,j}$, our selection function for ubiquitous services is formulated as follows:

$$\text{maximize} \ \sum_{i=1}^{n} \sum_{j=1}^{n_i} z_{i,j} \varphi_{i,j} \quad (6)$$

$$s.t. \begin{cases} o_k(s_i) \le \rho_k^{IC}(d_{i,j}) & \forall k \\ \sum_{j=1}^{n_i} z_{i,j} = 1 \end{cases}$$

where $z_{i,j} = \begin{cases} 1, & \text{if } d_{i,j} \text{ is selected to execute } S_i \\ 0, & \text{otherwise} \end{cases}$. n_i is the number of candidate devices of S_i.

III. SYNERGY-AWARE SELECTION MECHANISM

A. Service Launch

In this module, a ubiquitous service should define the related structures and initialize the individual data beforehand. [4] constructs the structure of a ubiquitous service according to user's needs. We assume the construction of a ubiquitous service has already finished. According to user profile (UP) which is composed of user preferences, user status and personal info, different users may set various parameters. User loads the required service information and launches the selection. The details and data structure are as follows:

1) *Service creation:* Design an abstract plan of a ubiquitous service and define the structure.
2) *Structure preparation:* Generate a concrete service table (CST) to record the information of $G_S(S,T,L)$ and initialize the executive device table (EDT). CST is a table including each concrete service S_i, adjacent-ancestor services SA_i and corresponding expected traffic load in a row. EDT is a table to save the IDs of each executive device and the real-time optimal $\varphi_{i,j}$ of S_i.
3) *User setting:* Set the weight and time limitation according to user's profile and set the packet structure for request.

B. Selection Module

This is the core of SSM. Owing to the limit resources, we design a synergy-aware device selection algorithm (SDSA) to make the computing decentralized to devices.

SDSA achieves searching the ubiquitous stub environment and finding the executive device for each S_i. We utilizes the Breadth First Search for $G_S(S,T,L)$ in service layer to fill the CST. SDSA is the implement of the device selection in Fig.3.

C. Sevice Maintenance Module

The mobility of the devices may lead to a decline in quality and affect the continuity of the service. In the meantime of cooperation among executive devices, service maintenance module takes charge of monitoring the quality of the ubiquitous service to ensure the user experience. Every executive device sends the monitoring message and gets the information from adjacent executive node and calculates the utility value. If it declines beyond the tolerance thresholds ($(\varphi_{i,j} - \varphi_{i,j}^{new})/\varphi_{i,j} \le 0.1$), the executive device will feedback the alert message to the initiative node. Besides, if the perceived user experience declines beyond the tolerance threshold, the initiative device redoes the selection module.

IV. SIMULATION AND RESULT ANALYSIS

In this section, the evaluation environment is established and the performance of our mechanism is shown by the figures below. The assessment of our work is mainly discussed on performance metrics such as user experience, execution delay and the number of reelections.

A. Simulation Setup

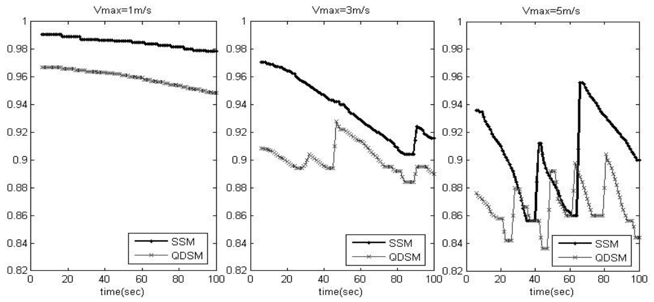
The scenarios of the simulation are set in two Beijing campuses. The topology of the network is generated by the wireless network deployment of the modeler. We select a [300m, 300m] area for each school according to the maps. We use the Android sensor support from MATLAB 8.1 (R2013a) to record the mobile data (The mobile phone with android and the computer installed MATLAB are both in the same campus wireless network.). We summarize the mobile data and make the trajectory files for different nodes.

We compare our mechanism with the one we call it QoS-driven selection mechanism (QDSM) which select an optimal set of devices with specific QoS.

B. Result analysis

1) We set up three scenarios with different maximum velocity. Fig.2 shows the quality of user experience of the two mechanisms during the simulation. As we can see, the experience of synergy-aware selection mechanism (SSM) is higher than QoS-driven selection mechanism (QDSM) and more smoother with fewer jitters.

2) The average reelections of different scenarios are shown in Fig.3. We conduct many simulations in 8 kinds of moving trajectories with V_{max}=3 and 5m/s. With the velocity increases, the number of reelections increases. The SSM with fewer times lies in considering the synergetic effect and underlying path quality between executive devices. These provide better mobility experience for users and the updating information make the service more sustainable.



(a)V_{max}=1m/s (b) V_{max}=3m/s (c)V_{max}=5m/s

Fig. 2 Experience under different maximum velocity

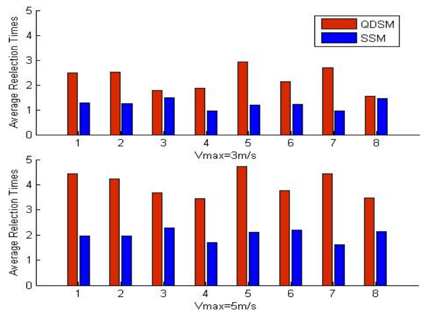


Fig.3 Number of reelections under different maximum velocity

V. CONCLUSION AND FUTURE RESEARCH WORK

On the background of ubiquitous stub environments, facing the characteristics of non-infrastructure, the limited resources of devices and the dynamic environment cased by the mobility, we propose a synergy-aware selection mechanism which includes three modules and a distributed algorithm based on a novel selection function. The consideration of synergetic effect between devices makes better performance for the perceived quality from the user's perspective. We design stamp information to make the synergetic capability and path quality accessible in order to calculate the synergy between devices. The design of the synergetic capability and the maintenance module make the service more sustainable. By simulating the real environment, the SSM can search out the executive devices with high service quality and guarantee the continuity and smoothness of the ubiquitous service.

In future research, we will make effort on other types of service failure and investigate the mobility prediction of the ubiquitous service. We will design a service reconfiguration mechanism to make lower price and less time of reelection.

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