Multi-Devices Composition and Maintenance Mechanism in Mobile Social Network

Wenjing Li, Yifan Ding, Shaoyong Guo, and Xuesong Qiu

Abstract: **In mobile social network, it is a critical challenge to select an optimal set of devices to supply high quality service constantly under dynamic network topology and the limit of device capacity in mobile ad-hoc network (MANET). In this paper, a multi-devices composition and maintenance problem is proposed with ubiquitous service model and network model. In addition, a multi-devices composition and maintenance approach with dynamic planning is proposed to deal with this problem, consisting of service discovery, service composition, service monitor and service recover. At last, the simulation is implemented with OPNET and MATLAB and the result shows this mechanism is better applied to support complex ubiquitous service.**

Index Terms: **Dynamic planning, maintenance, mobile social network, multi-devices composition, ubiquitous service.**

I. INTRODUCTION

As the rapid development of ubiquitous stub environment [1], [2], a mobile social network (MSN) is created from multi-devices to share content and resources among multi-users, and to supply ubiquitous service for multi-users in an "anytime, anywhere, on any device" manner, especially in the scenario that the core network resources are lack. In mobile social network, a ubiquitous service is regarded as a distributed application which consists of a set of less complex and smaller services deployed on multi-devices in mobile ad-hoc networks (MANETs), such as device-to-device instant messaging service, multimedia sharing service among users, etc. However, due to the dynamic characteristics [3] of MANET and the limit of device capacity [4], it is a critical challenge to dynamically select an optimal set of devices to supply high quality service constantly. Especially, when some of the devices exit, fail or power exhausted, the original service will be affected, and the service composition and maintenance become extremely necessary. Therefore, an effective dynamical composition and maintenance mechanism among multi-devices is a key problem to support ubiquitous service in MSN.

In MSN, each service executing cycle is divided into three processes: Service discovery, service composition and service maintenance as shown in Fig. 1. In service discovery process, the service logic is constructed according to the requirements, and then service is composed in service composition process.

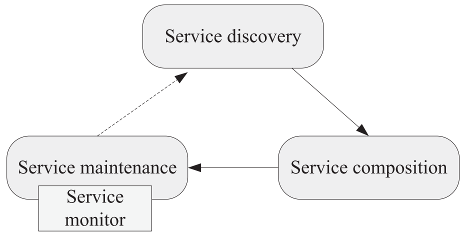

Fig. 1. Each service executing cycle in mobile social netowrk

During the executing period, the service is monitored constantly and maintained dynamically when service is interrupted. According to the maintenance requirements, the service logic can be reconstructed when necessary. In this executing cycle, limited network resources and device mobility will cause the increment of interruption duration or quality jitters of the ubiquitous service remarkably. The key problem in whole executing cycle is to minimize interruption duration and maximize service quality [3]. Therefore, our goal is to propose an effective composition and maintenance mechanism that enable users to access highly reliable ubiquitous service in MSN. To achieve this goal, we meet the following three challenges:

- How to quantitatively characterize and measure the impact of ubiquitous service in dynamic MSN.
- How to abstract problem model and how to weigh maintenance cost due to the interruption and service quality decline in the whole executing cycle.
- How to dynamically maintain service executing processes to ensure the continuity and stability of ubiquitous services, and to shorten interruption duration of the service.

To address those challenges, multi-devices composition and maintenance problem (MCMP) is generalized and formulated firstly. In MCMP, service model and mobile social network model are abstracted to characterize the ubiquitous service. And then we import the objective function based on service quality and service duration as maintenance cost to maintain service executing processes. Secondly, a multi-devices composition and maintenance mechanism (MCMM) based on dynamical programming principle is proposed to deal with MCMP which is a dynamical problem. Compared to the current mechanisms, MCMM takes multiple evaluation indices into account, such as service diversity, service jitter, service duration, and energy consumption, and it provides not only the composition mechanism but also the maintenance mechanism as well. At last, the simulation is implemented with OPNET and MATLAB. The simulation results show that it performs better than minimum-disruption service composition and recovery[4] (MDSCR), dynamic task-embedding anycasting [5] (DTA) and

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service-oriented device anycasting [6] (SDA).

The remainder of this paper is organized as follows. Section II describes related work. Section III describes multi-devices composition system framework. Section IV presents multi-devices composition and maintenance problem model. Section V presents multi-devices composition and maintenance mechanism, consisting of service discovery, service composition, service monitor and service recover. Section VI presents the simulation and experimental analysis. Finally, conclusions are drawn and the future work is discussed in Section VII.

II. RELATED WORK

There is an extensive literature on service composition among multi-devices over MANET. Mobile social network (MSN) is created from multi-devices to share content and resources among multi-users, and to supply ubiquitous service for multi-users in an "anytime, anywhere, on any device" manner. It is critical to automatically compose the services in mobile social network and attracts the significant attention at present from researchers. Service composition [7], [8] is to integrate loosely-coupled distribution service components into a composite service in MSN that provides end users with coordinated functionality.

DTA [5] and SDA [6] are two typical methods to solve service composition and maintenance problem in MSN. P. Basu *et al.* proposes DTA that is a dynamic task alliance with a tree-based services model. And then Wei-Tsung Su extends the limit of DTA for diverse services and proposes SDA with Graph-based service model. However, it is hard to monitor the jitter which remarkably affects the local service quality so that it can't support the global high quality service requirement. Additionally, Jiang *et al.* [4] proposes MDSCR that satisfies the quality requirement of the end-to-end service and minimizes the effect of service disruptions caused by dynamic link and node failures. And an evaluation model based on economic theory [9] is proposed to maximize the benefits for each user in MSN. However, it lacks of analysis about quality indicators, and has no maintenance mechanisms to keep the stability and quality of the service.

Based on previous research work, we provide an effective MCMM based on DTA and SDA to apply in MSN. To solve it, we import ubiquitous service model and mobile social network model to construct the mapping model between service and network in MSN as shown in Fig. 2. As shown in Fig. 2, there are two layers: Service layer and network layer. The aim of MCMP is to find an optimal multi-device composition set (MCS) in network layer for each ubiquitous service in service layer. For example, service in Fig. 2 is consisting of four sub-services s_1, s_2, s_3, s_4 in service layer and those sub-services are executed on different devices at different time in network layer, such as a, d, f, h at time τ_1 and a, e, f, h at time τ_2.

III. MULTI-DEVICES COMPOSITION SYSTEM FRAMEWORK

As shown in Fig. 2, the MCS supporting ubiquitous service is changing with mobile devices' movement in different network

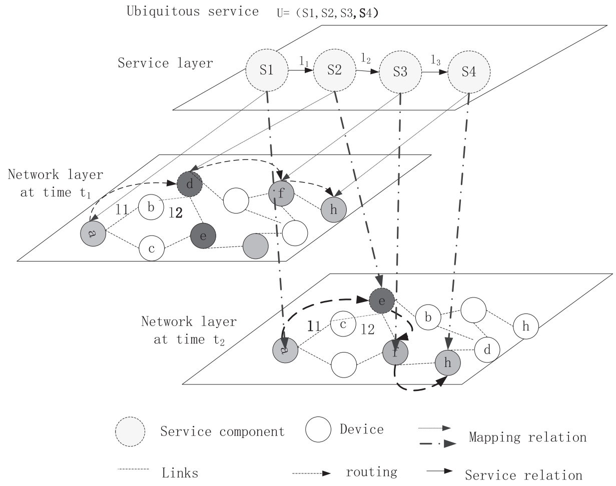

Fig. 2. Multi-devices composition environment in MSN.

topologies at different time. The aim of MCMP is to dynamic select optimal device set at different time to support ubiquitous service [6]. To model MCMP, Ubiquitous Service and Mobile Social Network Model are abstracted with time series firstly. Secondly, we imported technique for order preference by similarity to an ideal solution [10] (TOPSIS) to measure service utility reflecting service qualities at each time. And mean deviation is defined as index to measure the service qualities jitter. Meanwhile, interrupt time is imported to reflect service duration. Our goal is to provide stable ubiquitous service that enable highly reliable service delivery. Device capacity and bandwidth on network are viewed as constraint conditions [11] to formulate MCMP.

A. Ubiquitous Service Model

Ubiquitous service model (USM) is defined as the structure of a ubiquitous service [12], [13] in mobile social network as shown in Fig. 2. For a requested ubiquitous service, it consists of two sets, that is the sub-services set $S = s_v|v = 1, \cdots, V(|S| = V)$ and the interaction set $L = l_u|u = 1, \cdots, U(|L| = U, L = S * S)$. s_v is vth sub-service in ubiquitous service. And l_u is one interaction of the requested ubiquitous service. The requested ubiquitous service is represented by an undirected graph $G_{USM}(S, L)$ as shown in Fig. 2 in which S and L are vertex set and edge set, respectively. Moreover, the ubiquitous service could offer different quality levels to ensure a specific service quality. For example, multimedia applications typically provide the contents with high, medium, or low quality to users according to available bandwidth [11]. Certainly, the demand resources on required sub services and demand bandwidths on required interaction are diverse to achieve those different quality levels. Thus, two data structures are defined in USM.

- $r_{v,k}$ is defined as the demand value of resource type k to carry out sub-service s_v.
- b_u is defined as the demand value of bandwidth to carry out l_u.

As shown in Fig. 2, the ubiquitous service $S = \{s_1 \rightarrow s_2 \rightarrow s_3 \rightarrow s_4\}$ is linked in a sequence order, where $s_v(v = 1, 2, 3, 4)$ is a service component. In MSN, service composition refers that

Fig. 3. Example MANETs at time τ_1 and time τ_2.

construct a network routing among multi-devices to support service execution, such as $\{s_1[a] \rightarrow s_2[d] \rightarrow s_3[f] \rightarrow s_4[h]\}$ at time t_1 and $\{s_1[a] \rightarrow s_2[e] \rightarrow s_3[f] \rightarrow s_4[h]\}$ at time t_2. The composed service usually needs to satisfy certain quality of service (QoS) requirement.

B. Mobile Social Network Model

Mobile social network model (MSNM) is the network structure in mobile social network with graph theory. In this network, link connectivity and network topology change with mobile devices movement as shown in Fig. 2. To model this dynamic network environment, we import $G_{MSNM}(D, E, T)$ as network model where D refers devices and E refers that link connectivity in MSN. The time horizon $T \in [0, \infty)$ is decomposed into a set of time instances $T = \tau_1, \tau_2, \cdots$, so that the time interval $[\tau_t, \tau_{t+1})$ shows the network topology remains unchanged, and the same topology is at τ_t.

At each time τ_t, MSNM is defined as $G_{MSNM}(D, E, \tau_t)$, consisting of a set of devices $D = d_j|d_j, j = 1, \cdots, J(|D| = J)$ and the network connectivity set $E = \{E_e|E_e, e = 1, \cdots, O\}(|E| = O)$ where d_j is one of the devices in this network. And each element $E_e \in E$ is one of the network links between devices. Similarly, to illustrate a mobile social network, MSNM is represented by an undirected graph $G_{MSNM}(D, E, T)$. Moreover, to indicate the available resource on each device and the available bandwidth on each network link, two data structures are defined as follows:

- $R_{j,k} \in \overline{R}_j$, where $\overline{R}_j = R_{j,k}|R_{j,k}, k = 1, \cdots, K$ is defined as the available value of resource type k on device $d_j \in D$. And K is the number of capacity types on each device.
- B_e is defined as the available bandwidth on network connectivity $E_e \in E$.

For the requested ubiquitous service, there are many MCS to support them at each time τ_t. And each MCS $C_m(m = 1, \cdots, M)$ should satisfy two regulations as Formula 1 and Formula 2. That means, the resources and bandwidth of each requested ubiquitous service should meet the resource-limited and bandwidth-limited conditions.

$$r_{v,k} \leq R_{j,k},\ \forall k = 1, \cdots, K, \tag{1}$$

$$b_u \leq B_e. \tag{2}$$

Besides, $G_{MSNM}(D, E, T)$ is an undirected graph model and would change with mobility and capacity limit of each device in this network. For example, as shown in Fig. 3, two snapshots of the network topology at time instance τ_1 and τ_2 are shown in Figs. 3(a) and 3(b) respectively. Due to the mobility of node f and c, links (d, f) and (d, c) are no longer available in $G_{MSNM}(D, E, \tau_2)$. Therefore, it is a critical problem to support high quality service constantly in MANETs.

C. Service Quality Measurement

As shown in Fig. 3, limited network resources and device capabilities will cause the increment of interruption duration or quality jitters of the ubiquitous service remarkably in the whole execution cycle. To generalize MCMP, we need to define max utility $Q_t(= f(p_n, n = 1, \cdots, N))$ which is calculated in Formula 7, where $p_n(n = 1, \cdots, N)$ is the nth measurement index at each time interval $[\tau_t, \tau_{t+1})$. For each MCS $C_m(m = 1, \cdots, M)$ to support ubiquitous service, we cite $P = [p_{mn}]_{M*N}$ as Measurement- matrix to weigh the utility of each solution for ubiquitous service. And p_{mn} is the parameter value of utility index.Those different indexes have different units and different domain so that it's hard to obtain service utility from the simple linear addition. In order to solve it, we need to design a theoretical method to dimensionless processing[14]. From dimensionless processing, we get $P^{'} = [p^{'}_{mn}]_{M*N}$ from $P = [p_{mn}]_{M*N}$. The computation of $P^{'} = [p^{'}_{mn}]_{M*N}$ is computed with the character of index computation.

Efficiency index: It refers that the result will be increased by improving the value of index, such as coverage, bandwidth available, surplus energy and memory. And index computation is defined as Formula 3.

$$p^{'}_{mn} = \begin{cases} \frac{p_{mn} - p_n^-}{p_n^+ - p_n^-},\ p_n^+ - p_n^- \neq 0 \\ 1,\ p_n^+ - p_n^- = 0. \end{cases} \tag{3}$$

Here, $p_n^+ = \max\{p_{mn}|m = 1, \cdots, M\}$ and $p_n^- = \min\{p_{mn}|m = 1, \cdots, M\}$.

Cost index: It refers the result will be increased by drop the value of index, such as communication cost and energy loss. And index computation is defined as Formula 4.

$$p^{'}_{mn} = \begin{cases} \frac{p_n^+ - p_{mn}}{p_n^+ - p_n^-},\ p_n^+ - p_n^- \neq 0 \\ 1,\ p_n^+ - p_n^- = 0. \end{cases} \tag{4}$$

Here, $p_n^+ = \max\{p_{mn}|m = 1, \cdots, M\}$ and $p_n^- = \min\{p_{mn}|m = 1, \cdots, M\}$.

After get $P^{'} = [p^{'}_{mn}]_{M*N}$, this paper introduces TOPSIS to compute the utility of ubiquitous service. TOPSIS method[10] is a kind of multi-objective decision analysis method which commonly used to select optimal solution. The advantage is simple, practical and operability. Thus, this paper uses TOPSIS to optimize service utility function. The basic idea is to get ideal solutions $V^+ = (v_1^+, \cdots, v_n^+)$ in Formula 5 and minus ideal solution $V^- = (v_1^-, \cdots, v_n^-)$ in Formula 6 to construct dimensionless $V = [v_{mn}]_{M*N}$, and then calculate the comprehensive utility value Q_t of the implementation of the solution as shown in Formula 7.

$$v_n^+ = \max\{v_{mn}|m = 1, \cdots, M\} = \omega_n p_{mn}^+, \tag{5}$$

$$v_n^- = \min\{v_{mn}|m = 1, \cdots, M\} = \omega_n p_{mn}^-, \tag{6}$$

$$\begin{gathered} Q_t = \max_{m=1,\cdots,M} \left\{ \frac{y_m^-}{y_m^+ + y_m^-} \right\} \\ \begin{cases} y_m^- = \sum\limits_{n=1}^{N} \|v_{mn} - v_n^-\| = \sum\limits_{n=1}^{N} \omega_n^2 \Big(p^{'}_{mn} - p^{'-}_n\Big)^2 \\ y_m^+ = \sum\limits_{n=1}^{N} \|v_{mn} - v_n^+\| = \sum\limits_{n=1}^{N} \omega_n^2 \Big(p^{'}_{mn} - p^{'+}_n\Big)^2. \end{cases} \end{gathered} \tag{7}$$

Additionally, ω_n is defined as Formula 8.

$$\omega_n = \frac{1}{\left(p'_{mn} - p'^{+}_{n}\right)^2 \times \sum_{n=1}^{N} \left(p'_{mn} - p'^{+}_{n}\right)^{-2}}. \tag{8}$$

IV. MULTI-DEVICES COMPOSITION AND MAINTENANCE PROBLEM MODEL

A. Composition and Maintenance Cost

As shown in Fig. 2, limited network resources and device capabilities will cause the increment of interruption duration or quality jitters of the ubiquitous service remarkably in the whole execution cycle. Therefore, the problem of MCMP is how to dynamically select device set to execute the ubiquitous service $G_{USM}(S, L)$ from $G_{MSNM}(D, E, T)$ at each time τ_t. During the whole execution cycle, there exists two challenges:

- Firstly, the dynamic characteristic of MANET causes network topology changing, which will be reflected on service qualities jitter remarkably and service duration. It is critical to maintain high quality service constantly between $[\tau_t, \tau_{t+1})$ and $[\tau_{t+1}, \tau_{t+2})$.
- Secondly, the resources on devices and the bandwidth on network links are limited, especially in MANET. Because the devices and network links are shared with each other, it is a complex problem to arrange resource-limited devices in bandwidth-limited networks for each requested ubiquitous service [11].

In order to meet the first challenge, service qualities jitter and service duration are two factors for the objective function. For first factor, we view the max utility Q_t at each time interval $[\tau_t, \tau_{t+1})$ and define σ as measurement index for service qualities jitter as shown in Formula 9.

$$\sigma = \frac{1}{T} \sum_{t \in T} (Q_t - \overline{Q}) \tag{9}$$

where, Q_t is the utility function of service quality as defined in Formula 7 and $\overline{Q}$ is the average utility during the service execution cycle . And σ reflects service qualities jitter which is to reduce the changing extent of service utility between $[\tau_t, \tau_{t+1})$ and $[\tau_{t+1}, \tau_{t+2})$. In other words, it is to keep the consistency among service utilities for a requested ubiquitous service which could affect users experience.

For the second factor, we cite interrupt time to reflect service duration. And the objective function is defined as shown in Formula 10. And Δt refers the interrupt time in each time interval $[\tau_t, \tau_{t+1})$.

$$\rho = \sum_{t \in T} \frac{\Delta t}{T}. \tag{10}$$

B. Problem Model

Based on previous definition, we integrate service qualities jitter remarkably and service duration into building the model of MCMP as shown in Formula 11. Its aim is to ensure the continuity and stability of ubiquitous services, and to shorten interruption duration of service.

$$\min F = \sigma + \rho = \frac{1}{T} \sum_{t \in T} (Q_t - \overline{Q} + t)$$
$$s.t. \begin{cases} \sum_{m=1}^{M} \sum_{v=1}^{V} r_{v,k} x_{m,v,j} \le R_{j,k}, \ \forall j, k \\ \sum_{m=1}^{M} \sum_{u=1}^{U} b_u y_{m,e} \le B_e, \ \forall e. \end{cases} \tag{11}$$

Here, $x_{m,v,j}$ is 0–1 variable which refers d_j is selected to carry out ubiquitous service in C_m and $y_{m,e}$ is also 0–1 variable which refers E_e is selected to carry out ubiquitous service in C_m.

From the view of MCMP, the problem has the following characteristics.

Theorem 1. MCMP is an nondeterministic polynomial time (NP)-complete problem.

Proof: First the decision version of the MCMP is formulated as follows.

Instance: Graph $G_{USM}(S, L)$ and Graph $G_{MSNM}D, E, T$.

Problem: Is there a subgraph of $G_{MSNM}D, E, T$ that is isomorphic to $G_{USM}(S, L)$ such that each vertex C_m denoted by d_k, belongs to G_{UN} for $s_v \in S$, where $v = 1, \cdots, V$ and $F_t = Q_t - \overline{Q} + t$ from time interval $[\tau_t, \tau_{t+1})$ to $[\tau_{t+1}, \tau_{t+2})$. □

Lemma 1. The MCMP is an NP problem.

Proof: A non-deterministic algorithm of the MCMP is described as follows. In the guessing stage, C_m is regard as a subgraph of G_{MSNM} isomorphic to G_{USM}. In the checking stage, the value from time interval $[\tau_t, \tau_{t+1})$ to $[\tau_{t+1}, \tau_{t+2})$ is calculated by a polynomial algorithm. And then select C_m to execute service. □

Lemma 2. If a special case of a problem is NP-complete, then the general problem is also NP-complete [16].

Based on Lemma 1 and 2, we show that MCMP is NP-Hard by a polynomial time reduction from a general instance of a well know NP-complete problem call class constrained subgraph isomorphism (CC-SUBISO) problem [17].

Theorem 2. MCMP has optimal substructure and is a dynamic planning problem.

Proof: MCMP is a multistage decision process problem in whole execution cycle. The objective function F_t is composition and maintenance cost form time interval $[\tau_t, \tau_{t+1})$ to $[\tau_{t+1}, \tau_{t+2})$. The objective F refers that the executing time form $[\tau_1, \tau_2)$ to $[\tau_N, \tau_{N+1})$. And is calculated from $F_1, F_2, \cdots, F_t, \cdots, F_N$ as shown in Formula

$$F = \min \frac{1}{T} \sum_{t=1}^{N} F_t = \min \frac{1}{T} \sum_{t=1}^{N} (Q_t - \overline{Q} + t). \tag{12}$$

From formula 12, F has optimal substructure and its optimal substructure is as following.

$$\begin{aligned} \min F &\cong \min \sum_{t=1}^{N} (Q_t - \overline{Q} + t) \\ &= \min\{(\sum_{t=1}^{N-1} (Q_t - \overline{Q} + t)) + Q_N - \overline{Q} + N\}. \end{aligned} \tag{13}$$

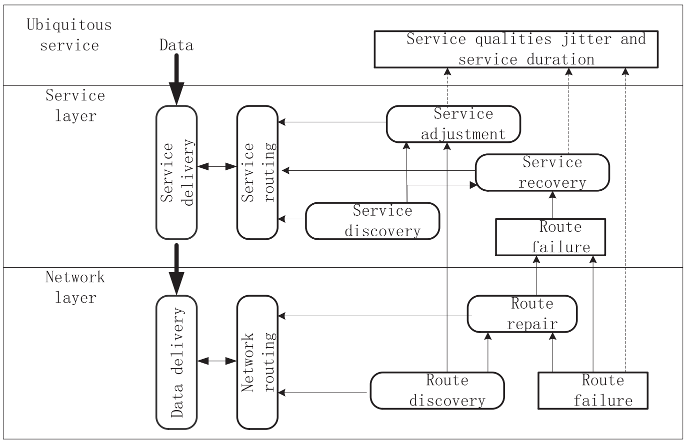

Fig. 4. Multi-devices composition and maintenance algorithm.

Therefore, MCMP has optimal substructure and is a dynamic planning problem. □

V. MULTI-DEVICES COMPOSITION AND MAINTENANCE MECHANISM

A. Multi-Devices Composition and Maintenance Framework

To sustain ubiquitous service execution, the service must be recovered in time to avoid service qualities jitter remarkably and shorten service interruption time. Service recovery is triggered by service failure detection at network route failure as shown in Fig. 4. There are two behaviors in service recovery to influence service qualities jitter and service duration: Service adjustment and service recovery. Those behviurs are caused by service failure in the processes of network route discovery again or network route repair. Obviously, the key of MCMP is to how to dynamic select optimal MCS to construct available network routing. In this paper, we propose a multi-devices composition and maintenance algorithm (MCMA) to solve it.

B. Multi-Devices Composition and Maintenance Algorithm

The goal of MCMA for MCMP is to find a series sub-network $G_{MSNM}(D, E, T)$ to execute $G_{USM}(S, L)$ and maintain the continuity and stability. To solve it, we introduce concept of time window and candidate multi-device composition set (C-MCS). To recover the ubiquitous service in time when service interrupts, the C-MCS will be updated regularly and the device set who keep the smoothness of composition and maintenance cost will be chosen as C-MCS. MDCM is constructed as shown in Fig. 5. The MDCM includes four modules: Service discovery, service composition, service monitor and service recover.

B.1 Service Discovery

In dynamic mobile social network, service discovery is the stage in service requiring. A requested ubiquitous service is represented by a service logic model $G_{USM}(S, L)$ on the service starting device. Besides, local network topology $NetTop = MCS, G\,\text{bit}$ is also initialized on this device. $MCS = (d_{k_0}, d_{k_1}, \cdots, d_{k_h}, \cdots, d_{k_H})$, d_{k_h} is the device to execute hth

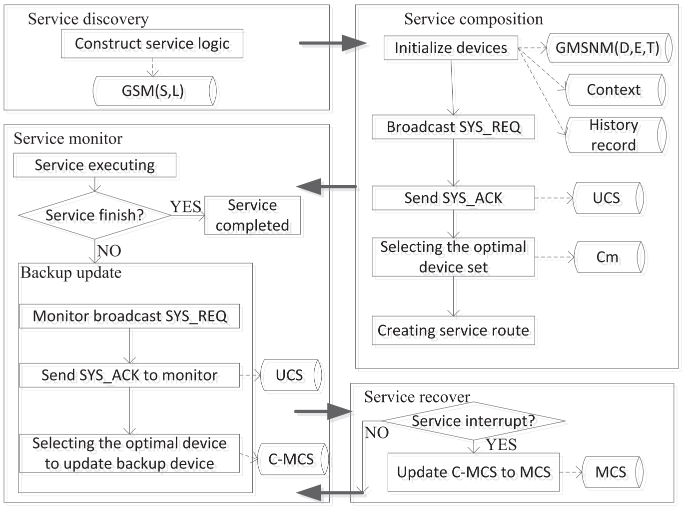

Fig. 5. Multi-devices composition and maintenance algorithm.

sub service for $G_{USM}(S, L)$ and G bit is mark bit which represents the sub service whether it executes on one device. The initialization of MCS is $MCS = (NULL, NULL, \cdots, NULL)$ and $G\ \text{bit} = 00\cdots0$.

B.2 Service Composition

After service discovery stage, there is service composition stage which is the main step to construct $NetTop = MCS, G\,\text{bit}$ for ubiquitous service $G_{USM}(S, L)$ in service composition process. AODV protocol carries $SYSREQ$ packets controlled by time to live TTL will be broadcasted among devices. In this process, the device who requests for the service is viewed as starting node. It broadcasts SYSREQ packet controlled by TTL as shown in Fig. 5. When other device receives SYSREQ packet, it will judge whether it is the relay node to perform the service. If it is, the context of the device will be put into SYSREQ packet and then it broadcasts new SYSREQ packet. This process will continue till the end node of the service is found. The end node will construct SYSACK packet with context of all the relay nodes of the service and forward it back to the starting device device. After collecting all the SYSACK packets, the starting device constructs CDS with measurement index context called universal cooperating device set (UCS). Then, the device will select C_m with the best quality according to the problem model f as defined in Formula 6. After that, the starting device sends messages with INSACK packet to the relay nodes and end node in the selected C_m and set up end to end routing for service.

B.3 Service Monitor

In Service monitor process, quality of ubiquitous service will be monitored routinely according to timer. The C-MCS will be prepared and updated. This would be helpful when the service utility degrades or service interruption happens. In this case, the ubiquitous service could be handed over to the candidate device set in time and the routing of the service can be reconstructed. The main idea of the algorithm in service monitor process is same as service composition in subsection V-B.

B.4 Service Recover

When the service utility of ubiquitous service decline or the service interrupts, service recover process will firstly choose the best candidate device set from C-MCS based on formula 6 and reconstruct the routing of the service. If there is no suitable device set in C-MCS, the device need to re-execute service composition process from a global prospect as shown in Fig. 5.

VI. SIMULATION ANALYSIS

A. Measurement Index

In MSN, we introduce service distance, availability, reliability to reflect user experience, terminal ability and network state during the processes of simulation. Those three indexes are imported as three columns in Measurement-matrix in subsection III-C. And the definition of each evaluation index is shown as follows.

Service distance: It is to show the difference between the average distance [11] from a user to the device and the best distance for a user to use a specific service performed on those devices as shown in Formula 14.

$$\rho_{dis} = \frac{d(d,\mu,\sigma)}{d(\mu,\mu,\sigma)}. \qquad (14)$$

Here, $d(d,\mu,\sigma) = 1/\sigma\sqrt{2\pi}\exp(-(d-\mu)^2/2\sigma^2)$, where d is the actual distance between device and user, the μ is the best expecting distance between device and user, σ is the sensitivity to service distance.

Availability: The time interval between when a user requests a service on those devices and when the user received the response which is defined as Formula 15.

$$\rho_{i,del} = \begin{cases} 1 - \frac{T_i}{T_{\max}},\ T_i \le T_{\max} \\ 0,\ T_i > T_{\max}. \end{cases} \qquad (15)$$

T_i is response time; $T_{\max}$ is the device regarded as successfully responded if $T_i < T_{\max}$.

Reliability: The probability [18] that service performed normally on those devices which is defined as $\rho_{i,rel} = \omega_1 \cdot Cap + \omega_2 \cdot mobil$. Here, Cap is service capacity which combined with the I/O storing velocity, current CPU load, memory capability and so on. And $mobil$ is moving speed of device, ω_1 and ω_2 are their weights.

B. Simulation Environment

Based on evaluation index, we use simulation parameters in table 1 during simulation process. To observe the performance of dynamic MCMA with multi-users, scenarios with 1, 4, and 8 users were simulated. Moreover, various maximum speeds (1, 5, 10, 15, and 20 m/s) are simulated to show that the MCMA is suitable for ubiquitous environments with high-mobility devices.

C. Result Analysis

To compare the performance of the MCMA, MDSCR, SDA and DTA approaches, the simulation results for service diversity, service jitter, service duration, and energy consumption are described as follows.

Table 1. Parameters used in the simulations.

Number of users	1, 4, 8, 15, 20
Number of devices	60+ number of users
Maximum workload	5 users
Simulation area	$100\times100\ \mathrm{m}^2$
Initial energy	1000 J
Routing protocol	AODV
Transmission radius	30 m
Mobility model	Random waypoint model
Maximum speed	1, 5, 10, 15, 20 m/s
Mac protocol	IEEE 802.11
Simulation time	250 s

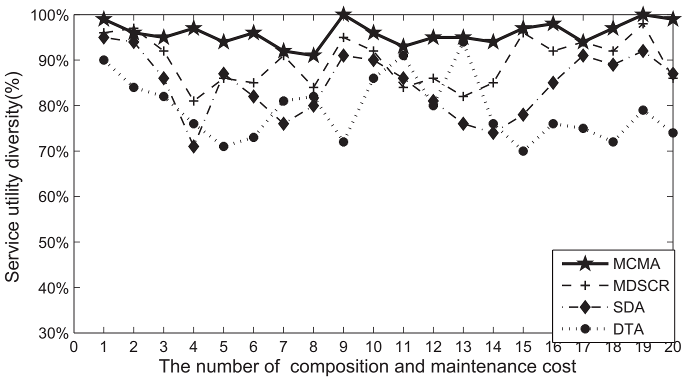

Fig. 6. The distribution of service utility diversity.

Service diversity: The MCMP has optimal solution with Theorem 2. However, the optimal solution could be calculated at the end of service execution so that we must use heuristic forecast method as shown in Section IV. Service Utility is cited to measure the difference between our solution and optimal solution which is defined in Formula 16. From the view of Fig. 6, Service Utility Diversity of our solution is closer to that of the optimal solution than other methods. And the value interval of MCMA is 91%–100%. MDSCR is 81%–98%. SDA is 71%–99%. DTA is 70%–100%.

$$\Delta\theta = \frac{F_t}{F_{t,\mathrm{opt}}} \times 100\%. \qquad (16)$$

Here, F_t refers composition and maintenance cost which is changed from time interval $[\tau_t, \tau_{t+1})$ to $[\tau_{t+1}, \tau_{t+2})$. And $F_{t,\mathrm{opt}}$ refers the ideal optimal cost changed from time interval $[\tau_t, \tau_{t+1})$ to $[\tau_{t+1}, \tau_{t+2})$.

Service jitter: We observed the distribution of service utility during a long time for a requested ubiquitous service in Fig. 7. Fig. 7(a) is to show the service utility of MCMA in the paper and Fig. 7(b) is to show the service utility of MDSCR. As shown in Fig. 7, the jitter range of service utility in MCMA is (0.60, 0.93) which is smoother than MDSCR in (0.40, 0.85). Service jitter is to keep the consistency among service utilities for a requested ubiquitous service to improve users experience.

Service duration: Service duration refers that the interrupt time, the number of service interruptions and the average time elapsed per re-selecting process in whole service execution cy-

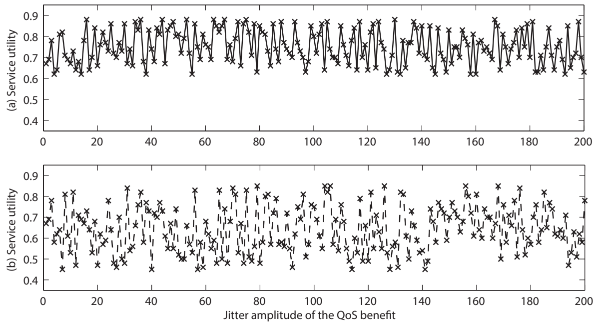

Fig. 7. The distribution of service utility.

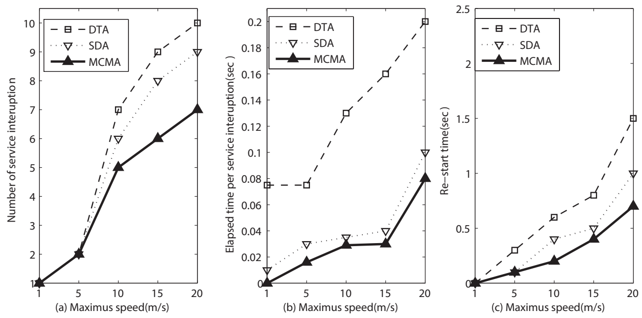

Fig. 8. (a) Number of service interruption, (b) average time elapsed per reselecting process, and (c) average re-start time at various maximum speeds with 8 users.

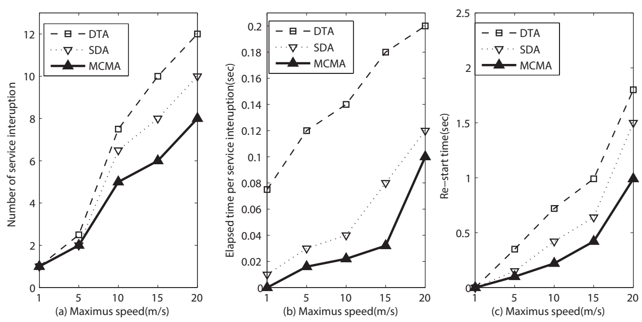

Fig. 9. (a) Number of service interruption, (b) average time elapsed per reselecting process, and (c) average re-start time at various maximum speeds with 15 users.

cle. The re-start time is defined as the average time spent resuming the interrupted ubiquitous service during the simulation, which can be calculated by the product of the number of service interruptions and average time spent on the initialization process. As shown in Fig. 8, there has 8 users. In Fig. 8(b), it is reasonable that the time spent on initialization in the MCMP is shorter than that in the SDA and DTA. Additionally, the number of service interruptions is effectively reduced in MCMP as shown in Fig. 8(a). And Fig. 8(c) thus shows that the MCMA still performs well with regard to the re-start time. Meanwhile, the number is 15 users in simulation and the result also shows that MCMA is performs better than others.

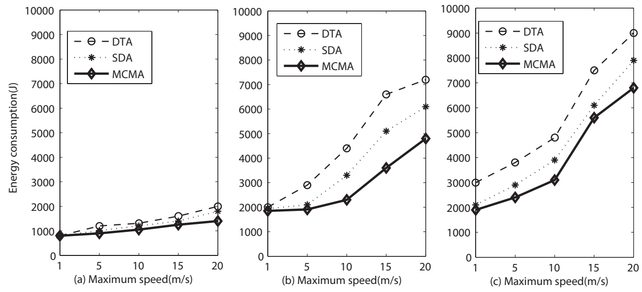

Fig. 10. Energy consumption at various maximum speeds with: (a) 1 user, (b) 4 users, and (c) 8.

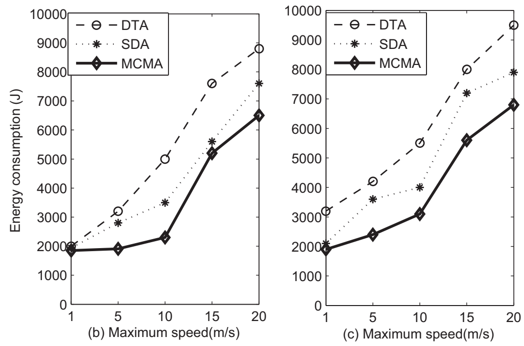

Fig. 11. Energy consumption at various maximum speeds with: (a) 15 user and (b) 20 users.

Energy Consumption: Energy consumption is calculated by all selected devices. As shown in Fig. 10, compared with SDA and DTA, MCMA approach saves 0–27% and 0–50% respectively in energy consumption. Energy consumption is improved as the number of users increases as shown in Fig. 10 and Fig. 11. Therefore, the advantage of MCMA is more applicative to multi-users environment.

VII. CONCLUSION

In MSN, limited network resources and device capabilities will cause the increment of interruption duration or quality jitters of the ubiquitous service remarkably in the whole execution cycle. The paper propose an effective composition and maintenance mechanism that enable users to access highly reliable ubiquitous service. At simulation, we use service diversity, service jitter, service duration, and energy consumption to reflect as evaluation index. The present research mainly focuses on solving an optimal set of devices for each individual requested ubiquitous service. Thus, our next stage work is to design a global multi-devices synergy mechanism in multi-user and multi-service ubiquitous environments.

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