Zhang et al. EURASIP Journal on Wireless Communications and Networking 2013, 2013:181
http://jwcn.eurasipjournals.com/content/2013/1/181

EURASIP Journal on Wireless Communications and Networking
a SpringerOpen Journal

RESEARCH Open Access

A novel multimedia device ability matching technique for ubiquitous computing environments

Jianwei Zhang[1], Pan Deng[2], Jiafu Wan[3*], Biying Yan[2], Xiaohui Rong[1] and Feng Chen[1]

Abstract

In wireless multimedia sensor networks (WMSNs), wirelessly interconnected devices are able to ubiquitously retrieve multimedia contents such as video and audio streams from the environment. However, since WMSN applications are large-scale, dynamic and highly concurrent, how to achieve both effective multimedia device resource management and collaborative task scheduling simultaneously becomes a serious problem. In this paper, using the hierarchical modeling technique, we first propose a device ability model including spatial information. In order to solve the problem of insufficient capacity of single devices, we then give a composite device ability model and relevant calculation formulae. Next, we introduce a novel device resource matching technique based on the proposed model. Compared with previous works, experimental results show that our technique achieves better recall and precision and meets WMSN application needs more effectively. Furthermore, our proposed approach greatly reduces the design complexity as well as the workload of application designers.

1 Introduction

Wireless multimedia sensor networks (WMSNs) [1] have drawn the attention of researchers in recent years, driven by a wealth of theoretical and practical challenges. This growing interest can be largely attributed to new applications enabled by large-scale networks of small devices, such as multimedia video surveillance systems, traffic avoidance and control systems, environment monitoring systems and so on [2]. Most WMSN applications require coordination and cooperation among large-scale multimedia devices in ubiquitous computing environments [3]. The matching between the large-scale device collaboration demand and device resources is the basis of the realization of WMSN applications. The resource ability matching technique [4], which is always a research hotspot in the field of collaboration technology [5-7], is realized by matching the requirement of virtual device capacity with the description of device resource ability.

In the WMSNs' environment, the multimedia device resource ability has the following characteristics [8]: (a) It is related to the spatial extent [9], i.e., the device resource ability in a certain point of the space depends on both the absolute spatial position of this device resource and the relative spatial distance between this point and itself [10,11]. (b) It can be superimposed, i.e., superimposing multiple device resource ability in a certain point of the space may achieve better device ability in this point and meet greater requirement which single device could not satisfy [12-14].

Resource matching researches [15-20] currently focus on the web service matching, including syntax service matching [21] and semantic service matching [22]. The former [23] do exact keyword matching by registration information including the name and valid property values of the service in the service library, while the latter is based on semantic web technology. With the combination of ontology repository, matching service and authentication service, the latter can determine the matching degree between the request and service ability [24].

However, both the syntax service matching and the semantic matching are limited. The syntax service matching method [25] cannot accurately describe the desired multimedia device ability and measure the distance between the physical device ability and the desired device

*Correspondence: jiafu_wan@ieee.org
[3]College of Information Engineering, Guangdong Jidian Polytechnic, Guangzhou, China
Full list of author information is available at the end of the article

ability. Besides, the high user involvement [26] makes it hard to do service matching automatically in ubiquitous computing environment. The semantic service matching method, due to the huge type and number of devices in WMSNs, could not establish the ontology repository and make users understand easily. Furthermore, in the current study [27-29], since resource ability modeling always regards the resource access interface as a function and lacks the spatial location information of device, users build their own collaborative process only by understanding the details of all devices in the system [30], which is not suitable for WMSN applications in the WMSNs.

Given the above problems, this paper proposes a multimedia device resource matching method based on the device resource ability model. The remainder of the paper is organized as follows: Section 2 introduces the related work, Section 3 first defines a multimedia device ability model with spatial location information and its calculation formula which can calculate the device ability accurately and then gives a device resource matching method based on the above model to reduce the complexity in the design of large-scale device collaboration process of WMSN application, Section 4 gives the experimental results, and Section 5 concludes the paper.

2 Related work

Currently, there are various syntax service modeling techniques such as Web Service Description Language (WSDL), Resource Specification Language, Resource Description Framework (RDF), etc. Besides, there are also semantic service modeling techniques which include the RDFS (RDF Schema) [26], Web Ontology Language (OWL)/OWL-S [29], WSDL [27,28], etc. Among them, the OWL-S has become a very important general resource description technique, which describes the attribute and function of the web resource from the syntax perspective and service perspective. Recently, researchers try to combine the OWL-S technique with the WSDL technique to achieve a new resource description resolution which has comprehensive superiority.

The syntax service matching method [31] focuses on the implementation details of the resource interface, which makes it easy to implement [32]. However, the recall and precision of this method is lower, and it cannot effectively support users doing service discovery based on functional semantic. The typical study is Universal Description, Discovery, and Integration (UDDI) [33-35]. UDDI uses WSDL to describe its web service and does exact keyword matching by the registration information in service library, mainly on ID, name, and valid property values of service.

The semantic service matching technique [36] focuses on the web service matching [37], including single service resource matching and service-oriented resource association matching [38]. The former research [39] used DAML-S for service modeling, which combines the users' needs with the properties of candidate service to achieve a single downlink (DL) expression. It judged the relationship between two collections of corresponding DL expressions by the DL inference engine and expanded the service matching algorithm. The latter research [40] solved the optimal matching problem among services using an exhaustive method. As the exponential growth of elapsed time, there will come a time-consuming problem when the parameters of service operation become larger [41], giving a service-oriented resource association matching mainly on interface parameter matching which does not filter the service matching according to the corresponding priority [42].

3 Modeling and matching method

3.1 Definition

In this section, we give the formal definition of device and device operation at first and then define the operation ability and performance attribute of device resource.

Definition 1. Terminal. In the large-scale device collaborative system, terminal is the smallest unit of the system control. Each terminal has finite states. Assume t_i is a terminal, its state set is $\{ts_1, ts_2, \ldots, ts_m\}$, and one terminal can only be in one state at a time.

Definition 2. Device. In the large-scale device collaborative system, a device is composed by n terminals and denoted as $d = \{t_1, t_2, \ldots, t_n\}$. The operation set supported by device d is Σ, and the state set of device is Q.

Definition 3. Device state. The state of device $d = \{t_1, t_2, \ldots, t_n\}$ is composed of n terminal states. Assume that device d has k states, the state set Q of device d is $Q = \{s_1, s_2, \ldots, s_k\}$. Each device state s is an ordered pair of n terminal state, i.e., $s = \{ts_{t1}, ts_{t2}, \ldots, ts_{tn}\}$, where ts_{ti} represents a state of terminal t_i.

According to the definition of the device state, we find that if a device contains n terminals and each terminal has m states, the number of device state is m^n.

Definition 4. Device operation. Device operation changes the device state by changing some terminal state of this device. Assume the collection Σ of device operation in device $d = \{t_1, t_2, \ldots, t_n\}$ is $\Sigma = \{op_1, op_2 \ldots, op_l\}$, where $op = \{< t_i, ts_i >, \ldots, < t_j, ts_j >\}, t_i, \ldots, t_j \in \{t_1, t_2, \ldots, t_n\}$.

In the large-scale device collaborative system, according to the impact on the device state, the operating ability of device resource can be divided into three categories: monitor ability, basic control ability, and combination control ability. The first ability of device resource is monitor operation, whose collection is empty, and it is used for gaining the current state of the device. The second one is terminal control operation, whose collection contains only one element, and it can only set one terminal state each time. The last one is advanced control operation, whose collection contains multiple elements, and it can set several terminal states each time.

Definition 5. Composite device. In the large-scale device collaborative system, it is necessary that several devices work in parallel to achieve a synergistic effect, where all these devices are called a composite device.

Assume $d_1 = \{t_{11}, t_{12}, \ldots, t_{1n}\}, \ldots, d_k = \{t_{k1}, t_{k2}, \ldots, t_{kn}\}$ is a set of concurrent collaborative working devices. Then, its corresponding device operation set is $\Sigma_1, \ldots, \Sigma_k$, and the device state set is $Q_1, \ldots, Q_k$. The composite device com_d contains $\sum_{i=1}^{k} in$ terminals, i.e., $com\_d = \{d_1, \ldots, d_k\}$.

The operation set supported by composite device com_d is $com\_\Sigma = \{com\_op_1, com\_op_2, \ldots, com\_op_r\}$, $com\_op = \bigcup_{i=1}^{k} op_{ij_i}, op_{ij_i} \in \Sigma_i, 1 \le j_i \le |\Sigma_i|$, and the number of composite device is $r = \prod_{i=1}^{k} |\Sigma_i|$.

The state set of composite device com_d is

$com\_q = \{com\_s_1, com\_s_2, \ldots, com\_s_s\}$, $com\_s = \sum_{i=1}^{k} s_{ij_i}, s_{ij_i} \in Q_i, 1 \le j_i \le |Q_i|$,

and the number of composite device is $s = \prod_{i=1}^{k} |Q_i|$.

3.2 The device resource ability model

In the large-scale device collaborative system, the minimum ability calculation unit is the terminal ability model of the device. The ability of a device's operation is a union of the ability of terminal controlled by this device. The following is the description and calculation formula of these ability models.

3.2.1 *Terminal ability model*

Definition 6. Terminal ability. The terminal ability of a device refers to a set of function parameters in its spatial extent and state. Assuming that t is a terminal and its state set is $\{ts_1, ts_2, \ldots, ts_m\}$, when $ts \in \{ts_1, ts_2, \ldots, ts_m\}$, the terminal ability is as follows:

$$tA(t, ts) = fa(\sigma\{(x_{t1}, y_{t1}, z_{t1}), \ldots, (x_{tm}, y_{tm}, z_{tm})\}, (a_1, a_2, \ldots, a_n))tm \ge 1, n \ge 1 \quad (1)$$

- $\sigma\{(x_{t1}, y_{t1}, z_{t1}), \ldots, (x_{tm}, y_{tm}, z_{tm})\}$ represents the spatial extent of the terminal, and $tm = 1$ indicates that the ability is on the point (x_{t1}, y_{t1}, z_{t1}) .
- $a_i, 1 \le i \le n$ represents the ith function parameter of the terminal.
- *fa* represents the map function between function parameters and spatial extent.

For example, denoting the state set in terminal of device $d = \{t_1, t_2, \ldots, t_n\}$ as {ON, OFF}, when the state of terminal t is ON its ability is $tA(t, \mathrm{ON}) = l \times r(lx)\{(x_0, y_0), \pi \times ((r + \Delta r)^2 - r^2), 0 \le r \le r_{\max}\}$, and when the state is OFF, its terminal ability is $tA(t, \mathrm{OFF}) = 0(lx)\{(x_0, y_0), \pi \times ((r + \Delta r)^2 - r^2), 0 \le r \le r_{\max}\}$. That is to say, in the two-dimensional spatial extent $(x_0, y_0), \pi \times ((r + \Delta r)^2 - r^2)$, the ability of terminal t is $l \times r$.

3.2.2 *Device ability model*

Definition 7. Device operation ability. The device operation ability refers to the aggregation of terminal ability in the spatial extent of device operation when this terminal is in its changing state. For device $d = \{t_1, t_2, \ldots, t_n\}$ and device operation $op = \{< t_i, ts_i >, \ldots, < t_j, ts_j >\}$, $t_i, \ldots, t_j \in \{t_1, t_2, \ldots, t_n\}$, the device operation ability is as follows:

$$opA(op) = fa(\sigma\{(x_{op1}, y_{op1}, z_{op1}), \ldots, (x_{opm}, y_{opm}, z_{opm})\}, (a_1, a_2, \ldots, a_n)), opm \ge 1, n \ge 1 \quad (2)$$

- $\sigma\{(x_{op1}, y_{op1}, z_{op1}), \ldots, (x_{opm}, y_{opm}, z_{opm})\}$ represents the spatial extent of the device operation.
- $a_i, 1 \le i \le n$ represents the ith function parameter of the device operation.
- $f a$ represents the map function between function parameters and spatial extent.

Rule 1. Device operation ability calculation. Assume the function Ω is the cumulative calculation function of spatial extent, and Φ_i is the aggregation function of the ith function parameter, $\Phi = \{\Sigma, \mathrm{MAX}, \ldots\}$. The spatial extent and calculation rule of the function parameter of the device operation is as follows:

- The space extent of the device operation can be calculated by all the space extents of terminal controlled by this device, i.e.,

$$\begin{aligned} &\sigma\{(x_{op1}, y_{op1}, z_{op1}), \ldots, (x_{opm}, y_{opm}, z_{opm})\} \\ &= \Omega(\sigma\{(x_{ti1}, y_{ti1}, z_{ti1}), \ldots, (x_{tim}, y_{tim}, z_{tim})\}, \ldots, \\ &\quad \sigma\{(x_{tj1}, y_{tj1}, z_{tj1}), \ldots, (x_{tjm}, y_{tjm}, z_{tjm})\}). \end{aligned} \quad (3)$$

- The function parameter of the device operation in spatial extent $\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\}$ can be aggregated by all these function parameters of terminal controlled by this device in the same spatial extent, i.e.,

$$\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_i = \Phi_i(\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{ii},\ldots, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{ji}), \quad (4)$$

where $a_{ii},\ldots,a_{ji}$ is the corresponding function parameter of terminal control ability by the device operation.

For example, denoting the operation of device $d = \{t_1,\ldots,t_n\}$ as $op = \{<t_1,\mathrm{ON}>,<t_2,\mathrm{ON}>\}$, when the state of terminal t_1 is ON, its terminal ability is $tA(t_1,\mathrm{ON}) = l_1 \times r_1(lx)\{(x_{01},y_{01}),\pi\times((r_1+\Delta r)^2 - {r_1}^2),0\le r_1\le r^1_{\max}\}$, and when the state of terminal is OFF, its terminal ability is $tA(t_2,\mathrm{OFF}) = l_2\times r_2(lx)\{(x_{02},y_{02}),\pi\times((r_2+\Delta r)^2 - {r_2}^2),0\le r_2\le r^2_{\max}\}$. That is to say, in the two-dimensional spatial extent $(x_0,y_0),\pi\times((r+\Delta r)^2-r^2)$, the ability of terminal t is $l\times r$.

Assume the operation space intersection for terminal t_1 and t_2 is as follows:

$$\{(x_{01},y_{01}),\pi\times((r_1+\Delta r)^2-{r_1}^2),0\le r_1\le r^1_{\max}\}\cap \{(x_{02},y_{02}),\pi\times((r_2+\Delta r)^2-{r_2}^2),0\le r_2\le r^2_{\max}\} = \sigma(r_1,r_2). \quad (5)$$

Then, the ability of device operation is as follows:

$$opA(op)=\begin{cases} l_1\times r_1(lx),\{(x_{01},y_{01}),\pi\times((r_1+\Delta r)^2-{r_1}^2)-\sigma(r_1,r_2),0<r_1\le r^1_{\max}\} \\ (l_1\times r_1+l_2\times r_2)(lx),\{\sigma(r_1,r_2),0\le r_1\le r^1_{\max},0<r_2\le r^2_{\max}\} \\ l_2\times r_2(lx),\{(x_{02},y_{02}),\pi\times((r_2+\Delta r)^2-{r_2}^2)-\sigma(r_1,r_2),0<r_2\le r^2_{\max}\}. \end{cases} \quad (6)$$

The spatial extent of device operation OP is the union of the operation spatial extent for terminal t_1 and t_2, i.e., $\{(x_{01},y_{01}),\pi\times((r_1+\Delta r_1)^2-{r_1}^2)\}\cup\{(x_{02},y_{02}),\pi\times((r_2+\Delta r_2)^2-{r_2}^2)\}$. The device operation ability is a piecewise function: in the intersection of two terminal's operation space $\sigma(r_1,r_2)$, the ability is $(l_1\times r_1+l_2\times r_2)$, i.e., the joint result of two terminals; in the terminal t_1's operation space, the ability is $l_1\times r_1$, i.e., the result of terminal t_1; and in the terminal t_2's operation space, the ability is $l_2\times r_2$, i.e., the result of terminal t_2.

Definition 8. Device ability. The device ability refers to all the device operation abilities in spatial extent. Assume the collection of device operation in device $d = \{t_1,t_2,\ldots,t_n\}$ is $\Sigma = \{op_1,op_2,\ldots,op_l\}$. The device ability is denoted as follows:

$$dA(d) = fa(\sigma\{(x_{d1},y_{d1},z_{d1}),\ldots,(x_{dm},y_{dm},z_{dm})\}, (a_1,a_2,\ldots,a_n)), dm\ge 1, n\ge 1 \quad (7)$$

- $\sigma\{(x_{d1},y_{d1},z_{d1}),\ldots,(x_{dm},y_{dm},z_{dm})\}$ denotes the spatial extent of the device.
- $a_i, 1\le i\le n$ denotes the ith function parameter of the device.
- fa denotes the map function between function parameters and spatial extent.

Rule 2. Device ability calculation. Assume the function Ω is the cumulative calculation function of spatial extent, Φ_i is the aggregation function of the ith function parameter, $\Phi = \{\Sigma,\mathrm{MAX},\ldots\}$. The spatial extent and calculation rule of function parameter of a device is as follows:

- The space extent of a device can be calculated by all the space extents of the terminals controlled by this device, i.e.,

$$\sigma\{(x_{d1},y_{d1},z_{d1}),\ldots,(x_{dm},y_{dm},z_{dm})\} = \Omega(\sigma\{(x_{t11},y_{t11},z_{t11}),\ldots,(x_{t1m},y_{t1m},z_{t1m})\},\ldots, \sigma\{(x_{tn1},y_{tn1},z_{tn1}),\ldots,(x_{tnm},y_{tnm},z_{tnm})\}). \quad (8)$$

- The function parameter of a device in spatial extent $\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}$ can be aggregated by all the device operations in the same spatial extent. The minimum value of device function parameter a_i in this spatial extent is:

$$\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:\theta^{ai}_{\min} = \mathrm{MIN}(\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{1i}, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{2i},\ldots, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{li}), \quad (9)$$

where $a_{1i},\ldots,a_{li}$ is the corresponding function parameter of device ability.

The maximum value of device function parameter a_i in this spatial extent is:

$$\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:\theta^{ai}_{\max} = \mathrm{MAX}(\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{1i}, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{2i},\ldots, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{li}), \quad (10)$$

where the interval of function parameter a_i is:

$$\begin{aligned} &\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_i \\ &=[\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:\theta^{ai}_{\min}, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:\theta^{ai}_{\max}] \\ &=[\mathrm{MIN}(\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{1i}, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{2i},\ldots, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{li}), \\ &\mathrm{MAX}(\sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{1i}, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{2i},\ldots, \sigma\{(x_1,y_1,z_1),\ldots,(x_m,y_m,z_m)\}:a_{li})] \end{aligned} \quad (11)$$

For example, assume the operation set of device $d = \{t_1, t_2, t_3\}$ is $\Sigma = \{op_1, op_2\}$, $op_1 = \{< t_1, \mathrm{ON} >, < t_2, \mathrm{ON} >\}$, $op_2 = \{< t_2, \mathrm{OFF} >, < t_3, \mathrm{ON} >\}$. The abilities of device operation op_1 and op_2 are:

$$opA(op_1) = \begin{cases} l_1 \times r_1(lx), \{(x_{01}, y_{01}), \pi \times ((r_1 + \Delta r)^2 - {r_1}^2) - \sigma(r_1, r_2), 0 < r_1 \leq r^1_{\max}\} \\ (l_1 \times r_1 + l_2 \times r_2)(lx), \{\sigma(r_1, r_2), 0 \leq r_1 \leq r^1_{\max}, 0 < r_2 \leq r^2_{\max}\} \\ l_2 \times r_2(lx), \{(x_{02}, y_{02}), \pi \times ((r_2 + \Delta r)^2 - {r_2}^2) - \sigma(r_1, r_2), 0 < r_2 \leq r^2_{\max}\} \end{cases} \tag{12}$$

$$opA(op_2) = l_3 \times r_3(lx)\, \pi \times ((r_3 + \Delta r)^2 - {r_3}^2), 0 \leq r_3 \leq r^3_{\max} \tag{13}$$

The intersection of operation spatial extent of terminals t_1, t_2, and t_3 is:

$$\{(x_{01}, y_{01}), \pi \times ((r_1 + \Delta r)^2 - {r_1}^2), 0 \leq r_1 \leq r^1_{\max}\} \cap \{(x_{02}, y_{02}), \pi \times ((r_2 + \Delta r)^2 - {r_2}^2), 0 \leq r_2 \leq r^2_{\max}\} \cap \{(x_{03}, y_{03}), \pi \times ((r_3 + \Delta r)^2 - {r_3}^2), 0 \leq r_3 \leq r^3_{\max}\} = \sigma(r_1, r_2, r_3). \tag{14}$$

Assume $l_1 \leq l_2 \leq l_3$, then the minimum device ability in operation spatial extent $\sigma(r_1, r_2, r_3)$ is:

$$\theta^a_{\min} = \mathrm{MIN}((l_1 + l_2) \times r(lx), l_3 \times r(lx)) = l_3 \times r(lx). \tag{15}$$

The maximum device ability is:

$$\theta^a_{\max} = \mathrm{MAX}((l_1 + l_2) \times r(lx), l_3 \times r(lx)) = (l_1 + l_2) \times r(lx). \tag{16}$$

The function parameter interval of the device ability is:

$$a = [\theta^a_{\min}, \theta^a_{\max}] = [l_3 \times r(lx), (l_1 + l_2) \times r(lx)]. \tag{17}$$

Similarly, when the operation spatial extent is $r^1_{\max} < r \leq r^2_{\max}$ or $r^2_{\max} < r \leq r^3_{\max}$, the corresponding function parameter interval of the device ability is:

$$a = [\theta^a_{\min}, \theta^a_{\max}] = [l_2 \times r(lx), l_3 \times r(lx)]. \tag{18}$$

$$a = [\theta^a_{\min}, \theta^a_{\max}] = [l_3 \times r(lx), l_3 \times r(lx)]. \tag{19}$$

The ability of the device $d = \{t_1, t_2, t_3\}$ is:

$$dA(d) = \begin{cases} [l_3 \times r(lx), (l_1 + l_2) \times r(lx)]\, \pi \times ((r + \Delta r)^2 - r^2), 0 \leq r \leq r^1_{\max} \\ [(l_2 \times r(lx), l_3 \times r(lx)]\, \pi \times ((r + \Delta r)^2 - r^2), r^1_{\max} < r \leq r^2_{\max} \\ [l_3 \times r(lx), [l_3 \times r(lx)]\, \pi \times ((r + \Delta r)^2 - r^2), r^2_{\max} < r \leq r^3_{\max} \end{cases} \tag{20}$$

3.2.3 Composite device ability model

Definition 9. Composite device operation ability. It refers to the aggregation of device operation ability when devices execute concurrently in the spatial extent of device operation. Assume $comD = \{d_1, \ldots, d_k\}$ is a composite device; the operation of this device is $comOp = \bigcup_{i=1}^{k} op_i, op_i \in \Sigma_i$, and the operation ability is as follows:

$$comOpA(comOp) = fa(\sigma\{(x_{comOp1}, y_{comOp1}, z_{comOp1}), \ldots, (x_{comOpm}, y_{comOpm}, z_{comOpm})\}, (a_1, a_2, \ldots, a_n)), comOpm \geq 1, n \geq 1 \tag{21}$$

- $\sigma\{(x_{comOp1}, y_{comOp1}, z_{comOp1}), \ldots, (x_{comOpm}, y_{comOpm}, z_{comOpm})\}$ represents the spatial extent of the device operation.
- $a_i, 1 \leq i \leq n$ represents the ith function parameter of the device operation.
- fa represents the map function between function parameters and spatial extent.

Rule 3. Composite device operation ability calculation. Assume the function Ω is the cumulative calculation function of spatial extent and is the aggregation function of the ith function parameter, $\Phi = \{\Sigma, \mathrm{MAX}, \ldots\}$. Then, the spatial extent and calculation rule of function parameter of composite device operation is as follows:

- The space extent of composite device operation can be calculated by all the space extents of participated device operations, i.e.,

$$\sigma\{(x_{comOp1}, y_{comOp1}, z_{comOp1}), \ldots, (x_{comOpm}, y_{comOpm}, z_{comOpm})\} = \Omega(\sigma\{(x_{op11}, y_{op11}, z_{op11}), \ldots, (x_{op1m}, y_{op1m}, z_{op1m})\}, \ldots \sigma\{(x_{opk1}, y_{opk1}, z_{opk1}), \ldots, (x_{opkm}, y_{opkm}, z_{opkm})\}) \tag{22}$$

- The function parameter of composite device operation in spatial extent $\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\}$ can be aggregated by all these function parameters of participated device operations in the same spatial extent, i.e.,

$$\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : a_i = \Phi_i(\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : a_{1i}, \ldots, \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : a_{ki}), \tag{23}$$

where $a_{1i}, \ldots, a_{li}$ is the corresponding function parameter of the device operation ability.

Definition 10. Composite device ability. The composite device ability refers to all the participated device abilities in spatial extent. Assume $comD = \{d_1, \ldots, d_k\}$ is a composite device. The ability is denoted as follows:

$$comDA(comD) = fa(\sigma\{(x_{comD1}, y_{comD1}, z_{comD1}), \ldots, (x_{comDm}, y_{comDm}, z_{comDm})\}, (a_1, a_2, \ldots, a_n)), comDm \geq 1, n \geq 1 \tag{24}$$

- $\sigma\{(x_{cds1}, y_{cds1}, z_{cds1}), \ldots, (x_{cdsm}, y_{cdsm}, z_{cdsm})\}$ represents the spatial extent of composite device.
- $a_i, 1 \leq i \leq n$ represents the ith function parameter of the device.
- fa represents the map function between function parameters and spatial extent.

Rule 4. Composite device ability calculation. Assume the function Ω is the cumulative calculation function of spatial extent, Φ_i is the aggregation function of the ith function parameter, and $\Phi = \{\Sigma, \mathrm{MAX}, \ldots\}$. The spatial extent and calculation rule of function parameter of composite device is as follows:

- The space extent of composite device can be calculated by all the space extents of participated devices, i.e.,

$$\begin{aligned}&\sigma\{(x_{cds1}, y_{cds1}, z_{cds1}), \ldots, (x_{cdsm}, y_{cdsm}, z_{cdsm})\}\\ &= \Omega(\sigma\{(x_{d11}, y_{d11}, z_{d11}), \ldots, (x_{d1m}, y_{d1m}, z_{d1m})\}, \ldots,\\ &\quad \sigma\{(x_{dk1}, y_{dk1}, z_{dk1}), \ldots, (x_{dkm}, y_{dkm}, z_{dkm})\})\end{aligned} \tag{25}$$

- The function parameter of composite device in spatial extent $\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\}$ can be aggregated by all these function parameters of participated devices in the same spatial extent, i.e., the minimum value of the device function parameter in this spatial extent is:

$$\begin{aligned}&\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{ai}_{\min}\\ &= \mathrm{MIN}(\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a1i}_{\min},\\ &\quad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a2i}_{\min}, \ldots,\\ &\quad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{aki}_{\min}),\end{aligned} \tag{26}$$

where $a_{1i}, \ldots, a_{li}$ is the corresponding function parameter of composite device ability.

The maximum value of device function parameter a_i in this spatial extent is:

$$\begin{aligned}&\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{ai}_{\max}\\ &= \mathrm{MAX}(\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a1i}_{\max},\\ &\quad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a2i}_{\max}, \ldots,\\ &\quad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{aki}_{\max}),\end{aligned} \tag{27}$$

where the interval of the function parameter a_i is:

$$\begin{aligned}&\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : a_i\\ &=[\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{ai}_{\min},\\ &\quad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{ai}_{\max}]\\ &=[\mathrm{MIN}(\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a1i}_{\min},\\ &\qquad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a2i}_{\min}, \ldots,\\ &\qquad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{aki}_{\min}),\\ &\quad \mathrm{MAX}(\sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a1i}_{\max},\\ &\qquad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{a2i}_{\max}, \ldots,\\ &\qquad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \theta^{aki}_{\max})].\end{aligned} \tag{28}$$

3.3 Device resource matching method based on ability model

Resource matching is a process [43,44] which selects a resource candidate set among the device resource sets based on a given user demand. Every device resource contained in the resource candidate set meets the demand. We first give the description of user device ability requirements as follows and then propose the device ability matching method in a large-scale device collaboration system.

3.3.1 Description of user demand

The user demand for device resource ability [45,46] involved in a process is a sum of all ability demands for virtual device resource. It is denoted as $R = \{r_1, \ldots, r_m\}, m \geq 1$, where r presents a description of a user's demand, i.e., the ability demand of virtual device resource. r can be presented in a tuple: $r = (dss, rs)$.

- $dss = ds$ represents the virtual device resource involved in the description of user demand.
- rs represents the user demand for the virtual device resource ability in the description: $rs = dA(ds_1)$.

3.3.2 Device ability matching method

Rule 5. Device ability matching. Assume $R = \{r_1, \ldots, r_m\}$, $m \geq 1$ is the description of user demand in device collaboration process. The demand of device resource ability $r = (dss, rs), rs = dA(ds)$ is as follows:

$$dA(ds) = fa(\sigma\{(x_{ds1}, y_{ds1}, z_{ds1}), \ldots, (x_{dsm}, y_{dsm}, z_{dsm})\}, (a_{1s}, a_{2s}, \ldots, a_{ns})), \quad dsm \geq 1, ns \geq 1, \tag{29}$$

and the ability of device d is:

$$dA(d) = fa(\sigma\{(x_{d1}, y_{d1}, z_{d1}), \ldots, (x_{dm}, y_{dm}, z_{dm})\}, (a_1, a_2, \ldots, a_n)), \quad dm \geq 1, n \geq 1. \tag{30}$$

If device d meets the following three conditions at the same time, then we believe that this device matches the device resource ability in users' demand:

- $$\sigma\{(x_{ds1}, y_{ds1}, z_{ds1}), \ldots, (x_{dsm}, y_{dsm}, z_{dsm}) \preceq \sigma\{(x_{d1}, y_{d1}, z_{d1}), \ldots, (x_{dm}, y_{dm}, z_{dm}) \tag{31}$$
- $$(a_{1s}, a_{2s}, \ldots, a_{ns}) \subseteq (a_1, a_2, \ldots, a_n) \tag{32}$$
- $$\begin{aligned} &\text{If } \forall \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} \preceq \sigma\{(x_{ds1}, y_{ds1}, z_{ds1}), \ldots, (x_{dsm}, y_{dsm}, z_{dsm}), \\ &\text{then } \forall a_{is} \in (a_{1s}, a_{2s}, \ldots, a_{ns}) \\ &\quad \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : \\ &\quad a_{is} \cap \sigma\{(x_1, y_1, z_1), \ldots, (x_m, y_m, z_m)\} : a_i \neq \varphi \\ &\text{where } a_{is} \text{ and } a_i \text{ are the same function parameter} \\ &\quad a_i \in (a_1, a_2, \ldots, a_n). \end{aligned} \tag{33}$$

3.3.3 Composite device ability matching method

Definition 11. Matching distance of device ability. It refers to the size of operation spatial extent and function parameter matching between two devices. Assume the abilities of devices d_1 and d_2 are as follows:

$$dA(d_1) = fa(\sigma\{(x_{d11}, y_{d11}, z_{d11}), \ldots, (x_{d1m}, y_{d1m}, z_{d1m})\}, (a_{11}, a_{12}, \ldots, a_{1n})), d1m \geq 1, 1n \geq 1 \tag{34}$$

$$dA(d_2) = fa(\sigma\{(x_{d21}, y_{d21}, z_{d21}), \ldots, (x_{d2m}, y_{d2m}, z_{d2m})\}, (a_{21}, a_{22}, \ldots, a_{2n})), d2m \geq 1, 2n \geq 1. \tag{35}$$

The matching distance of device ability is calculated as follows:

$$F(dA(d_1), dA(d_2)) = \sqrt{(\sigma_1 - \sigma_2)^2 + \sum_{i=1}^{n} (a_{1i} - a_{2i})^2} \tag{36}$$

Table 1 Configuration of ability matching experiment

Name	Hardware	Software
Device collaborative task requests simulator	CPU Intel Core Duo 2.6 GHz Memory 2.00 GB Network 10/100M Ethernet	Windows XP JDK1.5
Large-scale device collaboration system	CPU Intel Core 2.6 GHz Memory 4.00 GB Network 10/100M Ethernet	Suse Linux JDK1.5
Device simulator server	CPU Intel Core 2.6 GHz Memory 2.00 GB Network 10/100M Ethernet	Suse Linux JDK1.5 Tomcat 5.5.14

- $$\sigma_1 = \sigma\{(x_{11}, y_{11}, z_{11}), \ldots, (x_{1m}, y_{1m}, z_{1m})\}, \quad \sigma_2 = \sigma\{(x_{21}, y_{21}, z_{21}), \ldots, (x_{2m}, y_{2m}, z_{2m})\} \tag{37}$$
- a_{1i} and a_{2i} are the same function parameters, $a_{1i} \in (a_{11}, a_{12}, \ldots, a_{1n}), a_{2i} \in (a_{21}, a_{22}, \ldots, a_{2n})$.

Now, we give our composite ability matching algorithm based on the above matching distance. Assume $D_s = \{d_1, \ldots, d_l\}, l \geq 0$ is the device satisfied by users, and $D_{al} = \{d_1, \ldots, d_k\}, k \geq 1$ is the device in the large-scale collaborative system. The description of algorithm is as follows:

1. The first input is the device resource ability $r = (dss, rs), rs = dA(ds)$ of users' demand $R = \{r_1, \ldots, r_m\}, m \geq 1$ in the large-scale collaborative system, i.e.,

$$dA(ds) = fa(\sigma\{(x_{ds1}, y_{ds1}, z_{ds1}), \ldots, (x_{dsm}, y_{dsm}, z_{dsm})\}, (a_{1s}, a_{2s}, \ldots, a_{ns})), dsm \geq 1, ns \geq 1. \tag{38}$$

The second input is the device set $D = D_{as} - D_s = \{d_1, \ldots, d_n\}, n \geq 1$ except that meets the demand, i.e.,

$$dA(d_i) = fa(\sigma\{(x_{di1}, y_{di1}, z_{di1}), \ldots, (x_{\dim}, y_{\dim}, z_{\dim})\}, (a_{1i}, a_{2i}, \ldots, a_{ni})), \dim \geq 1, ni \geq 1. \tag{39}$$

Table 2 Parameters of ability matching experiment

Name	Description
Depth	Device ability matching depth, i.e., the maximum number of matching candidate found by virtual device
DN	The number of devices with different abilities in large-scale collaborative system
AN	The number of ability parameters in large-scale collaborative system

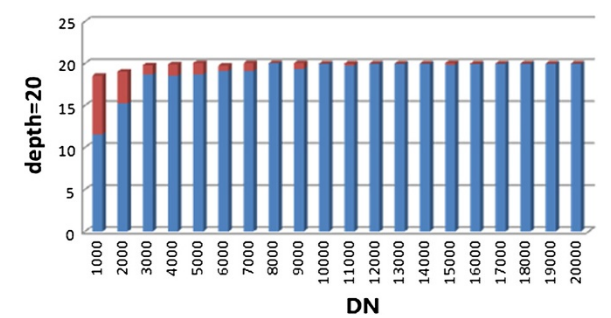

Figure 1 Distribution of candidate device resource (depth = 20).

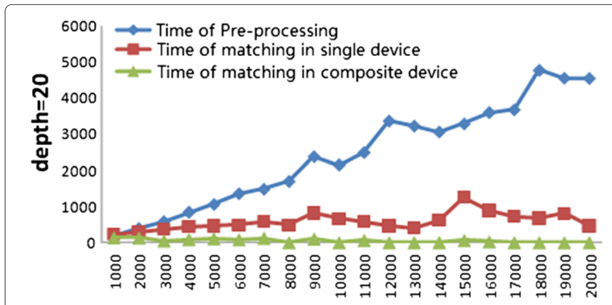

Figure 3 Time of device ability matching (depth = 20).

2. Set the matching depth of composite device be k.
3. Calculate the device ability matching distance $F(dA(d_i), dA(ds)), d_i \in D$ in device set $D = \{d_1, \ldots, d_n\}, n \geq 1$.
4. Add the device d_i with the minimum matching distance to the candidate composite device $comD_k$ where $D = D - d_i$, $dA(ds) = dA(ds) - dA(d_i)$.
5. Repeat steps 3 and 4 until $dA(ds) = 0$; now $comD_k$ is a candidate composite device.
6. If all the devices are traversed and $dA(ds) \neq 0$, the algorithm terminates; otherwise, repeat steps 3, 4, and 5 to find the candidate composite devices $comD_k$ which meet the matching depth k.

The following is the detail algorithm (Algorithm 1):

4 Experiments

4.1 Configuration

The experiments are conducted in three desktop computers: the first one simulates the requests of device collaborative tasks, the second one deploys a large-scale device collaboration system which uses our proposed matching method to assign the device resource with collaborative tasks, and the last one deploys a device simulator which can produce a lot of device resources with different abilities. Tables 1 and 2 show the configuration and parameters in our experiments, respectively.

4.2 Effect of matching method

This part measures the relationship between the number of candidate device resource in virtual device and the total number of device resource in a system. Assume the matching depth of device ability depth = 40, the parameter number of device ability AN = 2, and the number of device in large-scale collaborative system is 1,000, 2,000,..., 20,000, respectively. In order to reduce the random error, each test performs 50 times.

Figures 1 and 2 show the result: When the total number of devices DN = 1,000, our matching method can ensure the percentage of candidate device resource to be more than 75; and with the growth of the total number, this percentage becomes nearly 100, which indicates that our matching method can meet the effect demand of large-scale device collaboration system.

4.3 Performance of matching method

This part tests the performance of our matching method. Assume the matching depth of device ability depth = 40, the parameter number of device ability AN = 2, and the number of device in large-scale collaborative system be 1,000, 2,000, ..., 20,000, respectively. In order to reduce the random error, each test is performed 50 times.

Figures 3 and 4 show the result due to the preprocessing operation for device matching; the growth of the total number of device in the system only affects the increase in time of pre-processing, while it affects matching time a little. Besides, when DN = 20, 000, the total

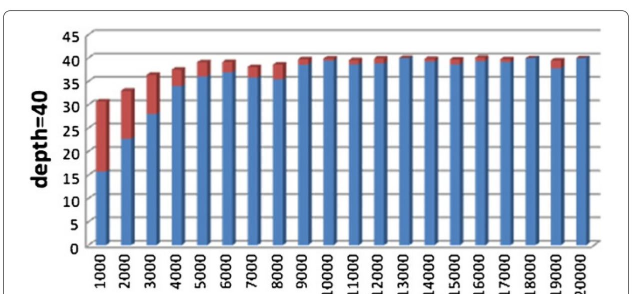

Figure 2 Distribution of candidate device resource (depth = 40).

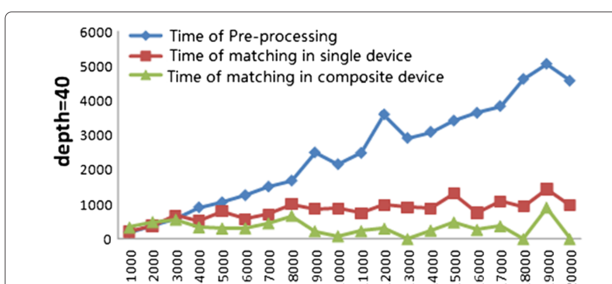

Figure 4 Time of device ability matching (depth = 40).

Algorithm 1 Composite device ability matching method

Input:

$dA(ds) = fa(\sigma\{(x_{ds1}, y_{ds1}, z_{ds1}), \ldots, (x_{dsm}, y_{dsm}, z_{dsm})\}, (a_{1s}, a_{2s}, \ldots, a_{ns})), dsm \geq 1, ns \geq 1$

$D = \{d_1, \ldots, d_n\}, n \geq 1$

$dA(d_i) = fa(\sigma\{(x_{di1}, y_{di1}, z_{di1}), \ldots, (x_{\dim}, y_{\dim}, z_{\dim})\}, (a_{1i}, a_{2i}, \ldots, a_{ni})), \dim \geq 1, ni \geq 1$

Output:

$comCD = \{comD_i | comD_i \in \rho(D)\}$

while k–!=0 **do**
  for every elements in D **do**
    if F(dA(di), dA(ds)) is Min **then**
      $comD_k$.add(di);
      D=D-di;
      dA(ds)=dA(ds)-dA(di);
    end if
    if dA(ds)=0 **then**
      $comCD$.add($comD_k$);
    end if
    if dA(ds)!=0 **then**
      break;
    end if
  end for
end while
return $comCD$;

Table 3 The number of matching resources in the case of different devices

Device number	Depth = 20 Total number	*d* Number	comD Number	Depth = 40 Total number	*d* number	comD Number
1,000	18.55	11.55	7	30.7	15.8	14.9
2,000	19.05	15.25	3.8	33	22.8	10.2
5,000	20	18.7	1.3	39.1	36.1	3
10,000	20	20	0	39.9	39.5	0.4
15,000	20	19.8	0.2	39.7	38.7	1
20,000	20	20	0	40	40	0

Table 4 The time of matching resources in the case of different devices

Device number	Depth = 20 Filter time	*d* Time	comD Time	Depth = 40 Filter time	*d* Time	comD Time
1,000	195.8	223.0	134.15	184.1	210.6	327.6
2,000	380.7	296.3	132.65	365.2	382.15	487.4
5,000	1,048.2	461.8	112.35	1,049.1	794.05	302.7
10,000	2,144.1	659.8	0	2,148.9	882.2	79.55
15,000	3,279.2	1,248	59.25	3,411.8	1,304.85	477.35
20,000	4,544.2	458.7	0	4,566.2	964.05	0

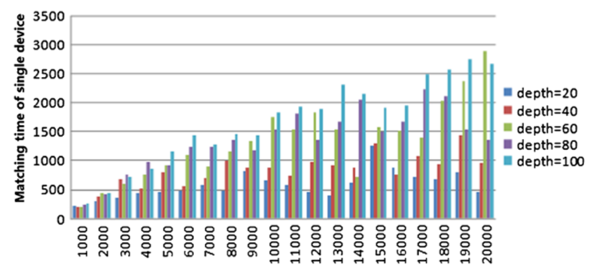

Figure 5 The relationship between single device matching time and DN.

time of device ability matching is less than 6 s, which indicates that our matching method can meet the performance demand of large-scale device collaboration system. The details are in Tables 3 and 4.

4.4 Matching method between single and composite device

This part measures the relationship between matching time and number of device resource in the case of different matching depths. Assume the matching depth of device ability depth $= 20, 40, 60, 80,$ and 100, respectively, the parameter number of device ability AN $=$ 2, and the number of device in large-scale collaborative system be $1,000, 2,000, \ldots, 20,000$, respectively. In order to reduce the random error, each test is performed 50 times.

Figures 5 and 6 show the result when depth $<$ 40; the matching time of both single and composite device increase slowly with the growth of total device number DN. The reason is that in device ability matching process, we should use as less as possible devices to meet the demand of virtual device in order to reduce the conflict of device operations. Thus, when the matching depth is small, single device will meet the requirement.

However, the matching time of composite device grows rapidly with the growth of total device number DN, which indicates that considering both the less conflict of device

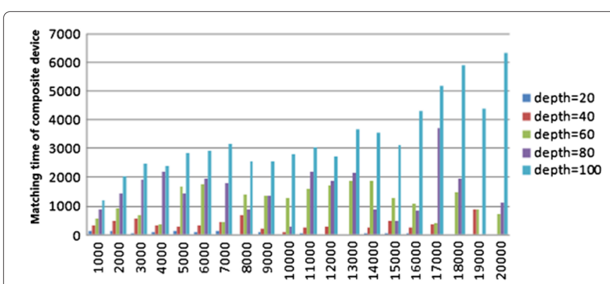

Figure 6 The relationship between composite device matching time and DN.

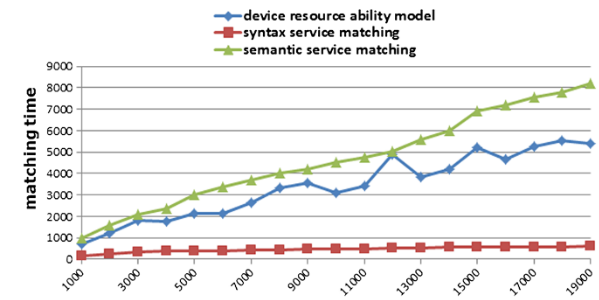

Figure 7 The relationship between matching time and DN in the case of three methods.

operation and higher matching efficiency of device ability, we should select as less as possible devices to meet the demand of virtual device.

4.5 Comparisons with traditional methods

At present, resources matching research mainly conclude syntax service matching and semantic service matching. In order to compare the efficiency of our proposed device resource matching method based on the device resource ability model with the two traditional resource matching methods, we designed a set of comparative experiments, testing in the case of the same user requirements how much time is cost by each of the resource matching technique and how many devices are matched up by each of the technique.

Assume the matching depth of device ability depth $=$ 40, the number of device in large-scale collaborative system is $1,000, 2,000, \ldots, 20,000$, respectively. In order to reduce the random error, each test is performed 50 times.

In Figures 7 and 8, horizontal axes show the total number of devices DN in large-scale device collaboration system, and the vertical axes show the cost time used for matching and the number of the candidate devices matched, respectively. It can be seen that syntax service

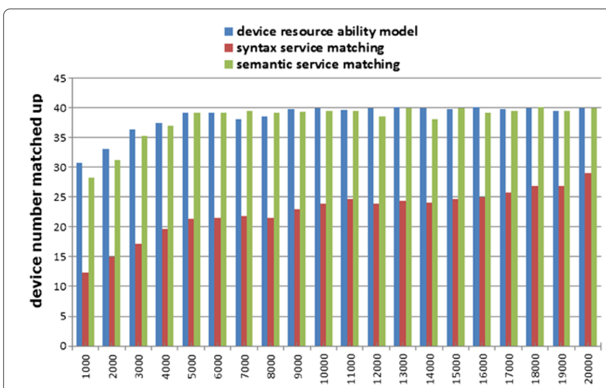

Figure 8 The relationship between device number matched up and DN in the case of three methods.

Table 5 Part of the experimental data

Device number	Cost time			Number of matched resources		
	Device ability model	Syntax service matching	Semantic service matching	Device ability model	Syntax service matching	Semantic service matching
1,000	722.3	163.4	986.05	30.7	12.4	28.3
2,000	1,234.75	240.33	1,564.35	33	15	31.2
5,000	2,145.85	398.15	2,988	39.1	21.3	39.2
10,000	3,110.65	478.25	4,534.38	39.9	23.9	39.5
15,000	5,194.05	553.25	6,933.55	39.7	24.6	40
20,000	5,530.25	602.3	8,022.25	40	29	40

matching method costs the least amount of time, but the matching result is not so good as the result of our proposed method. The number of the candidate devices is far less than the number of matched devices in the case of the device resource ability model matching method and semantic matching method. The effect of the semantic service matching method is almost the same with our proposed device resource matching method based on the device resource ability model, but the semantic service matching method costs much more time than that of our proposed method cost. In order to analyze the experimental results quantitatively, we give part of the experimental data in our experiments (Table 5).

5 Conclusions

WMSN applications usually involve a large number of devices and complex spatial information configurations. To address this challenge, in this article, we propose a multimedia device ability model, which incorporates spatial information management into the modeling phase. Based on this model, we further derive a multimedia device resource matching technique for ubiquitous computing environments. By adopting this technology, automatic execution of the collaboration process is done efficiently. Experimental results show that our proposed technique achieves better recall and precision. Compared with previous works, our approach not only has better performance but also meets WMSN application needs much better. The multimedia device ability matching method can greatly reduce the design complexity and workload of application designers.

Competing interests

The authors declare that they have no competing interests.

Acknowledgements

The work was supported by the National Natural Science Foundation of China (nos. 61100066, 61133005, 61262013), Special Fund Research in the Public Interest (no. 201008002), the National Science Foundation of Guangdong Province, China (no. S2011010001155), and the High-level Talent Project for Universities, Guangdong Province, China (431, YueCaiJiao 2011).

Author details

[1]State Key Laboratory of Software Development Environment, Beihang University, Beijing, China. [2]Lab of Parallel Software and Computational Science, Institute of Software Chinese Academy of Sciences, Beijing, China. [3]College of Information Engineering, Guangdong Jidian Polytechnic, Guangzhou, China.

Received: 1 January 2013 Accepted: 15 May 2013
Published: 4 July 2013

References

1. M Chen, CF Lai, HG Wang, Mobile multimedia sensor networks: architecture and routing. EURASIP J Wireless Commun. Netw. **2011**, 1–9 (2011)
2. J Campbell, PB Gibbons, S Nath, P Pillai, S Seshan, R Sukthankar, in *Proceedings of the 13th Annual ACM International Conference on Multimedia*. IrisNet: an internet-scale architecture for multimedia sensors (ACM, New York, 2005), pp. 81–88
3. M Chen, V Leung, SW Mao, Y Yuan, Directional geographical routing for real-time video communications in wireless sensor networks. Comput. Commun. **30**(17), 3368–3383 (2007)
4. CH Chen-Ritzo, C Harrison, J Paraszczak, F Parr, Instrumenting the planet. IBM J. Res. Dev. **53**(3), 1 (2009)
5. P Deng, JW Zhang, XH Rong, F Chen, Modeling the large-scale device control system based on PI-calculus. Adv. Sci. Lett. **4**(6–7), 6–7 (2011)
6. P Deng, F Chen, XH Rong, P Jiang, W Jin, A meta communication protocol in support lighting device unified access of olympic center. ITCS. **2**, 48–52 (2009)
7. DJ Sobajic, YH Pao, Artificial neural-net based dynamic security assessment for electric power systems. Power Sys. IEEE Trans. **4**, 220–228 (1989)
8. T Devadithya, K Chiu, K Huffman, DF McMullen, in *Proceedings of the First International Conference on Science and Grid Computing, 2005*. The common instrument middleware architecture, overview of goals and implementation (IEEE, Piscataway, 2005), pp. 96–106
9. IM Atkinson, Dd Boulay, C Chee, K Chiu, P Coddington, A Gerson, T King, DF McMullen, R Quilici, P Turner, A Wendelborn, MJ Wyatt, D Zhang, Developing CIMA-based cyberinfrastructure for remote access to scientific instruments and collaborative e-research. CRPIT. **68**, 3–10 (2007)
10. R Bramley, K Chiu, T Devadithya, N Gupta, C Hart, JC Huffman, K Huffman, Y Ma, DF McMullen, Instrument monitoring, data sharing, and archiving using common instrument middleware architecture (CIMA). J. Chem. Inf. Mod. **46**(3), 1017–1025 (2006)
11. JF Wan, HH Yan, H Suo, F Li, Advances in cyber-physical systems research. KSII Trans. Internet Inf. Sys. **5**(11), 1891–1908 (2011)
12. K Chiu, R Bramley, JC Huffman, K Huffman, DF McMullen, *Instruments and, Sensors as Web Services*. (National Science Foundation of ACI, Arlington, 2003)
13. M Chen, JF Wan, F Li, Machine-to-Machine Communications: Architectures, Standards and Applications. KSII Trans. Internet Syst. **6**(2), 480–497 (2012)

14. JH Shi, JF Wan, HH Yan, H Suo, in *2011 IEEE International Conference on Wireless Communications and Signal Processing (WCSP)*. A survey of cyber-physical systems (IEEE, Piscataway, 2011), pp. 1–6
15. J Peng, KH Law, in *Proceedings of the International Symposium on Earthquake Engineering in the Past and Future Fifty Years*. A Reference Data Model for NEESgrid Shake Table Experiments (Harbin, August 2004)
16. M Chen, "Towards smart city: M2M communications with software agent intelligence", Multimedia Tools Appl., pp.1–12, Feb.2012
17. M Chen, S Gonzalez, Q Zhang, VC Leung, Code-centric RFID system based on software agent intelligence. IEEE Intell. Syst. **25**(2), 12–19 (2010)
18. M Chen, S Gonzalez, Y Zhang, VC Leung, in *Quality of Service in Heterogeneous Networks*. Multi-agent itinerary planning for wireless sensor networks (Springer, Heidelberg, 2009), pp. 584–597
19. M Chen, V Leung, SW Mao, T Kwon, M Li, in *IEEE International Conference on Communications, 2009*. Energy-efficient itinerary planning for mobile agents in wireless sensor networks (IEEE, Piscataway, 2009), pp. 1–5
20. L Zhou, X Wang, W Tu, GM Muntean, B Geller, Distributed scheduling scheme for video streaming over multi-channel multi-radio multi-hop wireless networks. Selec. Areas Commun. IEEE J. **28**(3), 409–419 (2010)
21. DucklingTeam, CERC (2009). http://duckling.escience.cn/dct/. Accessed 2 July 2010
22. GRIDCC Project report (2008). http://ec.europa.eu/information_society/apps/projects/logos/2/511382/080/publishing/readmore/GRIDCC-WP8-D8_3-20080201-06-INF-Final_Report.pdf. Accessed 10 June 2009
23. AS McGough, A Akram, L Guo, M Krznaric, L Dickens, D Colling, J Martyniak, R Powell, P Kyberd, C Kotsokalis, in *Proceedings of the 2nd Workshop on Workflows in Support of Large-scale Science*. GRIDCC: real-time workflow system (ACM, New York, 2007), pp. 3–12
24. E Christensen, F Curbera, G Meredith, S Weerawarana, *Web Services Description Language (WSDL) 1.1*. (World Wide Web Consortium, Cambridge, 2001)
25. Z Huang, L Gu, B Du, C He, in *Proceedings of 2004 IEEE International Conference on Services Computing*. Grid resource specification language based on XML and its usage in resource registry meta-service (IEEE, Piscataway, 2004), pp. 467–470
26. D Brickley, RV Guha, *RDF Vocabulary Description Language 1.0: RDF Schema*. (World Wide Web Consortium, Cambridge, 2004)
27. V Tosic, B Pagurek, K Patel, *"WSOL - a language for the formal specification of classes of service for web services"*. (International Conference on Web Services, Las Vegas, Nevada, USA, June 2003)
28. V Tosic, K Patel, B Pagurek, in *Web Services, E-Business, and the Semantic Web*. WSOL-web service offerings language (Springer, Heidelberg, 2002), pp. 57–67
29. D Martin, M Burstein, O Lassila, M Paolucci, T Payne, S McIlraith, Describing Web services using OWL-S and WSDL. DAML-S Coalition working document. [http://www.daml.org/services/daml-s/0.7/daml-s-wsdl.html] Accessed 13 Aug 2002
30. A Matoussi, R Laleau, *A Survey of Non-functional Requirements in Software Development Process*. (University of Paris, Paris, 2008)
31. L Li, I Horrocks, A software framework for matchmaking based on semantic web technology. Int. J. Electron. Commerce. **8**(4), 39–60 (2004)
32. M Paolucci, T Kawamura, TR Payne, K Sycara, in *The Semantic Web-ISWC 2002*. Semantic matching of web services capabilities (Springer, Heidelberg, 2002), pp. 333–347
33. N Srinivasan, M Paolucci, K Sycara, Semantic web service discovery in the OWL-S IDE. Proc. 39th Annual IEEE Hawaii Int. Conf. Syst. Sci. **6**, 109b (2006)
34. D Ardagna, B Pernici, Adaptive service composition in flexible processes. Softw. Eng. IEEE Trans. **33**(6), 369–384 (2007)
35. B Xu, T Li, Z Gu, G Wu, in *The 8th IEEE International Conference on E-Commerce Technology, 2006 and The 3rd IEEE International Conference on Enterprise Computing, E-Commerce, and E-Services*. SWSDS: Quick web service discovery and composition in SEWSIP (IEEE, Piscataway, 2006), pp. 71–71
36. IB Arpinar, R Zhang, B Aleman-Meza, A Maduko, Ontology-driven web services composition platform. Inf. Syst. E-Business Manage. **3**(2), 175–199 (2005)
37. M Tian, A Gramm, H Ritter, J Schiller, in *Proceedings of the 2004 IEEE/WIC/ACM International Conference on Web Intelligence, IEEE Computer Society*. Efficient selection and monitoring of QoS-aware web services with the WS-QoS framework (IEEE, Piscataway, 2004), pp. 152–158
38. A Soydan Bilgin, MP Singh, in *Proceedings of IEEE International Conference on Web Services, 2004*. A DAML-based repository for QoS-aware semantic web service selection (IEEE, Piscataway, 2004), pp. 368–375
39. L Sha, G Shaozhong, C Xin, L Mingjing, A QoS based web service selection model. IFITA. **3**, 353–356 (2009)
40. F Qiqing, P Xiaoming, L Qinghua, H Yahui, A global QoS optimizing web services selection algorithm based on MOACA for dynamic web service composition. IFITA. **1**, 37–42 (2009)
41. AJS Cardoso, *Quality of service and semantic composition of workflows. PhD thesis*. (University of Georgia Athens, Georgia, 2002)
42. M Kerrigan, in *Proceedings of the 2006 ACM Symposium on Applied Computing*. Web service selection mechanisms in the web service execution environment (WSMX) (ACM, New York, 2006), pp. 1664–1668
43. C Zhou, LT Chia, BS Lee, in *Proceedings of IEEE International Conference on Web Services, 2004*. DAML-QoS ontology for web services (IEEE, Piscataway, 2004), pp. 472–479
44. Em Maximilien, MP Singh, A framework ontology for dynamic web services selection. Int. Comp. IEEE. **8**(5), 84–93 (2004)
45. L Sha, G Shaozhong, C Xin, L Mingjing, A qos based web service selection model. IFITA. **3**, 353–356 (2009)
46. S Ali, M Zeeshan, in *2012 IEEE Wireless Communications and Networking Conference (WCNC)*. A utility based resource allocation scheme with delay scheduler for LTE service-class support (IEEE, Piscataway, 2012), pp. 1450–1455

doi:10.1186/1687-1499-2013-181
Cite this article as: Zhang *et al.*: A novel multimedia device ability matching technique for ubiquitous computing environments. *EURASIP Journal on Wireless Communications and Networking* 2013 **2013**:181.