Service-oriented Device Anycasting using Quality First Search in Wireless Personal Area Network

Chien-Chung Su[1], Kuo-Shiang Lu[1], Mong-Fong Horng[2], Chao-Lieh Chen[3], Yau-Hwang Kuo[1], Jang-Pong Hsu[4], and Wen-Hsin Cheng[4]

[1] Center for Research of E-life DIgital Technology, Department of Computer Science and Information Engineering, National Cheng Kung University, Tainan, Taiwan
{succ, liugs, kuoyh}@ismp.csie.ncku.edu.tw
[2] Department of Computer Science and Information Engineering, Shu-Te University, Kaohsiung, Taiwan
mfhorng@mail.stu.edu.tw
[3] Department of Electronics Engineering, Kun-Shan University, Tainan, Taiwan
frederic@ieee.org
[4] Advanced Multimedia Internet Technology Incorporation, Tainan Hsien, Taiwan
{jp, vincent}@amit.com.tw

Abstract. Service-oriented device anycasting using quality first search (DA-QFS) approach is proposed to coordinate various portable devices for providing wireless personal area network (WPAN) services[5]. We adopt a cross-layer design standing on not only the lower (network and data link) layer's point of view but also higher (application) layer's point of view to provide quality WPAN services. In DA-QFS the service profile (SP) of a WPAN service is well-represented by the proposed characterized task graph (CTG). The proposed weighted device anycasting (WDA) process then takes connectivity, implicit distance, work degree, and mobility as the criteria to select the most quality device according to the information embedded in CTG. The simulation results on energy consumption, packet loss rate, average delay, and re-start time show that DA-QFS is an efficient approach, especially in the environment with highly mobile devices and multiple users.

1 Introduction

In smart space, a user request can be accomplished by coordinating multiple devices around [1][2]. Consequently, automatically organizing various devices to provide wireless personal area network (WPAN) services is an important issue in smart space. There are significant previous results which principally focused on data link and network layers [3][4]. However, it is a challenge to provide a quality WPAN service only from lower layer's point of view. Therefore, a cross-layer

[5] This paper is based partially on work supported by the National Science Council, Taiwan under Grant NCS-94-2213-E-006-081.

design [5] is indispensable to bridge the gap of quality issues between higher and lower layers. For instance, Basu et al [6] published task-based device anycasting using breadth first search (DA-BFS) approach. In DA-BFS the required device classes and their associations of a WPAN service are denoted by nodes and edges in a task graph (TG), respectively. According to the BFS tree derived from TG, the required devices classes are instantiated from root node (user device) to leaf nodes (leaf device classes). Distance is the explicit factor which affects network performance and is the only criterion to select a device by DA-BFS. However, more implicit factors should be involved for determining the quality device in the environment with highly mobile devices and multiple users.

In proposed service-oriented device anycasting using quality first search (DA-QFS) approach, we embed detailed information of a WAPN service in the proposed characterized task graph (CTG). The proposed weighted device anycasting (WDA) process then takes four weighted factors, connectivity, implicit distance, work degree, and mobility to be the selection criteria according to the information embedded in CTG. By adjusting the weights of factors, DA-QFS is certainly applied to the WPAN services with different quality requirements in diverse environments. The simulation results on energy consumption, packet loss rate, and packet delay show that DA-QFS is efficient even in the environment with highly mobile devices and multiple users.

The rest of this paper is organized as follows. In Section 2, the problem statement and related issues are introduced. The proposed approach is described in Section 3. Then, we show the simulation setup and results to evaluate the proposed approach in Section 4. Finally, the conclusion and future work follows.

2 Related Work

A service profile (SP) describing the requirements of a WPAN service can be represented by a task graph (TG). In this paper, TG is denoted by (N_{TG}, E_{TG}) indicating the device classes needed to provide the WPAN service and the necessary associations between these device classes, respectively. A real network (RN) is denoted by (N_{RN}, E_{RN}). Each node in RN indicates a portable device. Each edge in RN indicates that two end nodes are in the mutual transmission range. The set of all candidate devices in RN of a device class $n_* \in N_{TG}$ is denoted by $\widetilde{N}_* \subset N_{RN}$. The instantiated device of n_* is denoted by $\overline{n}_* \in N_{RN}$ which is most quality one among all $\widetilde{n}_*^i \in \widetilde{N}_*$. For instance, the device class A is denoted by n_A as show in Fig. 1(a). $\widetilde{N}_A = \left\{\widetilde{n}_A^1, \widetilde{n}_A^2\right\}$ is the set of all candidate devices of n_A as show in Fig. 1(b). $\widetilde{n}_A^1$ is regarded as the instantiated device, $\overline{n}_A$, of n_A as shown in Fig. 1(c).

In order to provide the WPAN service, a device anycasting (DA) process is required to discover a quality pair of mappings, $\varphi_N : N_{TG} \rightarrow N_{RN}$ and $\varphi_E : E_{TG} \rightarrow P_{RN}$ where P_{RN} is the set of paths between all instantiated devices in RN. The following issues should be considered in DA process:

1) The location of the instantiated device. If a device class is instantiated only by its instantiated parent device in BFS tree, then the location of this

instantiated device is not necessarily the most quality one. For instance, we assume that $\overline{n}_A$ is the instantiated parent device of n_C in BFS tree in Fig. 1. Although the distance between $\widetilde{n}_C^1$ and $\overline{n}_A$ is the shortest, $\widetilde{n}_C^1$ is not the quality device because it is unable to directly communicate with $\overline{n}_B$. Therefore, $\widetilde{n}_C^2$ and $\widetilde{n}_C^3$ are more quality since they are in the transmission range of $\overline{n}_A$ and $\overline{n}_B$. In addition, if (n_A, n_C) is a data flow with high traffic load and (n_B, n_C) is a control flow with low traffic load, $\widetilde{n}_C^3$ is more quality than $\widetilde{n}_C^2$ because $\widetilde{n}_C^3$ is much closer to $\overline{n}_A$.
2) The work load of the instantiated device. The "hot device" problem

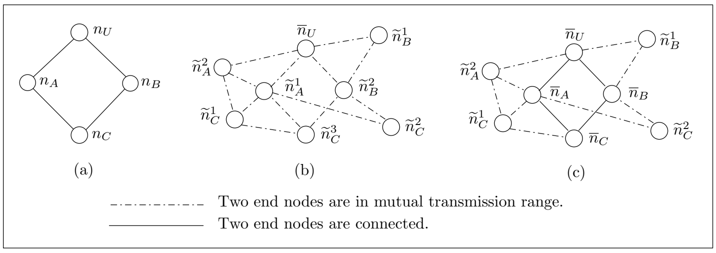

Fig. 1. (a) Service profile of a WPAN service. (b) A real network. (c) A pair of mapping from (a) to (b).

means that the system loads of the devices with the same functionalities are imbalanced. The packet loss rate and packet delay of the WPAN service may become higher because the high-loaded devices are selected. The problem is obvious in the environment with multiple users. In addition, φ_N is not necessarily a one-to-one mapping. The performance is improved if the task on a device class is distributed among multiple instantiated devices.
3) The mobility of the instantiated device. If an instantiated device is highly mobile, then the corresponding device class likely needs to be frequently re-instantiated.

According to above issues, four implicit factors are regarded as the criteria for instantiating a device class in the proposed approach. First, factor of connectivity is the number of instantiated parent devices in the transmission range of a candidate device. Second, the traffic load is embedded in the factor of implicit distance. Third, the factor of work degree is involved to balance the system load of devices. Finally, the factor of mobility is also involved to prevent the WPAN service from being interrupted due to the movement of the instantiated devices.

3 The Proposed Approach

The service-oriented device anycasting using quality first search (DA-QFS) approach is proposed to automatically organize the portable devices for providing quality WPAN services. DA-QFS consists of a service profile (SP) represented by characterized task graph (CTG) and a device anycasting (DA) process named weighted device anycasting (WDA). In this paper, the status of a device is assumed to be discovered by service discovery protocols [7][8].

3.1 Characterized Task Graph

An example of characterized task graph (CTG) for the WPAN service described in Fig. 1(a) is shown in Fig. 2. Two new features are added in CTG. First, the relative ratio of expected traffic load on each association between two device classes is specified according to the behavior of the WPAN service. The relative ratio of expected traffic load on (n_M, n_N) is denoted by $\epsilon_{(n_M,n_N)}$ in CTG. It is important to specify the expected traffic loads for instantiating a device class because energy consumption is direct proportion to the amount of transmitted data according to the general energy model in wireless networks [9]. For example, both n_A and n_B have associations with n_C as shown in Fig. 2. If the expected traffic load on (n_B, n_C) is higher than the expected traffic load on (n_A, n_C) (i.e. $\epsilon_{(n_B,n_C)} > \epsilon_{(n_A,n_C)}$), then the candidate device, $\widetilde{n}_C^i$, with smallest value of $\epsilon_{(n_B,n_C)} \times dist\left(\overline{n}_B, \widetilde{n}_C^i\right) + \epsilon_{(n_A,n_C)} \times dist\left(\overline{n}_A, \widetilde{n}_C^i\right)$ has priority to be regarded as $\overline{n}_C$ where $dist\left(\overline{n}_B, \widetilde{n}_C^i\right)$ and $dist\left(\overline{n}_A, \widetilde{n}_C^i\right)$ are the distances from $\widetilde{n}_C^i$ to $\overline{n}_B$ and $\overline{n}_A$, respectively. Second, since the requirement of multiple instantiated devices for a device class is critical to several distributed WPAN services, the maximum number of instantiated devices of each device class is specified in CTG. The notation, $n_*[k]$, means that at most k instantiated devices can be selected for n_* where $n_*[1]$ is also represent by n_* for short. For example, at most x and y instances could be selected for n_B and n_C in Fig. 2, respectively.

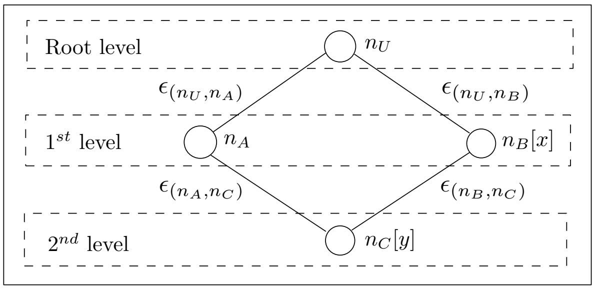

Fig. 2. An example of CTG.

3.2 Weighted Device Anycasting

In order to select the quality instantiated devices, the weighted linear combination of four implicit factors: connectivity, implicit distance, work degree, and mobility is regarded as the criterion for instantiating a device class. The weights in the weighted linear combination are specified according to the requirements of WPAN service and current environment. The proposed weighted device anycasting (WDA) process in DA-QFS is similar to WCA [10]. WCA is proposed to choose the cluster heads for cluster-based routing protocol (CRP) in mobile adhoc network. The optimal solution for selecting devices for WPAN service and selecting cluster heads for CRP is proved as an NP-hard problem [11]. Hence, existing solutions to this problem are based on distributed approaches. However, if the device classes are not carefully instantiated in real network (RN), then the overhead to maintain the existing connections is increased due to the topology change [10]. Therefore, WDA is a semi-distributed approach. The status of all candidate devices are collected locally and the decision of instantiated device is made centrally. Before we introduce the WDA, some notations are defined as follows:

- n_t is the device class being instantiated in CTG.
- $\widetilde{N}_t$ is the set of all candidate devices of n_t in RN.
- $\widetilde{n}_t^i$ is a candidate device with index i in RN ($\widetilde{n}_t^i \in \widetilde{N}_t$).
- P_{n_t} is the set of n_t's parents in CTG. For example, P_{n_A}, P_{n_B}, and P_{n_C} are $\{n_U\}$, $\{n_U\}$, and $\{n_A, n_B\}$, respectively.
- $\overline{P}_{\widetilde{n}_t^i}$ is the set of instantiated parent devices of n_t's parents in CTG which are in the transmission range of $\widetilde{n}_t^i$. If $\overline{n}_P$ belongs to $\overline{P}_{\widetilde{n}_t^i}$, then n_P belongs to P_{n_t}. However, although n_P belongs to P_{n_t}, it is not true that $\overline{n}_P$ belongs to $\overline{P}_{\widetilde{n}_t^i}$.
- $dist(M, N)$ is the distance between device M and device N.
- $dist_{max}$ is the maximum distance which two nodes are can directly communicate with each other.

Two typical definitions of $dist(M, N)$ are Euclidian distance and round trip time [12]. If Euclidian distance is adopted, then $dist_{max}$ is the maximum transmission range. However, if round trip time is regarded as the distance, then $dist_{max}$ is the threshold of round trip time. A device is unable to directly communicate with another device without a response in $dist_{max}$.

When n_t is being instantiated, the weighted linear combination of four implicit factors for each candidate device is obtained by the user device in WDA as follows:

Step 1) Obtaining the connectivity for all $\widetilde{n}_t^i \in \widetilde{N}_t$. The connectivity of $\widetilde{n}_t^i$ is given by

$$C_{\widetilde{n}_t^i} = \frac{|P_{n_t}| - |\overline{P}_{\widetilde{n}_t^i}|}{|P_{n_t}|} \tag{1}$$

where $|P_{n_t}|$ and $|\overline{P}_{\widetilde{n}_t^i}|$ are the degrees of P_{n_t} and $\overline{P}_{\widetilde{n}_t^i}$, respectively.

Step 2) Obtaining the implicit distance for all $\widetilde{n}_t^i \in \widetilde{N}_t$. The implicit distance of $\widetilde{n}_t^i$ is given by

$$D_{\widetilde{n}_t^i} = \sum_{\forall \overline{n}_P, \overline{n}_P \in \overline{P}_{\widetilde{n}_t^i}} \alpha(n_P, n_t) \frac{dist(\overline{n}_P, \widetilde{n}_t^i)}{dist_{max}} \tag{2}$$

where $\alpha(n_P, n_t)$ is the normalized traffic load on (n_P, n_t). $\alpha(n_P, n_t)$ is given by

$$\alpha(n_P, n_t) = \frac{\epsilon_{(n_P, n_t)}}{\sum_{\forall n_n, n_n \in P_{n_t}} \epsilon_{(n_n, n_t)}} \tag{3}$$

where ϵ is the relative ratio of expected traffic load specified in CTG.
Step 3) Obtaining the work degree for all $\widetilde{n}_t^i \in \widetilde{N}_t$. The work degree of $\widetilde{n}_t^i$ is given by

$$L_{\widetilde{n}_t^i} = \frac{I_{\widetilde{n}_t^i}}{\lambda_{\widetilde{n}_t^i}} \tag{4}$$

where $I_{\widetilde{n}_t^i}$ is the number of users using $\widetilde{n}_t^i$, and $\lambda_{\widetilde{n}_t^i}$ is the maximum number of users who can use $\widetilde{n}_t^i$. The value of $\lambda_{\widetilde{n}_t^i}$ depends on the computation power of $\widetilde{n}_t^i$.
Step 4) Obtaining the mobility for all $\widetilde{n}_t^i \in \widetilde{N}_t$. In our paper, the mobility of $\widetilde{n}_t^i$ is defined as the difference of observed distances. Assume that $k+1$ samples of observed distance at $t_0, t_1, t_2, ..., t_{k-1}, t_k$ and the mobility of $\widetilde{n}_t^i$ is given by

$$M_{\widetilde{n}_t^i} = \frac{1}{|\overline{P}_{\widetilde{n}_t^i}|} \frac{1}{k} \sum_{\forall \overline{n}_p, \overline{n}_p \in \overline{P}_{\widetilde{n}_t^i}} \sum_{j=1}^{k} \frac{|dist(\overline{n}_P, \widetilde{n}_t^i)_{t_j} - dist(\overline{n}_P, \widetilde{n}_t^i)_{t_{j-1}}|}{dist_{max}} \tag{5}$$

where $dist(\overline{n}_P, \widetilde{n}_t^i)_{t_j}$ is the observed distance at t_j.
Step 5) Obtaining the weighted linear combination for all $\widetilde{n}_t^i \in \widetilde{N}_t$. The weighted linear combination of $\widetilde{n}_t^i$ is given by

$$W_{\widetilde{n}_t^i} = w_C C_{\widetilde{n}_t^i} + w_D D_{\widetilde{n}_t^i} + w_L L_{\widetilde{n}_t^i} + w_M M_{\widetilde{n}_t^i} \tag{6}$$

where w_C, w_D, w_L, and w_M are the weights of four implicit factors and $w_C + w_D + w_L + w_M = 1$. The weights of four implicit factors are specified according to the requirements of the WPAN service and current environment. For multimedia services w_L and w_M are set to high to avoid selecting a high-loaded device and a highly mobile one which results in long packet delay. In the other hand, if the energy consumption is a critical concern, then w_C and w_D are set to high to reflect the importance of energy conservation.
Step 6) The candidate device with the smallest value of weighted linear combination is regarded as the instantiated device of n_t.
Step 7) Step 2-6 are repeated to instantiate remaining device classes until all device classes are instantiated.

The number of additional control packets sent to collect the status of all candidate devices in DA-QFS is given by $\sum_{i=1}^{n}(p_i + k_i \times l_i)$ where n, p_i, k_i, and l_i are the number of device classes required to provide the WPAN service, the number of instantiated parent devices of n_i, the number of candidate devices of n_i, and the level of n_i in CTG, respectively. Therefore, the number of additional control packets depends on the size and the structure of CTG (i.e. the service profile of WPAN service). Typically, n is small for a WPAN service. The functionalities provided by multiple simple device classes can be provided by a complex device class to further reduce n. On the other hand, p_i and l_i vary on the structure of CTG. This is an issue to design the best service profile for a given WPAN service.

In DA-QFS the weighted linear combination of four implicit factors on all instantiated devices are updated periodically by user device to maintain the performance of the WPAN service and to prevent the WPAN service being interrupted. Therefore, a device class needs to be re-instantiated when the weighted linear combination of current instantiated device drops by δ percent. The value of δ is determined according to the sensitivity to the performance of the WPAN service.

4 Simulation Result

4.1 Service Profile in Simulation

All simulation is accomplished with ns-2. The TG and CTG of the given WPAN service are depicted in Fig. 3(a) and Fig. 3(b), respectively. The parameters in our simulation are shown in Table 1. The Euclidian distance is adopted. In DA-BFS the HELLO timer is set to 7 seconds for detecting a failed device [6]. In DA-QFS if the weighted linear combination of an instantiated device drops by 10 percent, then the corresponding device class needs to be re-instantiated.

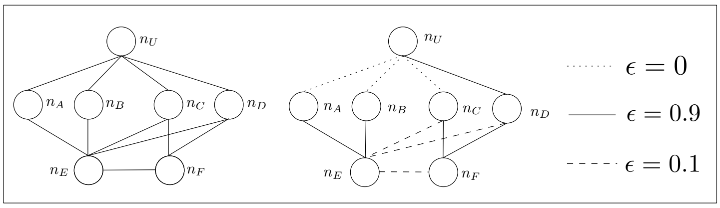

Fig. 3. (a) The TG and (b) The CTG of the given WPAN service.

Table 1. Simulation Parameters.

Number of device classes	6
Number of physical devices	60 (10 per device class) + n (number of users)
Number of user devices	1, 10
Relative traffic load ratio	Data flow: 0.9, Control flow: 0.1
Initial energy	1000 joules
(w_C, w_D, w_L, w_M)	(0.1, 0.35, 0.1, 0.45)
Simulation area	100 x 100 (m2)
Transmission range	30 (m)
Mobility model	Random Waypoint
MAC protocol	IEEE 802.15.4
Routing protocol	AODV
Simulation period	110 (sec)
Maximum speed	1, 5, 10, 15, 20 (m/s)

4.2 Performance Comparison

The performance metrics on energy consumption, packet loss, packet delay, and re-start time are evaluated. Two scenarios: (a) 1 user and (b) 10 users are simulated when the devices move with various maximum speeds. All experiment result is the mean value of 10 runs for each simulation.

1) Energy Consumption. In wireless network, the energy consumption is dominated by distance and the number of transmitted bits. Therefore, if a device with small implicit distance is regarded as the instantiated device for each device class, then the energy of each instantiated is efficiently conserved. The energy consumption for 1 user and 10 users are shown in Fig. 4(a) and Fig. 4(b), respectively. Because the implicit distance is a criterion in DA-QFS, the accumulated energy consumption of DA-BFS is smaller than the accumulated energy consumption of DA-BF. The difference is obvious when the maximum speed is from 10m/s to 20m/s. This is because the number of device classes needed to be re-instantiated is larger when the devices are highly mobile. Therefore, the energy is consumed to re-instantiate the failed device classes and to transmit the lost packets in DA-BFS is more than the energy consumed in DA-QFS.

2) Packet Loss Rate. The observed average packet loss rate is also reduced as show in Fig. 4(c) and Fig. 4(d). However, the difference between the scenario with 1 user and the scenario with 10 users is unobvious because the factor of work degree is less concerned in our simulation.

3) Packet Delay. Because the packet delay depends on the distance between the sender and the receiver, the one-way packet is low when the devices with small implicit distance are selected. The results depicted in Fig. 4(e) and Fig. 4(f) show that DA-QFS is suitable for the environment with multiple users because the observed one-way packet delay is obviously improved with the increased number of users.

4) Re-start Time. Finally, the re-start time spent on re-starting an interrupted WPAN service is observed. The re-start time is the product of the average number of interruption events, the average number of device classes needed to be re-instantiated per interruption event, and the average time spent on reinstantiating a device class. In our simulation the average time spent on re-instantiating a device class is 0.05 seconds for DA-BFS and is around 0.1 for DA-QFS. However, the number of interruption events and the number of device classes needed to be re-instantiated per interruption event are both reduced in DA-QFS as shown in Fig. 5(a) and Fig. 5(b), respectively. Thus, although the time spent on re-instantiating a device class in DA-QFS is higher than the time spent in DA-BFS, DA-QFS still perform well on re-start time as shown in Fig. 5(c).

5 Conclusion and Future Work

In this paper, we proposed the service-oriented device anycasting using quality first search (DA-QFS) approach to automatically organize the portable devices

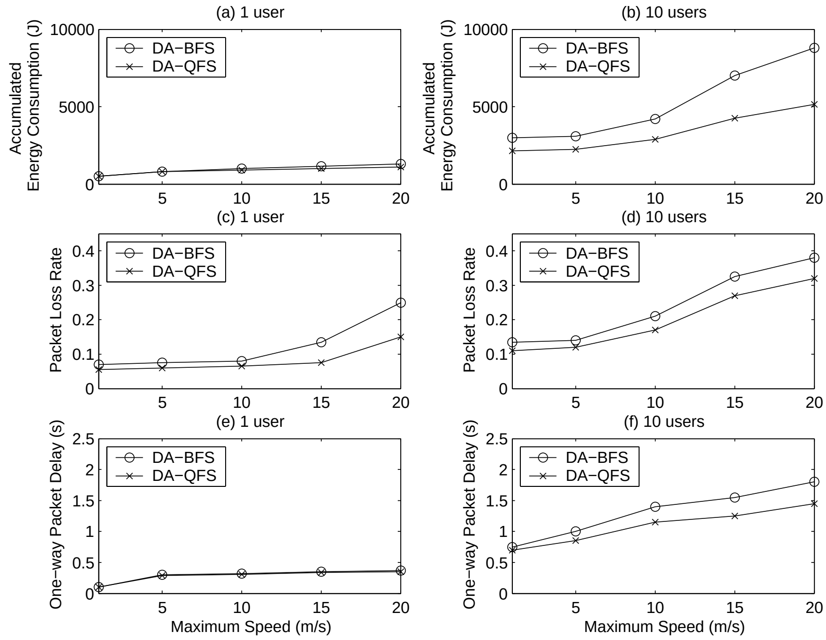

Fig. 4. Performance comparison on energy consumption, packet loss, and packet delay.

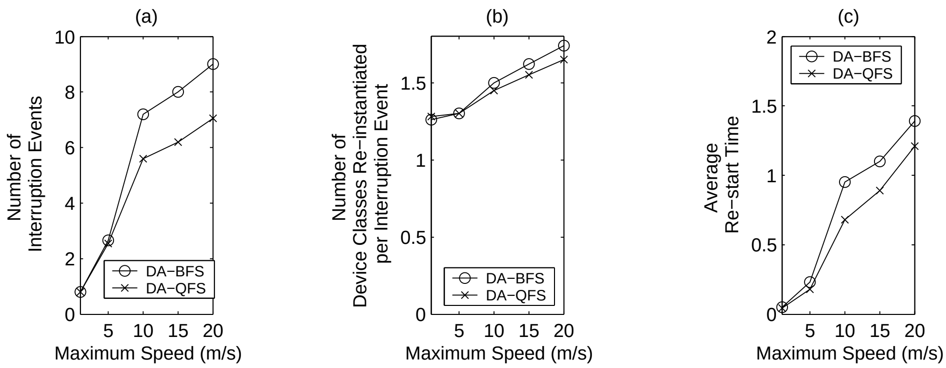

Fig. 5. Performance comparison on re-start time.

for wireless personal area network (WPAN) services. In DA-QFS the characterized task graph (CTG) is introduced to carefully describe the requirements for WPAN services. In addition, the weighted device anycasting (WDA) process is proposed to instantiate each device class according to the weighted linear combination of four implicit factors: connectivity, implicit distance, work degree, and mobility. The main contribution of DA-QFS is to provide a feasible approach to provide QoS for various WPAN services in the environment with highly mobile devices and multiple users.

An CTG generator creating a tree-based service profile (SP) will help us to reduce the overhead introduced by DA-QFS in the proactive manner. In addition, an adaptive WDA is another work in the future. There are two issues in an adaptive WDA. First, an algorithm takes SP as input and returns the weights in weighted linear combination of four implicit factors. Second, a feedback mechanism takes the status of the WPAN service as input and returns the adjusted weights in weighted linear combination of four implicit factors. Therefore, a better performance of the WPAN service can be expected.

References

1. M. Bohlen, J. Fabian, D. Pfeifer, and J.T. Rinker: Prototypes in pervasive computing. IEEE Pervasive Computing, **4(4)** (2005) 78–80
2. R. Banerjee: From research to classroom a course in pervasive computing. IEEE Pervasive Computing, **4(3)** (2005) 83–86
3. C. L. Chen, K. R. Lee, R. S. Wang, and Y. H. Kuo: An Energy-proportional Routing Algorithm for Lifetime Extension of Clustering-based Wireless Sensor Networks. In Proc. of Workshop on Wireless, Ad Hoc, and Sensor Networks, (2005)
4. R. F. Heile et al: IEEE Standard Part 15.3: Wireless Media Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs). IEEE, (2003)
5. V. Srivastava and M. Motani: Cross-layer design: a survey and the road ahead. IEEE Communications Magazine, **43(12)** (2005) 112–119
6. P. Basu, W. Ke, and T. D. C. Little: Dynamic Task-Based Anycasting in Mobile Ad Hoc Networks. Mobile Networks and Applications, **8(5)** (2003) 593–612
7. A. Joshi, D. Chakraborty, and Y. Yesha: An Integrated Service Discovery and Routing Protocol for Ad Hoc Networks. Technical Report, TR-CS-0323, University of Maryland, Baltimore County, (2003)
8. S. Helal, N. Desai, and C. Lee: Konark-A Service Discovery and Delivery Protocol for Ad-Hoc Networks. In Proc. of Third IEEE Conf. Wireless Comm. Networks, (2003)
9. K. Pahlavan and P. Krishnamurthy: Principles of Wireless Networks: A Unified Approach. Prentice Hall, (2001)
10. M. Chatterjee, S. K. Das, and D. Turgut: WCA: A Weighted Clustering Algorithm for Mobile Ad Hoc Networks. J. Cluster Computing, **5(2)** (2002) 193–204
11. S. Basagni, I. Chlamtac and A. Farago: A generalized clustering algorithm for peer-to-peer network. In Proc. of Workshop on Algorithmic Aspects of Communication, (1997).
12. E. Wu, J. Tsai, and M. Gerla: The effect of radio propagation on multimedia, mobile, multiho networks: models and countermeasures. In: Proc. of IEEE Singapore International Conference on Networks, (1997) 411–425