Opportunistic Service Composition in Pervasive Networks

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Abstract—**Composing pervasive services can be a challenging task, especially in networks where connectivity disruptions are prevalent and unpredictable, such as in networks formed spontaneously by connected things. In this paper, we propose a REST service composing system for such networks. This system has been built upon an opportunistic computing middleware to support connectivity disruptions. It implements orchestration-based and choreography-based composition techniques, and uses inter-contact time average as a metric to carry out the composition process.**

I. Introduction

Pervasive networks formed spontaneously by connected things (e.g., users' mobile phones, smart home devices, sensors, edge gateways) experience a renewed interest with the emergence of the mobile social networking, of the Internet of Things and of the edge computing. Indeed, in such networks, resources of heterogeneous things are often abstracted as services in order to allow these resources to be accessed through a simple and platform-independent interface. Thus, connected things do not only behave as clients of services available on the Internet, but can also deliver services to process and to produce data themselves. Automatically composing services offered by such things makes it possible to provide people with new and more sophisticated application services. Consider for example the context of a running race where the spectators hold mobile phones that form an intermittently connected network and where two services are available: the first one identifies runners with their bib, and the second one allows sharing photos taken by nearby spectators. The composition of these two services could make emerge a new service that enables the tagging of the shared photos with bib numbers, and hence the possibility to find or to filter photos based on bib numbers.

Service composition has been widely studied over the past years [1], [2], defining orchestration-based or choreography-based approaches relying on static composition descriptions, or devising dynamic composition approaches relying on a semantic description of services and on composition ontologies. Service composition is technically performed by chaining interfaces using a syntactical or semantical matching method. The interface chaining is usually represented as a graph or described with a specific language (e.g., BPEL, OWL-S). The data output of one service is piped into the next service input while filtering content and making slight format changes. Some works have addressed service composition issues in mobile environments [3], [4], [5], but very few of them have considered the problems posed by communication disruptions [6]. Yet in many real conditions, the discovery, the invocation and the composition of services is not feasible with Internet-legacy communication techniques due to the unpredictable and frequent connectivity disruptions induced by the mobility of some devices and the short radio range of wireless technologies such as Wi-Fi or Bluetooth.

In this paper, we propose a new REST service composition system that tolerates connectivity disruptions. It implements both an orchestration-based approach and a choreography-based one, and relies on an utility-based function to select, among several services exhibiting the same interfaces, the most relevant services to compose according to connectivity criteria. In the orchestration-based approach, the utility-based function is executed by the connected thing that initiates the composition process, while in the choreography-based one this function is called by each composition broker participating in the composition process (i.e., by each connected thing offering a required service and that has been selected as a good broker based on connectivity criteria). This composition system has been built upon a middleware that uses opportunistic communication in order to discover and to invoke remote services. The system has been evaluated in simulation on two different scenarios: one involving nomadic people roaming in an open area, and another one involving people attending a sport event. The utility-based function used in this evaluation is based on an inter-contact time average metric.

The remainder of the paper is organized as follows. Section II describes the service discovery, the service selection and the service composition processes implemented in our system. Section III presents the simulation results we obtained for our system. Section IV summarizes our contribution and concludes with directions for future work.

II. Opportunistic Service Composition

The composition system we have designed implements both an orchestration-based and a choreography-based composition algorithms. Like research works [3], [4], [5], [7], and [8], it supports an incremental and partial composition mechanism, thus allowing to compose services progressively according to their discovery, and to avoid to rebuild the whole composition when a service provider involved in the composition process becomes unreachable. In order to cope with connection disruptions in the service discovery and invocation processes, our system leverages on the C3PO opportunistic computing middleware, dedicated to the development and the deployment of opportunistic Android applications in the context of spontaneous and ephemeral social networks [9]. This middleware offers means to discover and invoke remote services thanks to opportunistic communication, based on

the store-carry-and-forward principle [10]. To improve the composition reliability and to reduce the composition time, our system can be parameterized with a utility-based function that helps select service providers that must be enrolled in a composition process. The current implemented utility-based function relies on a cumulative inter-contact time average between neighbor things. The inter-contact time average between two neighbors a and b is, by definition, the sum of all the inter-contact times divided by their number. It is more formally defined by : $ICA_{ab} = \frac{\sum_{k=1}^{n} IC_k^{ab}}{n}$ where ICA_{ab} is the average of inter-contact time between a and b, IC_k^{ab} is the k-th inter-contact time between a and b and n is the overall number of inter-contact. The averaging process starts from the first contact and includes all the past IC values from the beginning to the end. The contact is defined by the reception of an advertisement message. Finally, this system can also be parameterized with the number of hops that must be used in the discovery, in the invocation and in the composition processes. This number of hops reflects the size of the neighborhood of each object in terms of service discovery, invocation and composition.

A. Discovery and selection phase

Each object running our composition system maintains its own service registry. This registry contains the services provided by the object itself, and the services it has discovered recently. Each object periodically exchanges the content of its registry with the objects it is directly connected to. To do so, it emits an advertisement that is defined as a couple $\{L, R\}$, where L is a set including the description of the local services, R a set of quadruplets $\{s, d, i, h\}$. In the quadruplets, s refers to the description of a remote service, d to the date of reception of the last advertisement for this service, i to the cumulative inter-contact time average with the provider of this service, and h to the number of hops to reach the provider of this service. If it exists several providers of the service, our system selects the most reliable provider (i.e., the provider with the lower inter-contact time average and the lower number of hops). When they receive an advertisement, the objects update their service registry. When a service registry entry for a remote service has not been updated since a given time, the service is considered as unreachable, and the entry is removed from the service registry. Similarly if the inter-contact time average of a remote service is above a certain threshold, the entry corresponding to this service is also removed from the service registry.

B. Choreography-based Service Composition

The choreography-based service composition consists in transmitting the composition request to the first selected service provider, and in delegating to it both the execution of the first service and the selection of the next provider as specified in the composition request. When the execution of the required service is completed, the provider of this service passes the results of the service execution and the composition request to the next provider, if there is a next service in the composition request. Otherwise, it returns the results to the object that has initiated the service composition.

C. Orchestration-based Service Composition

Unlike the choreography-based service composition, in the orchestration-based service composition, the composition request is never transmitted to the service providers enrolled in the composition process, and the service invocation is never delegated to them. Indeed, the providers are selected and invoked by the object that has generated the composition request itself. This object selects the providers on the basis of the smallest inter-contact time averages. Similarly to the choreography approach, if the requester fails to find the next service instance, it will resume the composition process once it will discover a provider of the service it requires.

III. SIMULATION AND EVALUATION

A. Simulation setup

The choreography-based and the orchestration-based composition algorithms described above have been evaluated with simulation through two scenarios: one involving people roaming inside an open area of 500 square meters, and another one involving spectators of a marathon in the city of Vannes. In both scenarios, people move following the Levy walk [11] mobility model at a speed varying from 0.5 to 2 m/s, and use a smartphone equipped with our system that is able to communicate with surrounding devices using Wi-Fi Direct. The radio range is limited to 80 m. Each smartphone hosts 5 services. A composition request comprises from 3 to 6 services, and is generated periodically, with a period that can vary from 2 to 5 minutes. The discovery process is limited to 3 hops. Thus, smartphones can discover, compose and invoke remote services that can be reach at most in 3 hops. The simulation time is 1 hour.

B. Results

The remainder of this section presents the simulation results we obtained for the composition algorithms, when varying the number of hops that separate the requesters from remote services. The metrics measured were the success ratio of the composition requests, the time taken for the composition and the number of devices actually involved in the composition process.

The four curves in Figure 1a show the composition time against the number of hops needed to reach a remote service. In both scenarios, the choreography-based composition algorithm provides a faster composition of services than the orchestration-based one. Indeed in the open area scenario, the composition time average increases from 154 seconds (for 1 hop) to 361 seconds (for 3 hops) with the orchestration-based algorithm, whereas it increases from 459 seconds (for 1 hop) to 709 seconds (for 3 hops) with the choreography-based algorithm. Similarly in the Vannes city experiment, the composition time average increases from 125 seconds (for 1 hop) to 410 seconds (for 3 hops) with the orchestration-based algorithm, whereas it increases from 262 seconds (for 1 hop) to 585 seconds (for 3 hops) with the choreography-based algorithm. In the orchestration-based approach the composition requester must receive the responses from the services it invokes before calling the next ones with these responses. This introduces longer delays than with the choreography-based algorithm, in which only the final response is returned to the

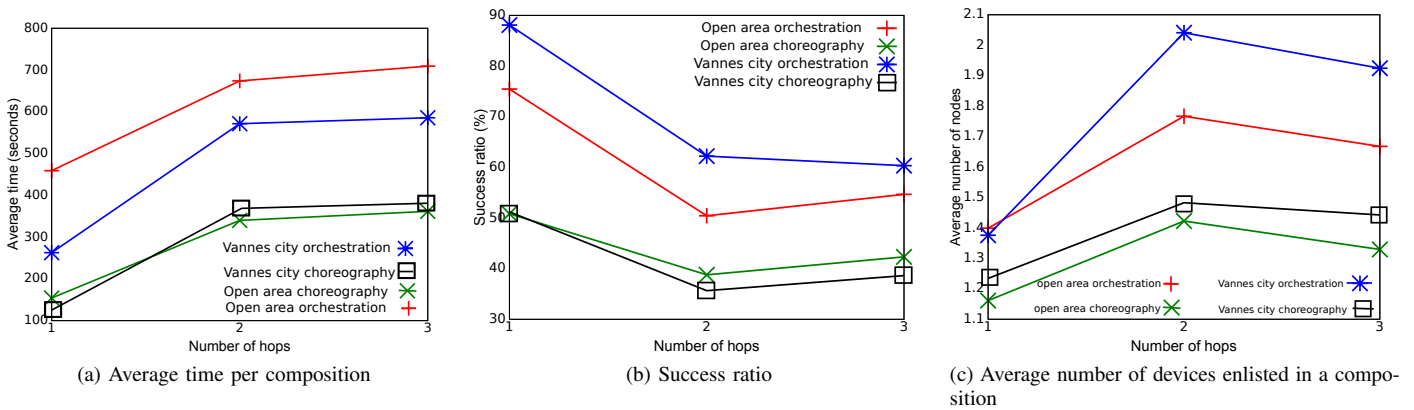| (a) Average time per composition | (b) Success ratio | (c) Average number of devices enlisted in a composition |

Figure 1: Service composition results

composition requester. The other responses are transmitted by the intermediate devices involved in the composition process as they invoke the next service to be composed.

Figure 1b shows the composition success ratio (in percentage) against the number of hops needed to reach a remote service. In both scenarios, the orchestration-based algorithm is clearly better than the choreography-based one, and its better for one hop than for 2 and 3 hops. This is explained by the fact that when the system performs a 1-hop discovery, the services invoked are directly provided by nearby devices. This is not the case for 2-hops and 3-hops discovery processes. Moreover, in the orchestration-based algorithm, only the device that initiates the composition process performs the service invocations, thus improving the chances to get responses back.

Finally, Figure 1c shows the average number of devices enrolled in a composition process against the number of hops needed to reach a remote service (including the intermediate devices that forward the requests and the responses). The orchestration-based algorithm enlists more devices than the choreography-based algorithm because more intermediate devices are solicited to forward the requests and the responses.

IV. CONCLUSION

In this paper, we have presented a service discovery and composition system for opportunistic environments. The system provides both a choreography-based and an orchestration-based algorithm. The discovery and the composition processes rely on a utility function that exploits the inter-contact time average between devices. The two algorithms have been compared and evaluated in simulation to study their behaviors. The orchestration-based algorithm provides a better success ratio than the choreography-based algorithm, but introduces longer delays in the composition process based on the utility function studied in this paper.

This system could probably be enhanced by considering utility functions based on other criteria, such as a form of device location or an exponential smoothing average of the inter-contact times in order to keep only the newer inter-contact time measurements. Developing a composition system that is able to select dynamically the most time-efficient and reliable composition algorithm to perform a given composition can be

a relevant future work in order to provide end-users with a better quality of service.

REFERENCES

[1] M. Garriga, C. Mateos, A. Flores, A. Cechich, and A. Zunino, "RESTful service composition at a glance: A survey," *Journal of Network and Computer Applications*, vol. 60, pp. 32 – 53, Jan. 2016.

[2] N. Ibrahim and F. Le Mouël, "A Survey on Service Composition Middleware in Pervasive Environments," *International Journal of Computer Science Issues (IJCSI)*, vol. 1, pp. 1–12, Aug. 2009.

[3] D. Chakraborty, A. Joshi, T. Finin, and Y. Yesha, "Service composition for mobile environments," *Mobile Networks and Applications*, vol. 10, no. 4, pp. 435–451, 2005.

[4] D. Chakraborty, Y. Yesha, and A. Joshi, "A distributed service composition protocol for pervasive environments," in *Wireless Communications and Networking Conference, 2004. WCNC. 2004 IEEE*, vol. 4, Mar. 2004, pp. 2575–2580.

[5] S. Kalasapur, M. Kumar, and B. Shirazi, "Seamless service composition (sesco) in pervasive environments," in *Proceedings of the First ACM International Workshop on Multimedia Service Composition*, ser. MSC '05. New York, NY, USA: ACM, 2005, pp. 11–20.

[6] U. Sadiq, M. Kumar, A. Passarella, and M. Conti, "Modeling and simulation of service composition in opportunistic networks," in *Proceedings of the 14th ACM international conference on Modeling, analysis and simulation of wireless and mobile systems*. ACM, 2011, pp. 159–168.

[7] L. D. Prete and L. Capra, "Reliable discovery and selection of composite services in mobile environments," in *In Proc. of 12th IEEE EDOC*, 2008.

[8] J. Wang, "Exploiting mobility prediction for dependable service composition in wireless mobile ad hoc networks," *IEEE Trans. Serv. Comput.*, vol. 4, no. 1, pp. 44–55, Jan. 2011.

[9] F. Laforest, N. Le Sommer, S. Frénot, F. De Corbière, Y. Mahéo, P. Launay, and al., "C3PO: a Spontaneous and Ephemeral Social Networking Framework for a collaborative Creation and Publishing of Multimedia Contents," in *International conference on selected topics in Mobile and Wireless Networking (MoWNet 2014)*, ser. Procedia Computer Science, vol. 40. Rome, Italy: Elsevier, Sep. 2014, pp. 129–134.

[10] N. Le Sommer, P. Launay, and Y. Mahéo, "A Framework for Opportunistic Networking in Spontaneous and Ephemeral Social Networks," in *10th ACM MobiCom Workshop on Challenged Networks (CHANTS 2015)*, ser. Proceedings of the 10th ACM MobiCom Workshop on Challenged Networks. Paris, France: ACM Press, 2015, pp. 1–4.

[11] I. Rhee, M. Shin, S. Hong, K. Lee, S. J. Kim, and S. Chong, "On the levy-walk nature of human mobility," *IEEE/ACM Transactions on Networking*, vol. 19, no. 3, pp. 630–643, Jun. 2011.