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Chapter 1

Device Search and Selection

Charith Perera, Chi Harold Liu, and Peter Christen

Cyber-physical systems (CPS) represent the expansion in computerized interconnectivity. This phenomenon is also moving towards the Internet of Things (IoT) paradigm. Searching functionality plays a vital role in this domain. Many different types of search capabilities are required to build a comprehensive CPS architecture. In CPS, users may want to search smart devices and services. In this chapter, we discuss concepts and techniques related to device search and selection. We briefly discuss different types of device searching approaches where each has its own objectives and applications. One such device searching technique is context-aware searching. In this chapter, we present context-aware sensor search, selection and ranking model called CASSARAM in detail. This model addresses the challenge of efficiently selecting a subset of relevant sensors out of a large set of sensors with similar functionality and capabilities. CASSARAM takes into account user preferences and considers a broad range of sensor characteristics, such as reliability, accuracy, location, battery life, and many more. Later in the chapter, we discuss three different techniques that can be used to improve the efficiently of CASSARAM. We implemented the proof of concept software using Java. Testing and performance evaluation results are also discussed. We also highlight open research challenges and opportunities in order to support future research directions.

platform is yet to be achieved by the research community. Addressing the open challenges mentioned in the previously will help to move towards that direction.

References

[1] K. Aberer, M. Hauswirth, and A. Salehi. Infrastructure for data processing in large-scale interconnected sensor networks. In *International Conference on Mobile Data Management*, pages 198–205, May 2007.

[2] G. D. Abowd, A. K. Dey, P. J. Brown, N. Davies, M. Smith, and P. Steggles. Towards a better understanding of context and context-awareness. In *Proceedings of the 1st international symposium on Handheld and Ubiquitous Computing*, HUC '99, pages 304–307, London, UK, 1999. Springer-Verlag.

[3] J. Ahn and B. Krishnamachari. Modeling search costs in wireless sensor networks. In *Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks and Workshops, 2007. WiOpt 2007. 5th International Symposium on*, pages 1–6, 2007.

[4] Apache Foundation. Commons math: The apache commons mathematics library, 2011. `http://commons.apache.org/math/` [2012-09-05].

[5] Apache Software Foundation. Apache Jena, November 2010. `http://jena.apache.org/` [accessed on: 2012-05-10].

[6] Australian Government, Bureau of Meteorology. Experimental environmental linked-data published by the bureau of meteorology, 2012. `http://lab.environment.data.gov.au/` [Accessed on: 2012-009-05].

[7] P. Barnaghi, W. Wang, C. Henson, and K. Taylor. Semantics for the internet of things: Early progress and back to the future. *Int. J. Semant. Web Inf. Syst.*, 8(1):1–21, Jan. 2012.

[8] C. Bizer and A. Schultz. The berlin sparql benchmark. *Int. J. Semantic Web Inf. Syst.*, 5(2):1–24, 2009.

[9] A. Broring, F. Bache, T. Bartoschek, and C. P. Elzakker. The sid creator: A visual approach for integrating sensors with the sensor web. In S. Geertman, W. Reinhardt, and F. Toppen, editors, *Advancing Geoinformation Science for a Changing World*, Lecture Notes in Geoinformation and Cartography, pages 143–162. Springer Berlin Heidelberg,

2011.

[10] T. A. Butt, I. Phillips, L. Guan, and G. Oikonomou. Trendy: an adaptive and context-aware service discovery protocol for 6lowpans. In *Proceedings of the Third International Workshop on the Web of Things*, WOT '12, pages 2:1–2:6, New York, NY, USA, 2012. ACM.

[11] J.-P. Calbimonte, H. Jeung, O. Corcho, and K. Aberer. Enabling query technologies for the semantic sensor web. *Int. J. Semant. Web Inf. Syst.*, 8(1):43–63, Jan. 2012.

[12] Casaleggio Associati. The evolution of internet of things. Technical report, Casaleggio Associati, February 2011. http://www.casaleggio.it/pubblicazioni/Focus_internet_of_things_v1.81%20-%20eng.pdf [Accessed on: 2011-06-08].

[13] R. Cattell. Scalable sql and nosql data stores. *SIGMOD Rec.*, 39(4):12–27, May 2011.

[14] D. Chalmers and M. Sloman. A survey of quality of service in mobile computing environments. *Communications Surveys Tutorials, IEEE*, 2(2):2 –10, quarter 1999.

[15] Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia. Phenonet: Distributed sensor network for phenomics supported by high resolution plant phenomics centre, csiro ict centre, and csiro sensor and sensor networks tcp., 2011. http://phenonet.com [Accessed on: 2012-04-20].

[16] M. Compton, C. Henson, H. Neuhaus, L. Lefort, and A. Sheth. A survey of the semantic specification of sensors. In *2nd International Workshop on Semantic Sensor Networks, at 8th International Semantic Web Conference,*, Oct. 2009.

[17] S. De, T. Elsaleh, P. Barnaghi, and S. Meissner. An internet of things platform for real-world and digital objects. *Scalable Computing: Practice and Experience*, 13(1):45–57, 2012.

[18] Digital Enterprise Research Institute. Linked sensor middleware (lsm), 2011. http://lsm.deri.ie/ [Accessed on: 2012-09-24].

[19] Z. Ding, X. Gao, L. Guo, and Q. Yang. A hybrid search engine framework for the internet of things based on spatial-temporal, value-based, and keyword-based conditions. In *Green Computing and Communications (GreenCom), 2012 IEEE International Conference on*, pages 17–25, 2012.

[20] J. Domingue and D. Fensel. Toward a service web: integrating the semantic web and service orientation. *IEEE Intelligent Systems*, 23(1):8688, 2009.

[21] B. M. Elahi, K. Romer, B. Ostermaier, M. Fahrmair, and W. Kellerer. Sensor ranking: A primitive for efficient content-based sensor search. In *Proceedings of the 2009 International Conference on Information Processing in Sensor Networks*, IPSN '09, pages 217–228, Washington, DC, USA, 2009. IEEE Computer Society.

[22] European Commission. Internet of things in 2020 road map for the future. Technical report, Working Group RFID of the ETP EPOSS, May 2008. `http://ec.europa.eu/information_society/policy/rfid/documents/iotprague2009.pdf` [Accessed on: 2011-06-12].

[23] R. Garcia-Castro, O. Corcho, and C. Hill. A core ontological model for semantic sensor web infrastructures. *Int. J. Semant. Web Inf. Syst.*, 8(1):22–42, Jan. 2012.

[24] P. Guillemin and P. Friess. Internet of things strategic research roadmap. Technical report, The Cluster of European Research Projects, September 2009. `http://www.internet-of-things-research.eu/pdf/IoT_Cluster_Strategic_Research_Agenda_2009.pdf`.

[25] D. Guinard, V. Trifa, S. Karnouskos, P. Spiess, and D. Savio. Interacting with the soa-based internet of things: Discovery, query, selection, and on-demand provisioning of web services. *Services Computing, IEEE Transactions on*, 3(3):223–235, 2010.

[26] International Telecommunication Union. Itu internet reports 2005: The internet of things. Workshop report, International Telecommunication Union, November 2005. `http://www.itu.int/dms_pub/itu-s/opb/pol/S-POL-IR.IT-2005-SUM-PDF-E.pdf` [Accessed on: 2011-12-12].

[27] V. Issarny, M. Caporuscio, and N. Georgantas. A perspective on the future of middleware-based software engineering. In *2007 Future of Software Engineering*, FOSE '07, pages 244–258, Washington, DC, USA, 2007. IEEE Computer Society.

[28] X. Jin, D. Zhang, Q. Zou, G. Ji, and X. Qian. Where searching will go in internet of things? In *Wireless Days (WD), 2011 IFIP*, pages 1–3, 2011.

[29] S. Jirka, A. Broring, and C. Stasch. Discovery mechanisms for the sensor web. *Sensors*, 9(4):2661–2681, 2009.

[30] P. Kulkarni. Distributed SPARQL query engine using MapReduce. Master's thesis, University of Edinburgh, 2010.

[31] S. Mayer, D. Guinard, and V. Trifa. Searching in a web-based infrastructure for smart

things. In *Proceedings of the 3rd International Conference on the Internet of Things (IoT 2012)*, Wuxi, China, 2012.

[32] M. Nagy, A. Katasonov, O. Khriyenko, S. Nikitin, M. Szydlowski, and V. Terziyan. Challenges of middleware for the internet of things. Technical report, University of Jyvaskyla, 2009. `http://cdn.intechopen.com/pdfs/8786/InTech-Challenges_of_middleware_for_the_internet_of_things.pdf` [Accessed on: 2011-12-20].

[33] N. Namatame, Y. Ding, T. Riedel, H. Tokuda, T. Miyaki, and M. Beigl. A distributed resource management architecture for interconnecting web-of-things using ubox. In *Proceedings of the Second International Workshop on Web of Things*, WoT '11, pages 4:1–4:6, New York, NY, USA, 2011. ACM.

[34] S. Nath, J. Liu, and F. Zhao. Sensormap for wide-area sensor webs. *Computer*, 40(7):90–93, July 2007.

[35] H. Noguchi, T. Mori, and T. Sato. Framework for search application based on time segment of sensor data in home environment. In *Networked Sensing Systems (INSS), 2010 Seventh International Conference on*, pages 261–264, 2010.

[36] OpenIoT Consortium. Open source solution for the internet of things into the cloud, January 2012. `http://www.openiot.eu` [Accessed on: 2012-04-08].

[37] B. Ostermaier, K. Roalter, L.o andmer, F. Mattern, M. Fahrmair, and W. Kellerer. A real-time search engine for the web of things. In *Proceedings of the 2rd International Conference on the Internet of Things (IoT 2010)*, pages 1 –8, 29 2010-dec. 1 2010.

[38] I. Paparrizos, H. Jeung, and K. Aberer. Advanced search, visualization and tagging of sensor metadata. In *Proceedings of the 2011 IEEE 27th International Conference on Data Engineering*, ICDE '11, pages 1356–1359, Washington, DC, USA, 2011. IEEE Computer Society.

[39] C. Perera, P. Jayaraman, A. Zaslavsky, P. Christen, and D. Georgakopoulos. *Big Data and Internet of Things: A Roadmap for Smart Environments*, chapter Context-aware Dynamic Discovery and Configuration of 'Things' in Smart Environments, page (in print). Springer Berlin Heidelberg, 2014.

[40] C. Perera, P. P. Jayaraman, A. Zaslavsky, P. Christen, and D. Georgakopoulos. Mosden: An internet of things middleware for resource constrained mobile devices. In *47th Hawaii International Conference on System Sciences (HICSS)*, page n/a, Kona, Hawaii, USA,

January 2014.

[41] C. Perera, A. Zaslavsky, P. Christen, M. Compton, and D. Georgakopoulos. Context-aware sensor search, selection and ranking model for internet of things middleware. In *IEEE 14th International Conference on Mobile Data Management (MDM)*, Milan, Italy, June 2013.

[42] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos. Ca4iot: Context awareness for internet of things. In *IEEE International Conference on Conference on Internet of Things (iThing)*, pages 775–782, Besanon, France, November 2012.

[43] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos. Context aware computing for the internet of things: A survey. *Communications Surveys Tutorials, IEEE*, XX:X, 2013.

[44] C. Perera, A. Zaslavsky, P. Christen, and D. Georgakopoulos. Sensing as a service model for smart cities supported by internet of things. *Transactions on Emerging Telecommunications Technologies (ETT)*, pages n/a–n/a, 2014.

[45] C. Perera, A. Zaslavsky, P. Christen, A. Salehi, and D. Georgakopoulos. Capturing sensor data from mobile phones using global sensor network middleware. In *IEEE 23rd International Symposium on Personal Indoor and Mobile Radio Communications (PIMRC)*, pages 24–29, Sydney, Australia, September 2012.

[46] C. Perera, A. Zaslavsky, M. Compton, P. Christen, and D. Georgakopoulos. Semantic-driven configuration of internet of things middleware. In *9th International Conference on Semantics, Knowledge & Grids (SKG)*, page n/a, Beijing, China, October 2013.

[47] D. L. Phuoc, H. N. M. Quoc, J. X. Parreira, and M. Hauswirth. The linked sensor middleware - connecting the real world and the semantic web. In *International Semantic Web Conference (ISWC)*, October 2011.

[48] S. Ran. A model for web services discovery with qos. *SIGecom Exch.*, 4(1):1–10, Mar. 2003.

[49] K. Romer, B. Ostermaier, F. Mattern, M. Fahrmair, and W. Kellerer. Real-time search for real-world entities: A survey. *Proceedings of the IEEE*, 98(11):1887–1902, 2010.

[50] S. Shakkottai. Asymptotics of query strategies over a sensor network. In *INFOCOM 2004. Twenty-third AnnualJoint Conference of the IEEE Computer and Communications Societies*, volume 1, pages –557, 2004.

[51] Z. Shelby. Embedded web services. *Wireless Communications, IEEE*, 17(6):52–57, 2010.

[52] H. Sundmaeker, P. Guillemin, P. Friess, and S. Woelfflе. Vision and challenges for realising the internet of things. Technical report, European Commission Information Society and Media, March 2010. `http://www.internet-of-things-research.eu/pdf/IoT_Clusterbook_March_2010.pdf` [Accessed on: 2011-10-10].

[53] C. C. Tan, B. Sheng, H. Wang, and Q. Li. Microsearch: A search engine for embedded devices used in pervasive computing. *ACM Trans. Embed. Comput. Syst.*, 9(4):43:1–43:29, Apr. 2010.

[54] C. Truong, K. Romer, and K. Chen. Fuzzy-based sensor search in the web of things. In *Proceedings of the 3rd International Conference on the Internet of Things (IoT 2012)*, Wuxi, China, 2012.

[55] w3.org. Semantic sensor network xg final report: W3c incubator group report, June 2011. `http://www.w3.org/2005/Incubator/ssn/XGR-ssn-20110628/` [Accessed on: 2012-09-25].

[56] H. Wang, C. Tan, and Q. Li. Snoogle: A search engine for pervasive environments. *Parallel and Distributed Systems, IEEE Transactions on*, 21(8):1188–1202, 2010.

[57] J. L. Wong and M. Potkonjak. Search in sensor networks: Challenges, techniques, and applications. In *Acoustics, Speech, and Signal Processing (ICASSP), 2002 IEEE International Conference on*, volume 4, pages IV–3752–IV–3755, 2002.

[58] A. Zaslavsky, C. Perera, and D. Georgakopoulos. Sensing as a service and big data. In *International Conference on Advances in Cloud Computing (ACC-2012)*, pages 21–29, Bangalore, India, July 2012.

[59] D. Zhang, L. Yang, and H. Huang. Searching in internet of things: Vision and challenges. In *Parallel and Distributed Processing with Applications (ISPA), 2011 IEEE 9th International Symposium on*, pages 201–206, 2011.