Charith Perera, Prem Prakash Jayaraman, Srimal Jayawardena, Chi Harold Liu, and Peter Christen, Mobile Sensing Devices and Platforms, *In Book the Cyber-Physical Systems: Architectures, Protocols and Applications*, CRC Press, Taylor & Francis Group, USA, 2014, Pages xx-xx (41) (Accepted for Publication) More: www.charithperera.net Full Chapter available on request for academic scholarly work

Contents

Chapter 1

Mobile Sensing Devices and Platforms

Charith Perera, Prem Prakash Jayaraman, Srimal Jayawardena, Chi Harold Liu,
and Peter Christen

A cyber-physical system (CPS) is a system of collaborating computational elements controlling physical entities. CPS represents the next stage on the road to the creation of smart cities through the creation of an Internet of Things, data and services. Mobility is one of the major characteristic of both CPS and IoT. In this Chapter, we discuss mobile sensing platforms and their applications towards different but interrelated paradigms such as IoT, sensing as a service, and smart cities. We highlight and briefly discuss different types of mobile sensing platforms and functionalities they offer. Mobile sensing platforms are more oftenly integrated with smart phones and tablet devices. The resource constrained nature of the mobile devices requires different types of designs and architectural implementations. We proposed a software-based mobile sensing platform called *Mobile Sensor Data Engine (MOSDEN)*. It is a plug-in-based scalable and extendible IoT middleware for mobile devices that provide an easy way to collect sensor data from both internal and external sensors. MOSDEN act as intermediary device that collects data from external sensors and upload to the cloud in real-time or on demand. We evaluate MOSDEN in both stand-alone and collaborative environments. The proof of concept is developed on Android platform.

constrained devices. MOSDEN can be installed in mobile devices (smart-phones and tablets) and can be used to collect data from both internal and external sensors. Due tothe plugin architecture, MOSDEN can retrieve data from virtually any smart device. Further, it has the capability to perform limited data processing and filtering tasks.

We also discuss a number of different ways that existing mobile system platforms have been used to support sensor data collection and processing. This chapter comprises a number of performance evaluation results where MOSDEN has been tested in standalone mode as well as in collaborative mode. In the later part of this chapter, we presented different real-world application that MOSDEN can be used. Finally, it is important to mentioned that the goal of building a unified middleware platform that supports a broad range of devices, ranging from low-level sensors to smart-phone to personal computers to the cloud, is yet to be achieved by the research community. Addressing the open challenges mentioned in the previously will help to move towards that direction.

Acknowledgement: Authors acknowledge support from SSN TCP, CSIRO, Australia and ICT Project, which is co-funded by the European Commission under seventh framework program, contract number FP7-ICT-2011-7-287305-OpenIoT. The Author(s) also acknowledge help and contributions from The Australian National University.

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. International Conference on Mobile Data Management, May 2007.

[2] V. Agarwal, N. Banerjee, D. Chakraborty, and S. Mittal. Usense – a smartphone middleware for community sensing. In *Mobile Data Management (MDM), 2013 IEEE 14th International Conference on*, volume 1, pages 56–65, 2013.

[3] L. Atzori, A. Iera, and G. Morabito. The internet of things: A survey. *Comput. Netw.*, 54(15):2787–2805, Oct. 2010.

[4] M. Blackstock, N. Kaviani, R. Lea, and A. Friday. Magic broker 2: An open and

extensible platform for the internet of things. In *Internet of Things (IOT), 2010*, pages 1–8, 2010.

[5] N. Brouwers and K. Langendoen. Pogo, a middleware for mobile phone sensing. In *Proceedings of the 13th International Middleware Conference*, Middleware '12, pages 21–40, New York, NY, USA,, 2012. Proceedings of the 13th International Middleware Conference, Springer-Verlag New York, Inc.

[6] M. Budde, M. Berning, M. Busse, T. Miyaki, and M. Beigl. The teco envboard: A mobile sensor platform for accurate urban sensing and more. In *Networked Sensing Systems (INSS), 2012 Ninth International Conference on*, pages 1–2, 2012.

[7] M. Budde, M. Berning, M. Busse, T. Miyaki, and M. Beigl. The teco envboard: A mobile sensor platform for accurate urban sensing and more. In *Networked Sensing Systems (INSS), 2012 Ninth International Conference on*, pages 1–2, 2012.

[8] D. Carlson and A. Schrader. Dynamix: An open plug-and-play context framework for android. In *Internet of Things (IOT), 2012 3rd International Conference on the*, pages 151–158, 2012.

[9] I. Carreras, D. Miorandi, A. Tamilin, E. Ssebaggala, and N. Conci. Crowd-sensing: Why context matters. In *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2013 IEEE International Conference on*, pages 368–371, 2013.

[10] G. Castignani, A. Lampropulos, A. Blanc, and N. Montavont. Wi2me: A mobile sensing platform for wireless heterogeneous networks. In *Proceedings of the 2012 32Nd International Conference on Distributed Computing Systems Workshops*, ICDCSW '12, pages 108–113, Washington, DC, USA, 2012. IEEE Computer Society.

[11] T. Choudhury, S. Consolvo, B. Harrison, J. Hightower, A. LaMarca, L. Legrand, A. Rahimi, A. Rea, G. Bordello, B. Hemingway, P. Klasnja, K. Koscher, J. Landay, J. Lester, D. Wyatt, and D. Haehnel. The mobile sensing platform: An embedded activity recognition system. *Pervasive Computing, IEEE*, 7(2):32–41, 2008.

[12] 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.

[13] Cosm. Cosm platform, 2007. `https://cosm.com/` [Accessed on: 2012-08-05].

[14] N. Eagle. *Mobile Phones as Social Sensors*. Oxford University Press, 2011.

[15] H. Franke, F. Koch, C. Rolim, C. Westphall, and D. Balen. Grid-m: Middleware to integrate mobile devices, sensors and grid computing. In *Wireless and Mobile Communications, 2007. ICWMC '07. Third International Conference on*, pages 19–19, 2007.

[16] R. Ganti, F. Ye, and H. Lei. Mobile crowdsensing: current state and future challenges. *Communications Magazine, IEEE*, 49(11):32 –39, november 2011.

[17] GSN Team. Global sensor networks project, 2011. `http://sourceforge.net/apps/trac/gsn/` [Accessed on: 2011-12-16].

[18] S. Hadim and N. Mohamed. Middleware: middleware challenges and approaches for wireless sensor networks. *Distributed Systems Online, IEEE*, 7(3):1, march 2006.

[19] M. C. Holger Neuhaus. The semantic sensor network ontology: A generic language to describe sensor assets. In *AGILE 2009 Pre-Conference Workshop Challenges in Geospatial Data Harmonisation*, 2009.

[20] P. P. Jayaraman, C. Perera, D. Georgakopoulos, and A. Zaslavsky. Efficient opportunistic sensing using mobile collaborative platform. In *9th IEEE International Conference on Collaborative Computing: Networking, Applications and Worksharing (COLLABORATECOM)*, Austin, Texas, United States, October 2013.

[21] T. Kakantousis and V. Kalogeraki. A mobile platform for managing mobile mapreduce participatory sensing data. In *Applications and the Internet (SAINT), 2012 IEEE/IPSJ 12th International Symposium on*, pages 196–201, 2012.

[22] W. Khan, Y. Xiang, M. Aalsalem, and Q. Arshad. Mobile phone sensing systems: A survey. *Communications Surveys Tutorials, IEEE*, 15(1):402–427, 2013.

[23] D. Kharrat and S. Quadri. Self-registering plug-ins: an architecture for extensible software. In *Electrical and Computer Engineering, 2005. Canadian Conference on*, pages 1324–1327, 2005.

[24] T. T.-T. Lai, W.-J. Chen, K.-H. Li, P. Huang, and H.-H. Chu. Triopusnet: Automating wireless sensor network deployment and replacement in pipeline monitoring. In *Proceedings of the 11th International Conference on Information Processing in Sensor Networks*, IPSN '12, pages 61–72, New York, NY, USA, 2012. ACM.

[25] N. Lane, E. Miluzzo, H. Lu, D. Peebles, T. Choudhury, and A. Campbell. A survey of mobile phone sensing. *Communications Magazine, IEEE*, 48(9):140 –150, sept. 2010.

[26] T. Laukkarinen, J. Suhonen, and M. Hnnikinen. An embedded cloud design for internet-

of-things. *International Journal of Distributed Sensor Networks*, 2013:13, 2013.

[27] E. A. Lee. Cyber-physical systems: A rehash or a new intellectual challenge?, June 2013. Invited Talk in the Distinguished Speaker Series, sponsored by the IEEE Council on Electronic Design Automation (CEDA) held at the Design Automation Conference (DAC), Austin, Texas.

[28] J.-S. Lee, Y.-W. Su, and C.-C. Shen. A comparative study of wireless protocols: Bluetooth, uwb, zigbee, and wi-fi. In *Industrial Electronics Society, 2007. IECON 2007. 33rd Annual Conference of the IEEE*, pages 46–51, 2007.

[29] W. Lee, B. Priyantha, T. Hart, G. DeJean, Y. Xu, and J. Liu. The cleo mobile sensing platform. In *Proceedings of the 10th ACM Conference on Embedded Network Sensor Systems*, SenSys '12, pages 371–372, New York, NY, USA, 2012. ACM.

[30] Libelium Comunicaciones Distribuidas. libelium, 2006. `http://www.libelium.com/` [Accessed on: 2012-011-28].

[31] P. Lilly. Mobile devices to outnumber global population by 2017.

[32] C. Perera, P. Jayaraman, A. Zaslavsky, P. Christen, and D. Georgakopoulos. Dynamic configuration of sensors using mobile sensor hub in internet of things paradigm. In *IEEE 8th International Conference on Intelligent Sensors, Sensor Networks, and Information Processing (ISSNIP)*, pages 473–478, Melbourne, Australia, April 2013.

[33] 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.

[34] 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.

[35] 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.

[36] 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 Telecommu-*

nications Technologies (ETT), page (in print), 2014.

[37] 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.

[38] B. Predic, Z. Yan, J. Eberle, D. Stojanovic, and K. Aberer. Exposuresense: Integrating daily activities with air quality using mobile participatory sensing. In *Pervasive Computing and Communications Workshops (PERCOM Workshops), 2013 IEEE International Conference on*, pages 303–305, 2013.

[39] A. Purohit, Z. Sun, F. Mokaya, and P. Zhang. Sensorfly: Controlled-mobile sensing platform for indoor emergency response applications. In *Information Processing in Sensor Networks (IPSN), 2011 10th International Conference on*, pages 223–234, 2011.

[40] A. Sashima, Y. Inoue, T. Ikeda, T. Yamashita, and K. Kurumatani. Consorts-s: A mobile sensing platform for context-aware services. In *Intelligent Sensors, Sensor Networks and Information Processing, 2008. ISSNIP 2008. International Conference on*, pages 417–422, 2008.

[41] X. Sheng, J. Tang, X. Xiao, and G. Xue. Sensing as a service: Challenges, solutions and future directions. *Sensors Journal, IEEE*, 13(10):3733–3741, 2013.

[42] W. Sherchan, P. Jayaraman, S. Krishnaswamy, A. Zaslavsky, S. Loke, and A. Sinha. Using on-the-move mining for mobile crowdsensing. In *Mobile Data Management (MDM), 2012 IEEE 13th International Conference on*, pages 115–124. Mobile Data Management (MDM), 2012 IEEE 13th International Conference on, 2012.

[43] A. Shirazi, C. Winkler, and A. Schmidt. Sense-sation: An extensible platform for integration of phones into the web. In *Internet of Things (IOT), 2010*, pages 1–8, 2010.

[44] T. Starner. Wearable computing and contextual awarenes. Technical report, 1999.

[45] Y. Sun and K. Nakata. An agent-based architecture for participatory sensing platform. In *Universal Communication Symposium (IUCS), 2010 4th International*, pages 392–400, 2010.

[46] H. Sundmaeker, P. Guillemin, P. Friess, and S. Woelffle. 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].

[47] D. Trossen and D. Pavel. Nors: An open source platform to facilitate participatory sensing with mobile phones. In *Mobile and Ubiquitous Systems: Networking Services, 2007. MobiQuitous 2007. Fourth Annual International Conference on*, pages 1–8, 2007.

[48] D.-L. Yang, F. Liu, and Y.-D. Liang. A survey of the internet of things. In *International Conference on E-Business Intelligence (ICEBI-2010)*, Advances in Intelligent Systems Research, pages 358–366. Atlantis Press, 2010.

[49] A. Zaslavsky, P. P. Jayaraman, and S. Krishnaswamy. Sharelikescrowd: Mobile analytics for participatory sensing and crowd-sourcing applications. *2013 IEEE 29th International Conference on Data Engineering Workshops (ICDEW)*, 0:128–135, 2013.

[50] 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.

[51] L. Zhang, Q. Wang, and X. Shu. A mobile-agent-based middleware for wireless sensor networks data fusion. In *Instrumentation and Measurement Technology Conference, 2009. I2MTC '09. IEEE*, pages 378–383, 2009.