Sensor Networks:
Enabling the Sensor Web and Facilitating Data Fusion

J G Foley† and G E Churcher‡

† University College London, ‡ British Telecommunications Plc

Abstract: This paper provides a summary of the work carried out by BT Research over the last three years while investigating Generic Sensor Network Architectures and Sensor Web Enablement (SWE). An overview of SWE and Complex Event Processing (CEP) is provided. In addition, the SAPHE and BRIDGE projects are discussed, which have served as case studies for the application of SWE specifications or CEP techniques.

1. Introduction

Since there was a wealth of BT projects covering a range of innovative sensor network deployments, this provided the inspiration for the author's EngD topic. While at BT Research, we began to examine generic architectures which could be reused on a number of sensor network projects ranging from healthcare to RFID. Rather than continuing to design bespoke solutions for every individual project, the idea was to design a reusable architecture which enables plug-in elements and interfaces with diverse sensor networks and enables data fusion.

We learned that projects such as AFIS (Advanced Fire Information System) [1] and SANY (Sensors Anywhere) [2] had adopted Open Geospatial Consortium (OGC) [3] standards to achieve their objectives. Therefore, we investigated Sensor Web Enablement (SWE) [4] and applied the specifications to the SAPHE (Smart and Aware Pervasive Healthcare Environment) [5] project. We also examined alternatives such as Nortel's Sensor Dispatch System. In addition, we examined Complex Event Processing (CEP) to ascertain if it could be used to filter sensor data obtained.

2. Sensor Web Enablement

Under BT Research, we participated in a number of sensor network projects covering a wide range of domains from Telecare through to environmental monitoring (SECOAS) [6], traffic management (Traffimatics) [7], and radio frequency identification (BRIDGE) [8]. This led to our interest in SWE from the OGC as a possible component for the virtualization of sensors as part of BT's strategy for building a more generic sensor network architecture with reusable components for diverse sensor network projects. In particular, we investigated the SWE standards for the Sensor Observation Service (SOS) and Sensor Alert Service (SAS) [9] and how they may be applied to one of our existing sensor network projects, SAPHE. SAPHE is a Telecare project which assists the elderly and infirm to continue living independently. Telecare relies on non-invasive monitoring by healthcare professionals using intelligent, low power sensors deployed around the home and/or body worn sensors, depending on the patient's condition. Telecare is increasingly seen as the solution to the ageing population and the limited number of healthcare professionals. Thus, SAPHE enables people to look after themselves in their home and only alert community matrons when required, prior to an emergency. Healthcare professionals access the SAPHE Web portal via a PDA to monitor the condition of their patients, which may be classified in virtual wards as green, amber or red priority.

In 2007, while engaged in BT Research's Sensor Virtualization theme, we began by attending the SWE workshop organised by the SANY project consortium at the University of Muenster. Following this event, BT organised a workshop at Adastral Park led by Dr. Ingo Simonis and SWE developers from 52 North [10] to apply the SWE specifications to the SAPHE project architecture. This was a useful exercise and the findings were published at ISWPC 2008 [11].

SWE was also evaluated during another BT project, BRIDGE (Building Radio frequency IDentification for the Global Environment) which aims to resolve the barriers to the implementation of RFID in Europe. “The EPC Network [12] and the SWE architectures are chosen due to their leading position in supporting two different technologies: Networked RFID and Web based sensor systems”. BRIDGE trialled a SWE installation for their Supply Chain scenario. Therefore, it may be possible for projects as diverse as Telecare and RFID to share sensor data and enable data fusion and inferencing, especially if they both use the SWE specifications, such as SOS and SAS. For example, a hospital could use sensor data regarding current stock levels to proactively reorder medical supplies based on patient needs or even according to real-time data supplied by ambulances whilst attending emergencies in readiness for when they return to the hospital. This kind of futuristic scenario has been illustrated by the “Fire in a Road Tunnel” video produced by the RUNES [13] project.

3. Generic Sensor Network Architectures

BT Research began to examine generic architectures which could be reused on a number of sensor network projects ranging from healthcare to RFID. Rather than continuing to design bespoke solutions for every individual project, the idea was to design a reusable architecture which enables plug-in elements and interfaces with diverse sensor networks. The design of generic architectures was envisaged to ensure a minimal overhead in new projects and the growth of new applications that benefit from incremental investment due to component re-use.

During EuroSSC 2007 [14] we presented a poster entitled, “Recent Developments in the Design of Sensor Network Architectures”, which provided an overview of a number of BT sensor network projects and how they may be able to share sensor data via a conceptual architecture. This research was further explored when investigating context architectures with Dr. Eliane Bodanese at Queen Mary, University of London.

Prior to researching Information Networking techniques such as cloud computing and Solace Systems’ content networking routers, we examined how SWE could be extended with Complex Event Processing (CEP).

4. Complex Event Processing

The research evolved to capturing, filtering and processing potentially hundreds or thousands of sensor readings, so we identified complex event processing to enable us to handle and filter the sensor data. These developments were described in our paper presented at COMSWARE 2009 [15].

An example CEP engine, Esper [16] was investigated with the view that the application of CEP to the SAS service may result in a number of benefits to sensor network architectures and to SAPHE in particular. CEP offers the ability to aggregate and correlate large volumes of events through the real-time processing of continuous queries and apply event pattern matching using logical and temporal event correlation, and window views. The paper highlights our experiences with SWE and exemplified how it can be retrofitted to an existing health care application. Whereas, the supply chain scenario in the BRIDGE project provides another example of where the SWE specifications may be applied. Also, where potential improvements to services such as the SAS can be made to extend the functionality of sensor network applications in general and facilitate data fusion.

As explained in the COMSWARE paper, the Sensor Event Interface Specification [17] is an enhancement to the SAS and introduces capabilities similar to CEP. Therefore, the SWE specifications appear to be developing inline with our research ideas.

5. International Summer Schools

In addition, our research ideas have been presented and well received at a number of international summer schools focusing on sensor networks. They have included Senzations 2007 [18], MCANAE

2008 [19], and SENIOT 2009 [20] and all were organised by some of the leading sensor network experts.

6. Conclusions

This paper has briefly summarised our research into generic sensor network architectures, SWE and CEP to enable sharing of sensor data across diverse sensor network platforms, in order to re-use components and to facilitate data fusion.

Creating SWE services offers a number of generic advantages and some specific to this type of application where local processing could prove advantageous. SWE offers a standardized protocol for discovering and accessing sensor data which enables data to be reused in potentially new and novel ways. An application could simply repurpose sensor data for another domain, or fuse together data from several services to provide radically different applications. Standardizing on the access mechanism and the data model for the sensor data conveys advantages to the application developers as there are a growing number of 3rd party tools that facilitate access, analysis and visualization of data, reducing the time to develop new applications and facilitating innovation.

SWE services can exist anywhere in the architecture between the sensors and the applications that utilize their data. Specific to SAPHE and similar sensor network architectures, placing the SWE services at the local level could reduce real-time bandwidth requirements. An SOS archives sensor data in a common data format allowing applications to query and retrieve data as appropriate. An SAS would be able to offer basic analysis of sensor data, publishing an alert or data fragment to subscribing applications. An application could then use the SOS to access relevant data when appropriate rather than receiving data in real-time for analysis.

Indeed we are a long way off seeing a generic, reusable sensor network architecture and being able to connect the world of sensors via a sensor web. However, the research has identified the benefits and high-lighted the possibilities of technology, such as SWE specifications, which is still in its early stages of development. However, we were able to help to extend the specifications, since mobile features of interest were required for the SAPHE project (e.g. body-worn sensors such as heart-rate monitor), not just the static sensors deployed within the home.

Discovery of sensors relies on accurate and timely catalogue registration. Whereas, control of sensors depends on their primary purpose and related security constraints. For example, weather data is freely publishable (due in some part to low accuracy rates) as opposed to military sensor system data or medical sensor data, which are highly classified, or sensitive patient data respectively.

Complex event processing has certainly proved to be feasible technology to interface with sensor systems in order to capture, filter and process real-time sensor data.

Finally, intelligent sensor deployments may have helped to avert or reduce the impact of the ongoing BP Oil Crisis in the Gulf of Mexico. Monitoring and predictive maintenance as used by utility companies (such as Severn Trent during the PIPES [21] project) may have led to early (proactive rather than reactive) leak detection and containment. Although, it’s difficult to guarantee that sensor deployments would be adequate due to the scale of the oil rig and harsh operating conditions in which oil refineries operate.

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