SensorWeb Semantics on MQTT for responsive Rainfall Recharge Modelling

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Abstract

Integrating Wireless Sensor Networks (WSNs) and spatial data web services is becoming common in ecological applications. However, WSNs were developed in application domains with different sensor and user types, and often with their own low-level metadata semantics, data format and communication protocols. The sensor web enablement initiative (SWE) within the Open Geospatial Consortium (OGC) has released a set of open standards for interoperable interface specifications and (meta) data encodings for the real time integration of sensors and sensor networks into a web services architecture. Such XML-based web services exhibit disadvantages in terms of payload and connectivity in low-bandwidth low energy unreliable networks, such as remote 3G uplinks. Monitoring stations deliver frequent measurements in real-time, but dynamic implementation of measurement frequencies, adapted to certain environmental conditions, are rarely implemented. Within this paper we describe a responsive integrated hydrological monitoring setup to calculate rainfall recharge for water management purposes. When rainfall is observed, a threshold event triggers a reconfiguration task for the soil moisture sensors, using asynchronous, push-based communication implemented with an MQTT queue. A Sensor Planning Service commits that request via MQTT into the wireless sensor network, and updates the measurement frequency of the target sensors to gain higher resolution for the vertical soil water infiltration. The system integrates a Sensor Observation Service (SOS) including field observations and internet-based environmental data with a rainfall recharge model that allows near-real time calculation of rainfall recharge in the Upper Rangitaiki catchment, Bay of Plenty region in New Zealand.

Keywords: OGC SWE, modelling, MQTT, sensor networks, hydrology.

1 Introduction

Environmental assessments naturally depend on field observations and technological advancements. Telemetry allow the automated collection, transmission and processing of these measurements. However, modelling of natural processes is typically a complex challenge and involves applying expertise of scientists as well as a host of data preparation steps [12]. In addition, automation of model execution with the most recent observation data is dependent on the integration of the data collection, storage and processing elements [9].

Wireless Sensor Networks (WSNs) are capable of monitoring and management of a large set of environmental data such as climatic, atmospheric and soil parameters in real-time. Sensor data collection is used for accurate illustrations of current conditions whilst also enabling prediction and forecasting of future conditions. The implementation of sensor networks combined with wireless communication networks are becoming affordable and reliable to measure parameters for agriculture and regional water management [6, 11].

The power management in sensor devices is essential for effective and reliable network operation. The WSN can also communicate to the outside world by means of GPRS/3G. For situations with difficult wireless connectivity such as mines each sensor device can store large number of sensor measurements in its SD card memory.

To enable a place independent sampling and real-time analysis for a rainfall recharge model wireless sensor network and Spatial Data Infrastructure (SDI) integration have been described by [8, 10]. Bidirectional sensor uplink methods have also been proposed by [5, 7]. They present a sensor network architecture that is controlled centrally and integrates a Wireless Sensor Network's (WSN) network stack with the publish/subscribe messaging middleware MQTT-S (Message Queue Telemetry Transport). MQTT is a publish/subscribe message passing system, developed for inherently unreliable networks and also increasingly popular for the Internet of Things (IoT) applications. MQTT has been suggested as a suitable bidirectional transport protocol for wireless sensor networks following the message queue pattern [4].

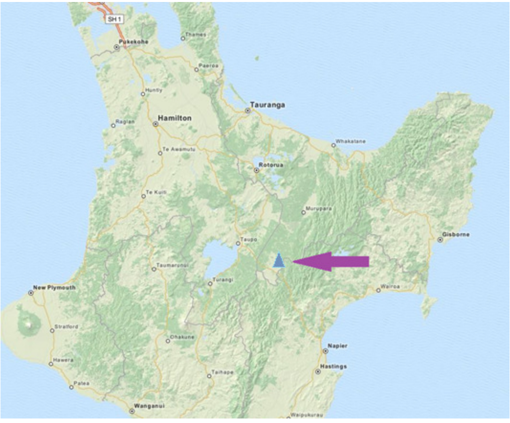
The Open Geospatial Consortium (OGC) provides a set of standards that enable an integrated architecture, linking domain of sensor networks into an SDI through the Sensor Web Enablement initiative (SWE) [1]. Message encoding within SWE services is defined in the specifications for OWS Commons (OGC Web Service Commons), SWE Common Data Model Encoding, Observations & Measurements (O&M) and SensorML. The sensor web standards have been exhaustively described [2]. O&M is a generic flexible application schema for the encoding of observation data and time-series, whereas WaterML2.0 is an encoding that extends O&M and has been specifically created for hydro-climate observations and time-series. Sensor descriptions, configurations, and capabilities can be expressed in SensorML. Main interfaces for data transmission and interaction with sensors and actors are the Sensor Observation Service (SOS) and the Sensor Planning Service (SPS). The OGC Web Processing service (WPS) provides a flexible toolbox design that enables exposure of scientific codes via open standards [3].

In this paper we describe a prototype system that integrates a Sensor Observation Service (SOS) for incoming field observations, a Sensor Planning Service (SPS) for field sensor reconfiguration tasks via MQTT transport, and an internet-based rainfall recharge model, realised as a Web Processing service (WPS), that allows near-real time calculation of rainfall recharge in the Upper Rangitaiki catchment, Bay of Plenty region, New Zealand.

2 Methods and Materials

The Upper Rangitaiki hydro-climate sensor station is situated in the Upper Rangitaiki catchment in the central North Island of New Zealand (Figure 1) and co-located with a commercial grade regional government (Bay of Plenty Regional Council) climate monitoring station (Rangitaiki at Kokomoka, elevation 760 m) for comparison purposes. The Kokomoka station measures rainfall, soil moisture, soil temperature and groundwater recharge in lysimeters.

Figure 1: Location of the sensor field site, central North Island, New Zealand.



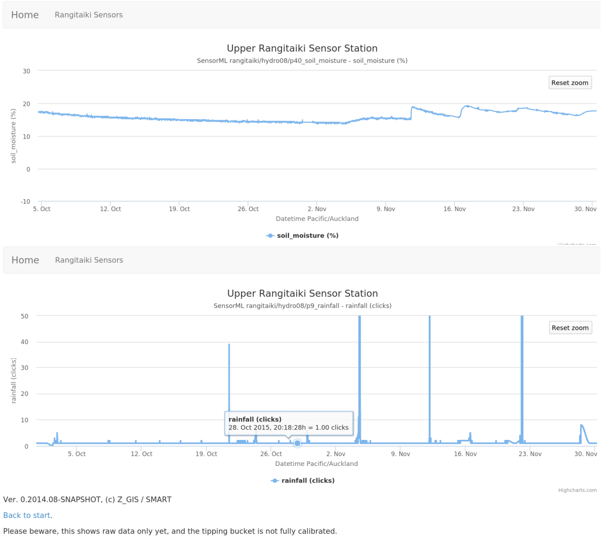
The prototype site comprises a main station conducting comprehensive measurements of meteorological, hydrological and pedological parameters. For the wireless data transmission within the local site installation XBee-PRO modules from the Digi Company ZigBee IEEE 802.15.4 protocol are used. The main station receives continuous sensor measurements from the attached sensor units, and acts as the gateway to the online SOS and SPS services by providing the communication channel from the local sensor network to the web-enabled data management infrastructure.

2.1 Sensor deployment at the fields site

The field site has been established in the Upper Rangitaiki catchment (Figure 1) and comprises a field computer (Raspberry Pi) with a direct internet link (GPRS/3G) and a sensor board (Waspmote) that has 12 typical meteorological, hydrological and pedological sensors attached (i.e., wind speed, wind direction, rainfall, 1x groundwater probe, 5x temperature and 3x soil moisture). The Raspberry Pi and Waspmote can be monitored and reprogrammed from an online server. The site setup allows scaling up to a multitude of low cost, low energy sensor stations throughout the catchment, with only one field computer that serves as data logger for backup.

The greatest advantage is the direct linkage of the collected SOS data into a hydrological model. In this prototype, a simple rainfall recharge model is used for demonstration purposes; the model is driven by the SOS field observations. This model, which covers 7.5 km^ of the Otangimoana Stream sub-catchment, uses 10 minute observations of rainfall, soil moisture and wind direction to calculate key environmental variables associated with groundwater resources (e.g., rainfall, soil moisture, groundwater recharge) at four intervals (i.e., 10 minute, daily, weekly and seasonal). That can be aggregated into summary information (e.g., groundwater recharge over various intervals) and are exposed via web-based spatial data provisioning and web processing services.

Figure 2: Raw sensor series visualized in a website from a SOS query.



Ver. 0.2014.08-SNAPSHOT, (c) Z_GIS / SMART

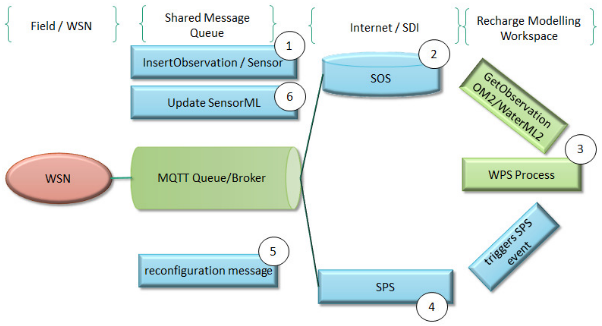
Back to start.

Please beware, this shows raw data only yet, and the tipping bucket is not fully calibrated.

2.2 Sensor web services orchestration

The central field computer (a Raspberry PI gateway) is equipped with a 3G / GPRS modem and a SIM card and manages the XBee radio, logging received sensor measurements to the local database before relaying the observation data further to the online SOS server. The sensor network management framework is linking the field computer via an MQTT broker to the SDI. The received observations are inserted into the SOS server and immediately accessible via well-known SWE semantics (e.g. SOS GetObservation). The field station receives sensor reconfiguration messages via SPS tasking messages on the MQTT queue. Both SWE SOS and SPS are linked on the same MQTT queue as show on the process diagram in Figure 3.

Figure 3: Process diagram, field observations via SOS, recharge model as WPS, tasking via SPS



The data and sensor management is based on SWE semantics and data access is provided via SOS directly, a web portal or a mobile application. Addressing and data transmission is done by a topic string and an arbitrary payload implementing SWE semantics for observations (SOS/O&M), sensor configuration (SensorML) and planning (SPS tasking). The topic string and the payload reflect the OGC operation and allows for a seamless bidirectional communication between the WSN and the SDI. Table 1 lists exemplary translation of OGC SWE operations to the MQTT topic string.

Table 1: Exemplary mapping of SOS and SPS on MQTT

SWE Operation	MQTT Topic
os:InsertSensor request	sos/insertSensor /sensorweb1337
sos:InsertObservation request	sos/insertObservation /sensorweb1337
sps:DescribeTask request	sps/describeTask/ /gateway0013A20040BA2318
sps:Submit request	sps/Submit/ /gateway0013A20040BA2318

3 Results

The capabilities of the environmental modelling system were demonstrated by the rainfall recharge model of part of the Otangimoana Stream sub-catchment. The Raspberry Pi, running a standard Linux operating system, transferred observation data in 10 minute intervals via a 3G mobile data connection to an online SOS server (Figure 3, #1 and #2). The Waspmote, a microprocessor and a custom circuit board with the sensors connected to it, has collected data and forwarded this data to the field computer in configured intervals via robust, low power, ZigBee wireless protocol. When rainfall was observed server (Figure 3, #3) the measurement frequency of the energy-intensive soil moisture sensor was increased to 5 minute intervals with a subsequent longer run of about 1 hour after rainfall stopped. The observations were available in a standardized open format. The website accessed the raw data from the SOS server and plotted data points within 5-10 minutes of field measurement. This website was easily accessible via browsers and smartphones (Figure 2).

We showed that it is possible to link the collected data directly to a simple rainfall recharge model. This model runs with the latest data points from the online SOS server(Figure 3, #3). The implemented infrastructure regularly pushes environmental data into the SOS via the shared MQTT queue(Figure 3, #1, #2). A WPS process regularly retrieves the latest rainfall observations and accumulates over the configured time period to calculate current rainfall recharge(Figure 3, #3). It also emits a reconfiguration event via the SPS when a rainfall is observed or respectively the rainfall is not observed within the fallback time period (Figure 3, #4). The SPS tasking message then reconfigures the field computer(Figure 3, #5) and updates the SensorML to reflect the configuration change(Figure 3, #6).

4 Discussion and Conclusion

The real-time monitoring system and web-based information system are designed for use by decision makers. With the leveraging of the established OGC Sensor Web Enablement standards, and the reliability, performance, efficiency, and robustness of the MQTT protocol, Wireless Sensor Networks can be linked directly to environmental SDIs and web processing services for online data access, modeling and sensor configuration. A specificity of environmental sensor networks is their requirement for low energy consumption and often the constraint of low uplink bandwidth. Reversely, radio or wireless transmission is a very energy consuming action. The differences in information transport and connection handling of HTTP in comparison with MQTT needs to be verified and validated in detail with respect to energy consumption. While the technical infrastructure has been tested reliable, the continuous field measurements have not been cross-validated with the co-located commercial grade sensor station yet.

The integrative capabilities of the SOS system were tested with a rainfall recharge model of part of the Otangimoana Stream catchment. Potential benefits of the system for water management will be described including the availability of more dynamic water management practices where data and modelling results are available, almost immediately, to the user.

We could show that the implemented message passing infrastructure is effective to allow for high level OGC SWE semantics on a low-level message transport protocol. The convergence of SDI, sensor web, and message passing can be seen as an important step towards a robust and efficient implementation of the Internet of Things. A new OGC standard, the SensorThings API, has been released recently. Here observations and (aka sensing) are implemented on MQTT in a new conceptual design, which deviates from the classical SWE SOS and SPS model. The data handling in the SensorThings API exposes a preference for data streams rather than single rich metadata observations. Furthermore, with the observation part (aka part 1: sensing) being released, the planned parts 2 and 3 (tasking and notifications) are also being envisioned as remodeled concepts of existing OGC standards.

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