An "Internet of Things" Vision of the Flood Monitoring Problem

Massimo Ancona*, Andrea Dellacasa*, Giorgio Delzanno*, Andrea La Camera* and Ivano Rellini†
*DIBRIS, University of Genoa
Genoa, Italy
Email: {massimo.ancona, giorgio.delzanno, andrea.lacamera}@unige.it, andrea@dellacasa.org
†DISTAV, University of Genoa
Genoa, Italy
Email: rellini.ivano@dipteris.unige.it

Abstract—**River flood monitoring is a complex problem of maximum social relevance in densely inhabited areas. Flash floods are becoming more and more dangerous every year due to an increase of rapid and extreme rainfalls events induced by climate changes, particularly in Genoa: the rivers flooded twice in twenty days in two different parts of the town. The complexity of the problem originates from the diversity of the territory involved in the monitoring process in regions like Liguria in Italy: from relatively far mountains (or plain regions) generally scarcely populated, to densely populated urban areas traversed by streams, often flowing underground. Environmental monitoring is classified at the 14th position among the Top 50 "Internet of Things" (IoT) applications for a Smarter World. IoT is an emerging paradigm that combines the main features of Cloud Computing (pervasive capability of storage and computation via Internet) with wireless sensor networks that provide cooperative use of distributed sensors. In addition to these features, IoT often provides interfaces for data streaming management in real-time, back end for data analysis and visualization. A IoT approach to the considered problem seems almost necessary in order to improve the integration level of the data, sensors and applications and provide software tools for cooperation of heterogeneous groups of end-users involving institutions with different level of responsibilities, knowledge and capabilities (from sensor experts to non-expert citizens). In the present paper, we redesign previous experiences based on intelligent wireless sensors network (WSN) in terms of IoT with the aim of improving its reliability and efficiency and especially of rendering the problem widely scalable.**

Keywords*–*Internet of Things; Communication networks; Stream; Flood; Sensor systems.

I. INTRODUCTION

Flood monitoring is a particularly challenging application for Internet of Things (IoT). In fact, it offers a complex scenario for the variety and number of sensors involved, their location and relative communication problems. The type of sensors involved in the process and the corresponding type of installation depend on the kind of collected data and on their geo-localization (i.e., urban areas, where powering and communications are relatively simple, or in remote and difficult to access mountainous or country locations). The kind of data collected ranges from rain monitoring to river gauging with several parameters to be monitored and compared. In the case of rivers, the problem depends on their size and dimension and geography of the region where they flow, if they are small creeks or wide rivers, if they flow in a steep or flat area, in open air or are channeled underground, etc. From this point of view, we already activated different collaborations and definitions of common goals with public administrations involved in the management of the experimental areas. To this aim, we designed a general hardware and software IoT infrastructure and architecture applicable to the environmental problem mentioned above, but extensible to the more general problem of monitoring the environment in densely inhabited areas.

Our research will be an element of great importance to train specific risk management and to deliver elements of innovation and encouragement for the definition of land management strategies both on the local and regional scale. Moreover, this research will help to provide knowledge and tools for effective decision making and public engagement. In particular, we detail the sensor classes (their design for the new ones), their communication mechanisms and associated software services as components of a general IoT infrastructure. The aim is to monitor either rainfalls, river discharge and their temporal correlation in order to obtain early alarming information. In our IoT approach, all collected data will be continuously transmitted, through the Internet communication infrastructure, to software components designed to compute the stream-flow and to quantify the spatial distribution of flood risk for each controlled watershed. The computed risks, together with data coming from other sources (barometric and river discharge sensors, cameras operators of public organizations, emergency agencies, private citizens), will be examined by a diagnostic decision system implementing a risk-alert scheduling strategy, able to diagnose the health state of the controlled environment and to define specialized alarm levels for each potentially interested area. Finally, the computed risks will be used for specializing alerting messages, to be sent to all citizens (ubiquity) present in each selected area only (alerting locality).

The interaction between instrumental data with other sources of information, including people, is another objective of our research. A connected aspect of the problem is the complexity of alarming organization and broadcast mechanism deriving from the inherent uncertain and aleatory nature of the estimates that strongly affect the management of related information [1][2], while the interaction of instruments with other sources of information, including people, is another objective of our research. In this paper, we present an approach based on intelligent WSN [3] in terms of IoT. Our research is intended for improving its reliability and efficiency and especially for rendering the problem widely scalable, from small towns to medium and large cities. In Section 2, we describe the different kind of sensors, and in Section 3 we present sub-1GHz network and standardization. Section 4 is dedicated to software needed to run the system. We summarize the conclusions in Section 5.

ISBN: 978-1-61208-421-3

II. SENSOR EVOLUTION TOWARDS AN ULTRA-LOW-POWER ARCHITECTURE AND M2M CONNECTION TO SUB-1 GHZ IOT NETWORKS

The early warning information is represented by rainfalls estimation and weather forecasting in a given stream basin. Flash-flood monitoring requires rainfall control at a dense spatial grid (1 km or finer) and frequent time-scale intervals (15-30 min, and even less in urban areas) [4]. Our analysis is based on the above assumption that impacts the kind of sensors considered, their communication mechanisms and management software. The kind of sensors for a near real-time control should be maintenance free, i. e., free from mechanical moving parts. Moreover, they should communicate via the Internet via a machine to machine (M2M) technology, which is typical in the IoT implementation, adopting an ultra-low-power management system, in order to operate for months from remote areas, supplied by small batteries. Note that the proposed IoT architecture can be extended (by replacing the specific sensors) to other environmental problems, e.g. for controlling landslides, another critical aspect of a territory. Legacy sensors are not ready for the IoT revolutions, because of power consumption, lack of wireless communications, and costs.

A. Rain gauges

If we consider a spatial sensor grid of 1 km the number of gauges installed grows as n^2 requiring 100 gauges for a grid of 10 km^2, a very high number raising cost and network complexity. This approach requires very cheap and reliable gauges. Cost reduction suggests to consider non mechanical (i. e., with no moving parts) rain gauges to reduce the need of ordinary maintenance of devices often installed in remote areas. The market is offering several kinds of devices: optical, ultrasound and based on other measuring principles, but generally they are not designed for ultra-low-power applications and Internet access in an IoT M2M connection. Thus, we have to shield them with an ultra-low-power microprocessor unit (MPU: a computer processing unit in a single integrated circuit), a technique used by Arduino and other MPU-based devices [5] for interfacing with peripheral accessories. Optical rain gauges (ORG) are able to provide ultra-fast real-time data about precipitation rate, with minimal maintenance, high reliability and sensitivity, We found both high precision (3%), power hungry (12V 1A, or direct AC power line connection), costly devices (5-7 k$), like the Osi 815-DS [6] and the All Weather Inc. 6030 [7]; and low power, low cost devices (50$), like the Hydreon RG-11 [8]. In the last case, errors usually are small (around 6% in mean) but not granted, and in some (rare) cases they could reach 30%. There exist also low cost, accurate ultrasound and electronic gauges; although they empty themselves automatically, they do not require adjustments and do not use moving parts. In conclusion, we can find on the market several adequate rain gauges, but we have to shield them with an ultra-low-power MPUs board (see Figure 1) for long-time, low power (and long distance) applications, when gauges are installed in remote areas. ORG are the more promising devices for several reasons: they are fast and maintenance free, they can measure true rain rate and no other gauge comes close to their performance and precision. Nowadays one of the main applications of low cost ORG is the automatic control of car wipers: for marketing reasons this devices will be rapidly improved in the next few years. Almost all devices communicate via a serial RS232 or 485 interface. The RG-11 drains 15mA nominal at 12V DC input, but can be operated also in a slightly less sensitive micro-power mode that can be set which should allow operation from a 9V battery at 1.5mA current draw. It does not guaranties a strict accuracy value below 28-36% of a tipping bucket, but much of the time it will read very close to it. The RG-11 is great for qualitative measurements versus quantitative, i.e., you will know when there is a heavy rain rather than a light mist but not an exact amount of rain, in other words, it is well suitable for our scope. By installing a large number of low cost devices alternated with few high precision gauges we may grant, through statistical corrections, a good precision at an acceptable cost.

B. River Gauges

The river gauging problem is more complex than the rain gauging for its intrinsic complexity: most of the short stream crossing Liguria and other similar hilly regions have an almost binary behavior. Their flow is extremely small or null for a large part of the year, while suddenly it becomes very impetuous for short time periods during October and November rain storms. This behaviour often generates disastrous flash-floods. During rain storms periods, floods eradicate trees, rocks and instruments working immersed in the water flow and they tend to modify their bed often in a remarkable way by transporting stones and trees that could obstruct their flow in a stable way. Generally, the flood phenomenon (flash-flood) lasts for few hours and produces incredible disasters. In these conditions, the river gauging problem represents one of the most critical part of our research and is, in large part, still an open problem. The available gauges on the market present several restrictions on their applicability. Also in this case, we limit our attention to non mechanical (i.e., with no moving parts) gauges for maintenance purposes. Moreover, we restrict our attention to devices not operating immersed in the stream, because their expected survival should be very short. There are some gauges that implement, in a single device like the Marsh-McBirney Flo-Dar [9]area/velocity flow meter, both measurements of water level and of flow velocity in order to compute stream flow. Their present limit is that they should be mounted above the flow at 1-3 m distance (optionally extensible to 6 m, which is a safe limit for our cases). New approaches based on particle imaging velocimetry (PIV) that give an accurate flow measurement, are appearing in literature. A promising approach based on PIV gauges is proposed in [10] where a digital camera installed on a roof of a building at 14 m above the river level and with an incident angle of 60^o provides a maximum error of 38.8% while its mean error is only the 5%. We plan to extend a PIV gauge with a small Light Detection And Ranging (LIDAR) (or two micro-cameras) for computing distance and reconstructing a 2D section of the bed of the controlled stream during the long no-raining periods when the stream is near empty. As an alternative, we could use a drone for reconstructing the complete section of the stream in all its extension during a single or few drone flies, but this approach requires operator's intervention.

C. Integrating gauges in an IoT hardware communication architecture

Most of the gauges offering the best precision are often power hungry devices, a defect limiting their installation in remote locations where power and network are not present. Indeed a precise information derived by a well distributed set of gauges could have a higher impact on the whole acquisition system (following a well geo-located gauge network) [4]. In this case, the IoT technology offers the best solution for ultra-low-power energy use and communication continuity in locations uncovered by power and communication lines. The IoT approach, while minimizing power consume, offers the advantage of making gauges able to communicate each-other via Internet in M2M communication mechanism satisfying an anything-anywhere connectivity framework independently from the availability of power systems and network access. The access to the Internet rises security problems that at an early research stage have a lower priority than the requirements of minimum power consumption and communication continuity. Because most of the rain and river gauges available today are not designed for power saving, the IoT based shielding approach, shown in Figure 1, solves this problem. A sensor is activated only for the minimum time needed for making a measurement, while the ULPM (Ultra-Low Power Micro-controller) together with other power control circuits manages the sleeping versus active state between two successive measurements.

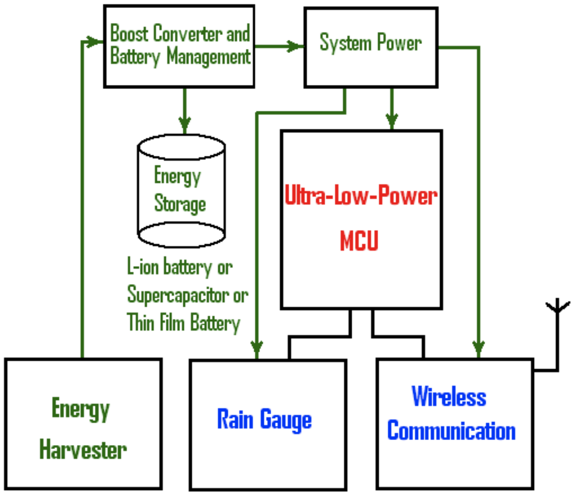

Figure 1. Gauge shielding architecture

In Figure 1, the sensor shielding architecture is composed by the sensor itself, a ULPM, a buck converter (e.g., tps62740 or lt3757a) a boost charger (e.g., bq25504) and a ultra-low-power wireless communication sub-system (e.g., Texas Instruments CC3100 for Wi-Fi connection to the Internet).

III. The Sub-1GHz Network and Relative New Standards

For covering a wide variety of cases, in different parts of the environment with different communication requirements, the network must adopt different wireless communication standards to support M2M connections between two connected devices, without the assistance of a human. Here, we mention the more likely to be used: Wi-Fi technology, based on the IEEE 802.11, today represents the widest wireless protocol adopted for short distances (100 m). Wi-Fi is so intimately integrated with the TCP/IP that the Wi-Fi term implicitly mean that they are also using a TCP/IP for Internet connectivity. Finally, the new *Weightless* (expressly designed for M2M communications), the IEEE 802.11ah and the IEEE 802.11af standards, all operating in the Sub-1GHz (together with many proprietary radio systems, and other well established standards yet working in the Sub-1GHz bands) are on the way [11]. They are capable to transmit over several km within a simple point-to-point or star topology all performing with an extremely low power consumption. To connect to the IoT, Sub-1 GHz systems require an application-layer Internet gateway that, in our case, is provided by the ultra-low-power MPU shielding every sensor and including the communication device itself (e.g., CC3100 or CC430).

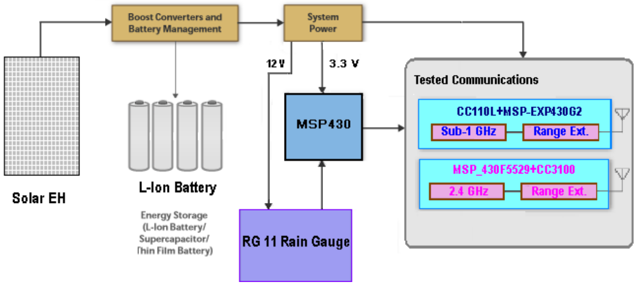

Figure 2. Implemented sensor node configurations

Figure 2 illustrates two configurations we have implemented for low power remote IoT/M2M connections. The CC3100 supports Wi-Fi short range connection, while the TI CC110L implements a long-range Sub-1GHz M2M wireless connection providing a ultra-low-power several km (up to 10-25) connectivity with the CC1120/CC1200 [12]. The Sub-1GHz frequency range is very suitable for rural regions [11].

IV. Software Infrastructure

Software requirements for IoT sensors node networks presents several challenging problems [13][14]. The system is widely distributed and able to orchestrate a wide variety of smart sensors, supported by energy harvesting mechanisms and managed by ULP-MPUs. The system follows an event-driven architecture centered on near-real-time asynchronous communication and control mechanisms [15]. The sensor shielding approach suggests a 2-tear structured network to the more common 3(or n)-tear layered architecture. Fault-tolerance is another fundamental requirement, because controlling a single event requires continuous and autonomous inter-device communication. The global interaction cannot be interrupted and must remain operational especially during stormy weather days, when it is required to be continuously operative. Collected data should be correlated in real-time for computing the lag time that is the time occurring between a rainfall peak and the corresponding expected discharge peak.

A. *IoT Platforms*

The sensor components are designed to be integrated in a IoT software platform built for integrating different types of services, sensors and data that could be used for improving the quality of social and environmental services of urban areas. An ideal IoT platform for our application domain should provide the following components:

- A device management component to handle registration of new devices, assignment of unique identifiers, format data, etc.
- Sensor services to provide interfaces to interconnect in a secure way heterogeneous information sources.
- Storage services to persistently store data.
- Analytic services to provide both predefined and customizable procedure to elaborate stored and real time data streams.
- Visualization services to disseminate collected data using different formats like visual diagrams, reports, graphs, etc. For the considered type of application, it is also important to consider georeferenced data dissemination of alarms and notifications.
- Application and user management to handle in a secure way registrations of users and of new applications that extend the functionality of the system.

For instance, alarms used in flood monitoring require real-time processing of data and rapid responses to public organizations. Furthermore, they require tight integration of data coming from very different sources (from sensors to sms sent by citizens via crowd sourcing applications). Another important aspect is the possibility of extending the set of available services with new components that could exploit the data collected by the system. Last but not least, there is the problem of taking the alarming decision based on flood forecasting and weather predictions methods [16].

Existing platform like Axeda [17], Thingworx [18], Thingsquare [19], Eclipse M2M [20], and Xively [21] provide powerful tools for setting up complex applications that combine data integration, analysis, and visualization. For instance, Thingworx provides a composer tool that helps the designer to set up a dashboard with graphical widgets to visualize the results of analysis of data coming from external services. Thingworx marketplace can be used to download and install additional packages, e.g., Google Maps widgets, device drivers, and database management system (DBMS) connection libraries. Platforms like Kaa [22], Kinoma [23], M2MLabs [24], Arduino provide similar features in an open source environment.

V. CONCLUSIONS AND FUTURE WORK

Flash flood alarming systems require a dense network of rain gauges for monitoring intense local rain storms both to ensure its survival in case of extreme weather and to have a more accurate collection of data. Those data have to be interpreted by means of empirical and formal models by correlating in real time the river level and the flow intensity for early flood forecasting and consequent anticipated alarming. The number of required sensors, their communication mechanisms and reliability requirements show that a IoT/M2M approach is able to resolve the problem, even if today commercially available gauges are not designed with the specific objective of flash floods control. Their main limits are high power consumption, inadequate communication mechanisms and costs. However, by supporting gauges with a ultra-low-power MPU minimizing gauges operational time, an M2M network with minimal power requirements can be implemented. Moreover, our research shows that new rain gauges have to be designed with the specific objective of flood control and not for general purpose applications, like agriculture. Next steps in this project will be: a deeper testing phase of the network of low cost sensors both in simulated and real-life scenarios, and an implementation of the software behaviour in Thingworx or other platforms.

REFERENCES

[1] H. McMillan, J. Freer, F. Pappenberger, T. Krueger, and M. Clark, "Impacts of uncertain river flow data on rainfall-runoff model calibration and discharge predictions," Hydrological Processes, vol. 24, no. 10, 2010, pp. 1270–1284.

[2] F. Pappenberger et al., "Visualizing probabilistic flood forecast information: expert preferences and perceptions of best practice in uncertainty communication," Hydrological Processes, vol. 27, no. 1, 2013, pp. 132–146.

[3] M. Ancona et al., "On the design of an intelligent sensor network for flash flood monitoring, diagnosis and management in urban areas position paper," Procedia Computer Science, vol. 32, 2014, pp. 941–946.

[4] M. Borga, E. Gaume, J. D. Creutin, and L. Marchi, "Surveying flash floods: gauging the ungauged extremes," Hydrological processes, vol. 22, no. 18, 2008, p. 3883.

[5] E. Gertz and P. Di Justo, Environmental Monitoring with Arduino. O'Reilly, 2013.

[6] "Org-815 - optical scientific," http://www.opticalscientific.com/pdf/press_releases/ORG815_PR%20120529.pdf, accessed: 2015-06-09.

[7] "6030 optical rain gauge - all weather inc," http://www.allweatherinc.com/wp-content/uploads/6030-0411.pdf, accessed: 2015-06-09.

[8] "Rg-11 - hydreon," http://www.rainsensors.com/docs/rg-11_instructions.pdf, accessed: 2015-06-09.

[9] "Flo-dar av sensor," http://www.hachflow.com/flow-sensors/flo-dar.cfm, accessed: 2015-06-09.

[10] J. Creutin, M. Muste, A. Bradley, S. Kim, and A. Kruger, "River gauging using piv techniques: a proof of concept experiment on the iowa river," Journal of Hydrology, vol. 277, no. 3, 2003, pp. 182–194.

[11] S. Ajah, A. Al-Sherbaz, S. J. Turner, and P. Picton, "Sub 1ghz m2m communications standardization: The advancement in white space utilization for enhancing the energy efficiency," in PGNET Proceedings of the 15th Annual Postgraduate Symposium on the Convergence of Telecommunications, Networking and Broadcasting 2014, M. Merabti, O. Abuelmaatti, and C. Oliver, Eds. Liverpool, UK: Liverpool John Moores University, June 2014.

[12] "Long-range rf communication: Why narrowband is the de facto standard," http://www.ti.com/lit/wp/swry006/swry006.pdf, accessed: 2015-06-09.

[13] D. Hughes et al., "An experiment with reflective middleware to support grid-based flood monitoring," Concurrency and Computation: Practice and Experience, vol. 20, no. 11, 2008, pp. 1303–1316.

[14] P. J. Smith et al., "Towards the provision of site specific flood warnings using wireless sensor networks," Meteorological Applications, vol. 16, no. 1, 2009, pp. 57–64.

[15] S. Gusmeroli, S. Piccione, and D. Rotondi, "Iot@ work automation middleware system design and architecture," in Emerging Technologies & Factory Automation (ETFA), 2012 IEEE 17th Conference on. IEEE, 2012, pp. 1–8.

[16] "Reliable, low power wireless sensor networks for the internet of things: Making wireless sensors as accessible as web servers," http://cds.linear.com/docs/en/white-paper/wp003.pdf, accessed: 2015-06-09.

[17] "Axeda," http://it.ptc.com/axeda, accessed: 2015-06-09.

[18] "Thingworx," http://www.thingworx.com/, accessed: 2015-06-09.

[19] "Thingsquare," http://www.thingsquare.com/, accessed: 2015-06-09.

[20] "Eclipse m2m," http://iot.eclipse.org/, accessed: 2015-06-09.

[21] "Xively," https://xively.com/, accessed: 2015-06-09.

[22] "Kaa," http://www.kaaproject.org/, accessed: 2015-06-09.

[23] "Kinoma," http://kinoma.com/, accessed: 2015-06-09.

[24] "M2m labs," http://www.m2mlabs.com/, accessed: 2015-06-09.