An Advanced Real-Time Rainfall Monitoring System Based on Commercial Satellite Broadcasting Service

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***Abstract*—correct regulation of meteoric surface and subsurface flow waters is a fundamental goal for the sustainable development of the territories. In this paper, a new system for real-time monitoring of rainfall and cumulated rainfall is resented and discussed. The system implements a Sensor Network based on the IoT paradigm and can cover a wide area with a relatively small number of sensors, strategically placed. A real application case, based on the implementation of the Monte Scarpino pilot plant, is also presented and discussed.**

I. INTRODUCTION

The correct regulation of meteoric surface and subsurface flow waters represents a fundamental goal for the sustainable development of the territories subjected to a transformation and environmental reclamation process. The management of devices and systems for the transfer and collection of rainwater must follow criteria consistent with the principles of permanent site safety. To achieve reclamation it is necessary to ensure, in particular, the isolation of any contaminating sources as well as the geotechnical stability of the soils and to have efficient environmental monitoring systems. In this sense, the fundamental parameters for the design and management of rainwater regeneration systems are the intensity and duration of rainfall.

Nowadays, the most often used rain sensors are the rain gauge with tilting trays and the weather radar (WR). The first one provides a precise datum (how much rain has fallen in the place where it is installed) while the second one provides real data at low resolution (typically of the order of 1 Km). The WR's have also significant constraints, concerning both implementation (as they need to be installed in isolated areas with particular features, usually on top of a mountain) and functional operation (monitoring remotely, one can not measure the rain conditions inside narrow valleys and not in line with the radar beam).

In this paper, an innovative system for rainfall monitoring is presented. Smart Rainfall System (SRS) is the result of a collaboration about innovation in rainfall monitoring between the start-up Artys and the University of Genoa. The system allows for real-time observation of the evolution of rainfall on the territory with a spatial and temporal sampling scale higher than traditional systems (rain gauges and radar) and has low construction costs. In this paper, after a short resume of SRS features, we present an application case in a mountain city dump.

II. THE SMART RAINFALL SYSTEM (SRS)

Smart Rainfall System (SRS) is an innovative, patented technological solution for estimating and pinpointing rainfall in real time and providing short-term forecasts of hydrogeological risk [1-3]. SRS exploits the signal emitted by commercial geostationary DVB satellites to evaluate the quantity of rain falling over the area to be monitored. A complete description of the satellite-earth link model can be found in [1]. Summarizing, the system is composed by a network of microwave sensors, each of which measures the signal intensity received from a satellite thanks to a parabolic dish and an LNB. It is well

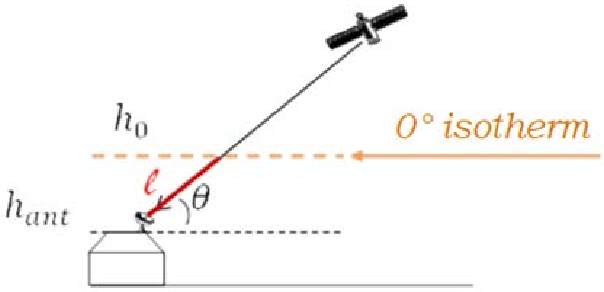

Fig. 1. Measurement segment for the measurement and rain estimation.

known that rainfall scatters microwaves, and the *Ku* band used for most of DVB-S transmissions is particularly sensitive to this phenomenon.

Specifically, the consequent attenuation of the satellite signal intensity (measured in dB) are linked by empirical relationship provided by the ITU (2005) Recommendation [4], to the mm/h of rain that are falling along the antenna-satellite section. With reference to Figure 1, it is defined by the segment *l,* which lies below the altitude h_0 of zero degree isotherm.

The rainfall intensity ***RI*** [*mm h*$^{-1}$] is formulated inverting the two-coefficient power-law function which links the specific attenuation $\gamma_{\text{rain}}^{\frac{\text{dB}}{\text{km}}}$ to ***RI*** and is parametrized according to the following expression:

$$\gamma_{\text{rain}}^{\frac{\text{dB}}{\text{Km}}} = \beta RI^{\alpha}$$

where α and β are proper parameters which depend on the frequency and polarization of the impinging electromagnetic wave.

The-measuring principle used by SRS is somewhat similar to the one used in weather radars, generating high-resolution rainfall maps in real time thanks to a network of innovative, easy-to-install measurement stations scattered over the area.

In order to provide more comprehensive information, the maps produced by SRS can incorporate measurements taken by traditional sensors (rain gauges, water gauges, anemometers, CCTV cameras, infrared systems, etc.), making the most of existing investments. Furthermore, SRS includes a Decision Support System (DSS) that allows for faster, more efficient and cheaper hydrogeological risk analysis compared to traditional solutions. SRS predicts the consequences of rainfall by monitoring whether critical rainfall levels have been exceeded in the basin and applying a semi- distributed continuous hydrological model.

Smart Rainfall System provides a high resolution rain gauge map (you can expect to have a resolution of the order of 100 m) which allows for faster risk analysis and more efficient anticipation of the consequences of precipitation in urbanized and natural basins.

SRS provides continuous observation of atmospheric conditions, using special sensors that analyze the intensity of the microwave signal in ku band (Digital Video Broadcasting Satellite - DVB-S) emitted by television satellites that are placed in geostationary orbit around the Earth and received from common parabolic antennas to which they are connected.

The infrastructural paradigm is that of the Internet of Things (IoT): actually, the whole monitoring system implements a network of measurement stations (parabolic antenna and SRS sensor) located in the area to be monitored in a potentially extensive and widespread manner, which continuously send small packets of data to the SRS data center. The latter, hosted on special cloud platforms, analyzes them and derives pluviometric information.

For SRS, the Italian patent was recognized in 2014 [5] and is now extended at European level [6].

Based on the information analyzed, SRS creates real-time interactive and high-resolution rainfall maps of the entire monitored area and makes them available to its users, via an online service (via web and on mobile devices). The service is designed to integrate data into specific hydrological models to provide a timely forecast of the consequences of precipitation.

SRS also stands out for its low implementation and maintenance costs: as a matter of fact, SRS measurement stations use already active infrastructures (satellite telecommunications, internet and mobile networks) and are made up of low-cost market components. In addition, each SRS sensor has an energy consumption comparable to that of a common battery charger for mobile devices.

III. THE TESTING PLANT OF MONTE SCARPINO

The case of the Monte Scarpino landfill in Genoa is of particular importance in relation to the monitoring of areas subject to environmental risk protection. The solid urban waste disposal plant covers an area of about half a million square meters (Fig. 2). Established in 1968, the landfill is located on the heights of Sestri Ponente, in the Metropolitan City of Genoa. The waste disposal plant is

Fig. 2. Satellite view of the Monte Scarpino landfill

about 650 meters over the sea level and is composed of two modules, that today are no longer in operation as the maximum allowed volume for filling has been reached. The over 10 million cubic meters of waste disposed of in landfills continue to feed a biogas transformation system into electricity, on average 60 million kWh per year entered into the national grid.

The Liguria Region and the Metropolitan City of Genoa have given prescriptions to increase and improve the monitoring of landfills through different environmental matrices that influence incoming and outgoing flows of matter and energy.

In this context, particular attention is given to the problem of water pollution [2]. In the event of sudden, intense and highly localized precipitation phenomena, it is necessary to measure rainfall in real time, identifying the "hot-spots" in which the events occur. There is a distance of 1.3 km and an elevation of about 300 m between the entrance to the landfill, to the north, and the borders to the south of it, where the containment tanks of the percolate are located [3]. The levels in the tank and the inflows in entrance must be constantly monitored during the rains. A system that acquires data in real time can also ensure greater safety for operators as well as can generally allow for the activation of emergency procedures based on nowcasting [7].

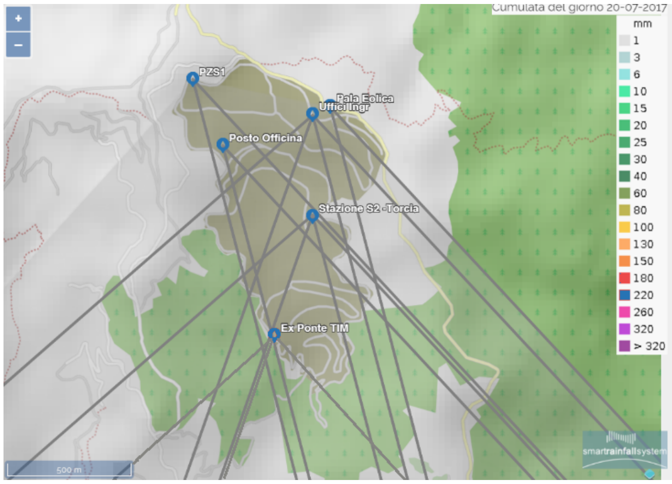

Fig. 3. Map of the geographical location of the SRS sensors and of the satellite connection tracks.

The network is composed of 18 sensors distributed in 6 different sites, guaranteeing an estimated coverage of 9.8 km^2 and above the landfill area for an analysis of the evolution of rainfall extended to adjacent areas. In Fig. 3 a map of the geographical location of the SRS sensors and of the satellite connection tracks is shown, while Table I summarizes the sensor distribution details, with their population of satellites.

An example of the rain intensity measurement, provided by the SRS sensors operating at the "Pala Eolica" site in the landfill area is shown in Fig. 4, while the corresponding signal strength, for each sensor, is given in Fig. 5.

Fig. 6 and 7 shows instead the spatial distributions of the accumulated daily rainfall for two different rainy days, produced by the Artys interactive GIS web platform.

IV. CONCLUSIONS

In this paper, a new system for real-time monitoring of rainfall and accumulated rainfall has been presented and discussed. The system implements a Sensor Network based on the IoT paradigm and can cover a wide area with a relatively small number of sensors, strategically placed. The experimental plant of Monte Scarpino has shown that the system is fast and reliable and can provide a timely forecast of the consequences of precipitation, as well as can generally allow for the activation of emergency procedures based on nowcasting.

TABLE I
Observation directions per site

		Satellite position			
		Hispasat 30W	*Eutelsat 5W*	*Astra 19.2E*	*Turksat 42E*
Site	PZS1			✓	✓
	Posto Officina			✓	✓
	Ex Ponte TIM	✓	✓	✓	✓
	Uffici a	✓	✓	✓	✓
	Pala Eolica			✓	✓
	Stazione S2 Torcia	✓	✓	✓	✓

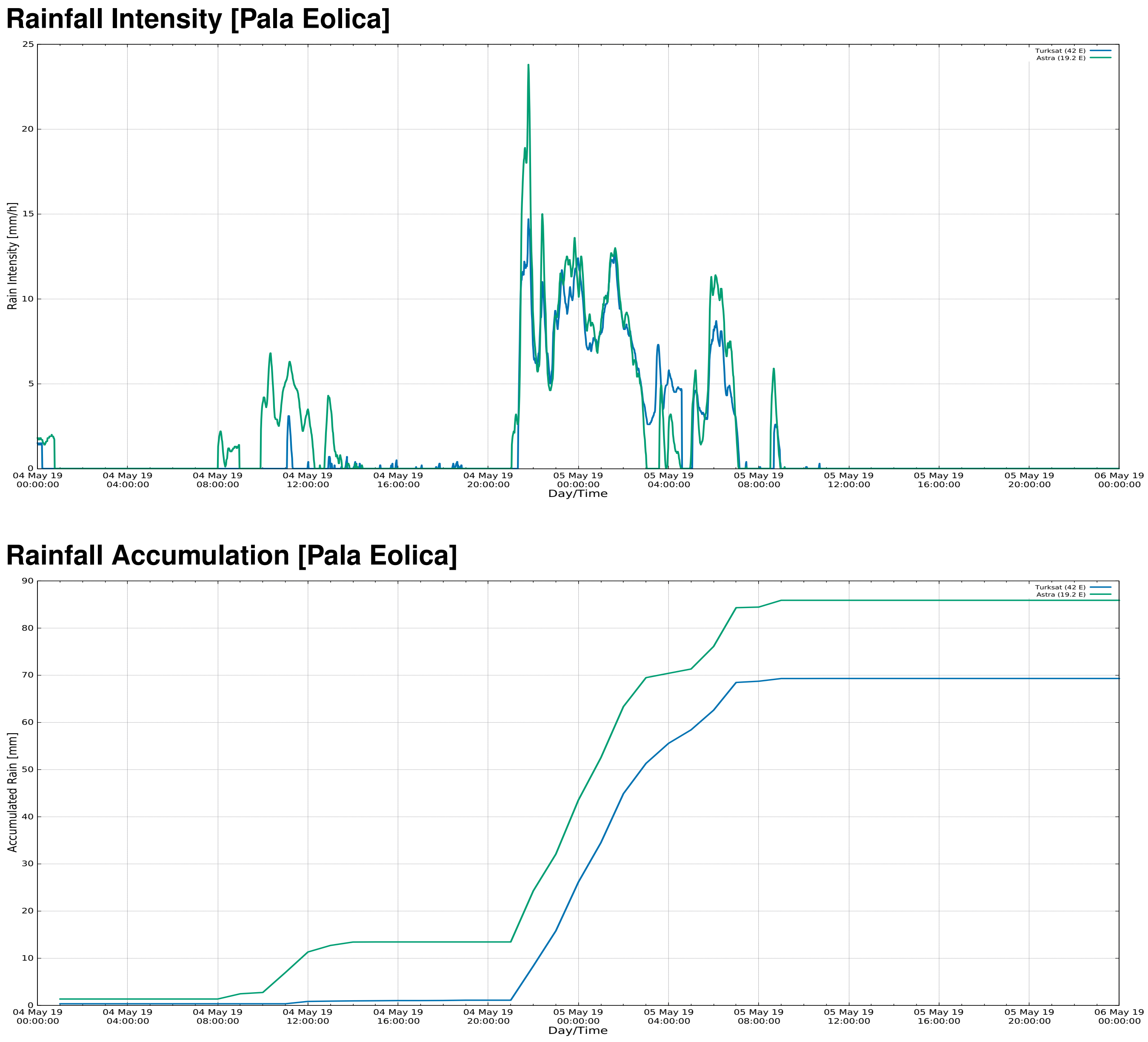

Fig. 4. Time series of rainfall intensity *RI* [mm/h] per minute and accumulated rainfall *RA* [mm] measured by the SRS sensors at the “Pala Eolica” site in the period between May 4, 2019 and May 6, 2019. Blue line: Turksat 42 E. Green line: Astra 19.2 E.

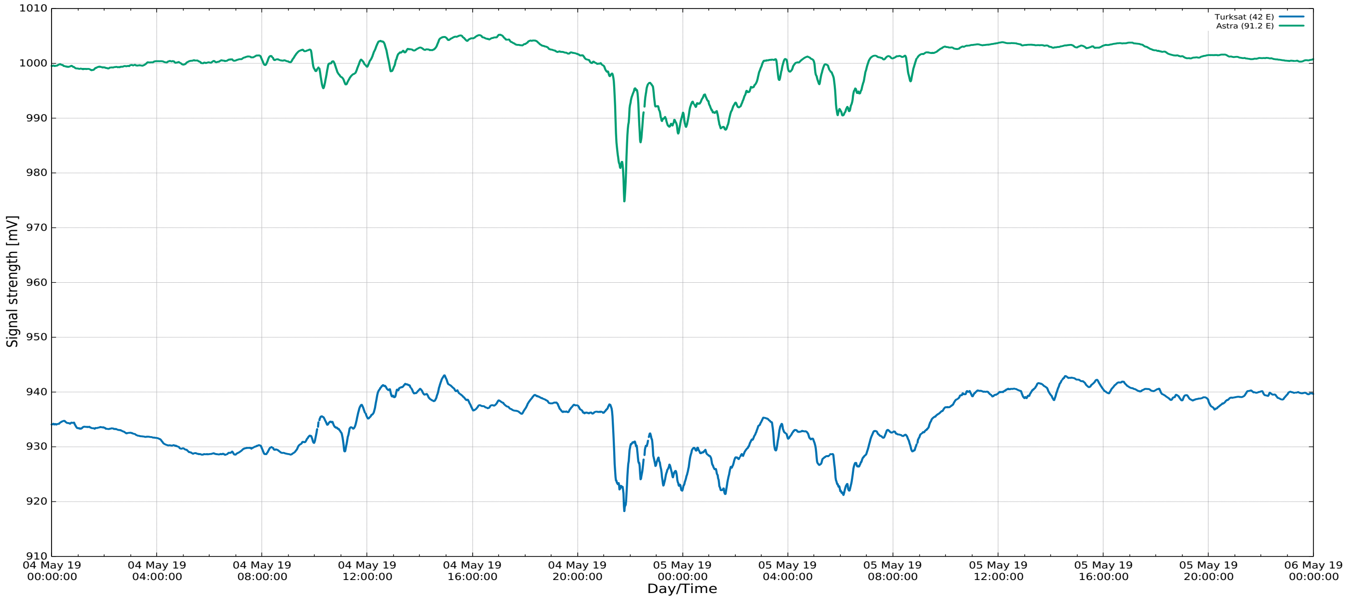

Fig. 5. Signal strengths [mV] at the "Pala Eolica" site, in the interval May 4, 2019; May 6, 2019. Green line: Astra (19.2 E). Blue line: Turksat (42 E).

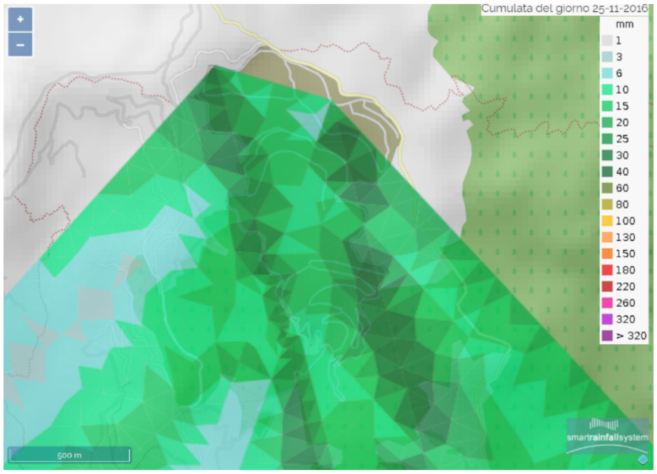

Fig. 6. Rain intensity maps measured by the SRS system for the events of November 11, 2016.

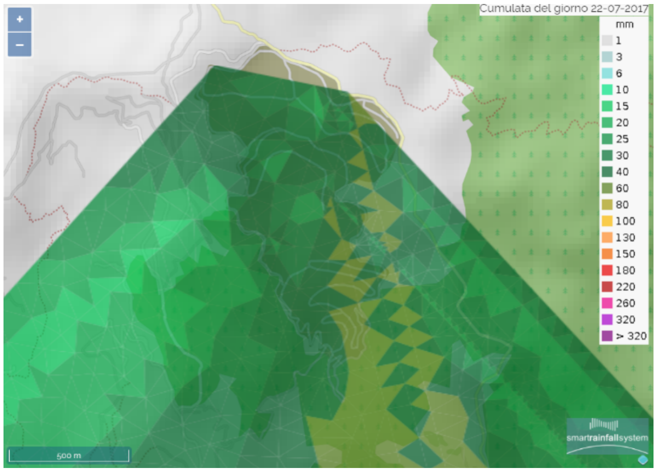

Fig. 7. Rain intensity maps measured by the SRS system for the events of July 22, 2017.

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