A field assessment of a novel rain measurement system based on earth-to-satellite microwave links

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Abstract:

This work presents the performance of an innovative environmental monitoring system - Smart Rainfall System (SRS) - that estimates rainfall in real-time by means of the analysis of the attenuation of satellite signals (DVB-S in the microwave Ku band). SRS consists in a set of peripheral microwave sensors placed on the field of interest, and connected to a central processing and analysis node. It has been developed jointly by the University of Genoa, with its departments DITEN and DICCA and the University spin-off "Artys Srl".

The rainfall intensity measurements accuracy and sensitivity performance of SRS are discussed, based on preliminary results from a field comparison experiment at the urban scale. The test-bed is composed by a set of preliminary measurement sites established since Autumn 2016 in the Genoa (Italy) municipality and the data collected from the sensors during a selection of rainfall events is studied. Point-scale rainfall intensity measurements made by calibrated tipping-bucket rain gauges constitute the reference for the comparative analysis of the system performance. The dynamic calibration of the reference rain gauges has been carried out at the laboratories of DICCA using an automatic calibration rig and the measurements have been processed taking advantage of smart algorithms to reduce counting errors. Additional information about the spatial distribution of precipitation have been provided by the WSR radar of Monte Settepani.

An objective of this investigation is the optimization of the specific attenuation model parameters for rain with respect to those recommended by the International Telecommunication Union standard ITU-R P.838-3. In addition, the experimental set-up allows a fine tuning of the retrieval algorithm and a full characterization of the accuracy of the rainfall intensity estimates from the microwave signal attenuation as a function of different precipitation regimes.

1 PREMISE

Many people and industries live and are located in high hydraulic hazard areas that are exposed to extreme precipitation events. To efficiently manage emergencies, Civil Protection operators need a valuable flood risk now-casting system. In this context, they suffer the lack of real-time information about the areal distribution of heavy rain. This information is fundamental for the short-term forecasting (now-casting) of flood risk and the management of the emergency phase, constituting a key element for Decision Support Systems (DSS).

The Smart Rainfall System (SRS) system produces an estimation map of the precipitation in terms of one-minute rainfall amounts by processing the attenuation of the satellite microwave link signal (Federici et al., 2014). The system consists in a set of peripheral microwave links placed on the field of interest and connected to a central processing and analysis node. The SRS architecture relies on low cost and low power Internet of Things (IoT) sensors that can be connected to the same commercial satellite dishes used by citizen to receive the digital television broadcasting, underpinning a participatory vision, where all "things", people and processes are connected through the "Internet of everything" leading to a capillary monitoring of the water-system.

The present contribution reports the results obtained by using three experimental SRS sensors installed in the City of Genoa (Italy) between 2016 and 2018. This is the first field comparative experiment organized at the urban scale involving several microwave link measuring station. Furthermore, dynamically calibrated tipping-bucket rain gauges (TBRG) provide the rainfall observations used for comparison. The TBRG measurements have been processed according to advanced algorithms developed by the Lead Centre "B. Castelli" on Precipitation Intensity of the World Meteorological Organization (Colli et al., 2013).

2 METHODOLOGY

In order to illustrate the working principle of the considered technique, let us consider a receiving (*Rx*) antenna located at a position $\mathbf{r}_{Rx}$ (Fig. 1). The satellite television dish receives a plane-wave EM signal transmitted by a commercial digital video broadcasting satellite (DVB-S).
Since the wave propagation is affected by the precipitation during its path, by using the ITU model described in [2], the rainfall intensity *RI* can be expressed as:

$$RI = \sqrt[a_p]{\frac{10\log(P_o/P)}{b_p l}} \tag{1}$$

where $P \propto |\mathbf{E}(\mathbf{r}_{Rx})|^2$ is the power available at the output of the antenna being $\mathbf{E}(\mathbf{r}_{Rx})$ the electric field impinging on the antenna (Balanis, 1989), P_o is the clear sky power at the output of the antenna, b_p and a_p are empirical parameters derived from the ITU model (ITU, 2005). The microwave link length is assumed equal to $l=H/\sin\vartheta$ where H is the elevation of the melting layer at the given latitude and ϑ the elevation angle of the *Rx* antenna (Fig. 1).

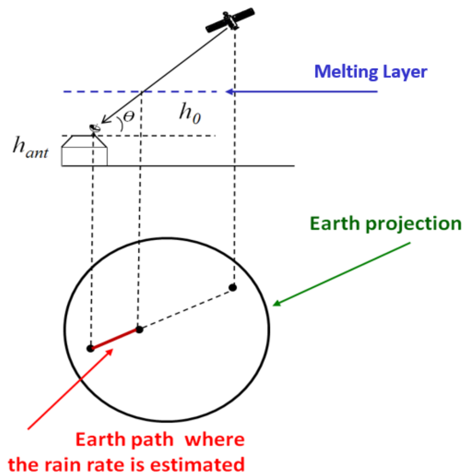

Figure 1. Rain estimation approach

As first validation tests, experiments aimed at verifying the operation and effectiveness of the SRS sensor, have been carried out in the laboratories of the University of Genoa – DITEN. The block diagram of the SRS sensor module is drawn in Fig. 2.

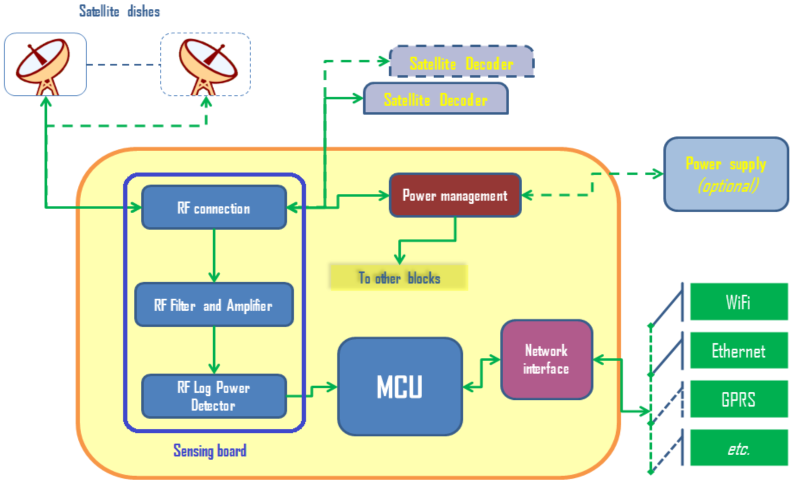

Figure 2. Block diagram of the sensor module: the "sensing board" on the left of the yellow area performs the detection of the incoming power intensity.

It exploits the information contained in the power level of the signal at the output of an LNB (Low Noise Block converter), commonly used in the receiving chain of a consumer DVB-S set.
For our purposes, it is worth using a low-cost Universal LNB. In such a case, the down-converted signal on the descending cable contains (in the band 915 MHz – 2150 MHz) one of the four possible bands which correspond to two different polarizations – vertical and horizontal – and, in the case of the Ku-band, two different frequency bands – lower and upper.
A proper circuitry detects the television level of the signal as a voltage obtained with a logarithmic detector (Fig. 2). Such a value makes possible the estimation of the rain intensity averaged along the path, and is transmitted on either a wired or a wireless link to a collection center, for recording and monitoring. A detail of the SRS sensing board is depicted in Fig. 3.

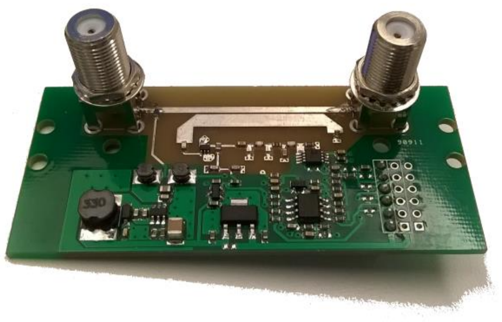

Figure 3. Sensing board: the two F connectors provide connectivity towards the satellite television decoder (left) and to the LNB (right).

To test our approach an experiment is under execution in the city of Genova (Italy) employing 3 antennas pointed towards the Turksat 42°E satellite. The antennas has been installed in three different sites (denominated A1, A2 and A3 in Fig. 4) and constitute a sub-system of a larger set of microwave links connected to various satellites conveniently selected given their favorable alignment shown in Fig. 4 (red lines). The three microwave links spans over the same portion of territory with a slight offset and site A2 and A3 site are equipped with tipping-bucket rain gauges (TBRG).
The experimental campaign started on November 2016 and the SRS voltage level signals are recorded with a one minute time interval.

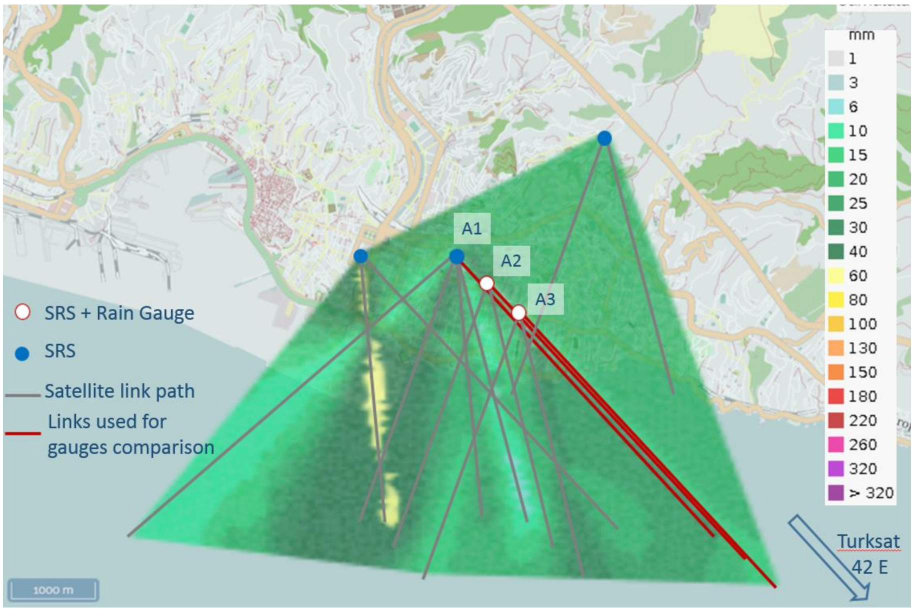

Figure 4. Daily cumulative precipitation (mm) measured by the SRS system of the experimental field site in Genoa (Italy) on 25th March 2017.

The TBRG have been dynamically calibrated according to the national standard UNI 11452 (2012) by the WMO Lead Centre B. Castelli on Precipitation Intensity and the one-minute rainfall intensity (RI) measurements are computed by using advanced interpretation algorithms (Colli et a., 2013).

3 RESULTS AND DISCUSSION

Fig. 5 shows a preview of the signal received by three antennas located in the A1, A2 and A3 sites and pointing towards Turksat 42°E. The rain gauges intensity measurements are reported in the bottom panel of Fig.5.

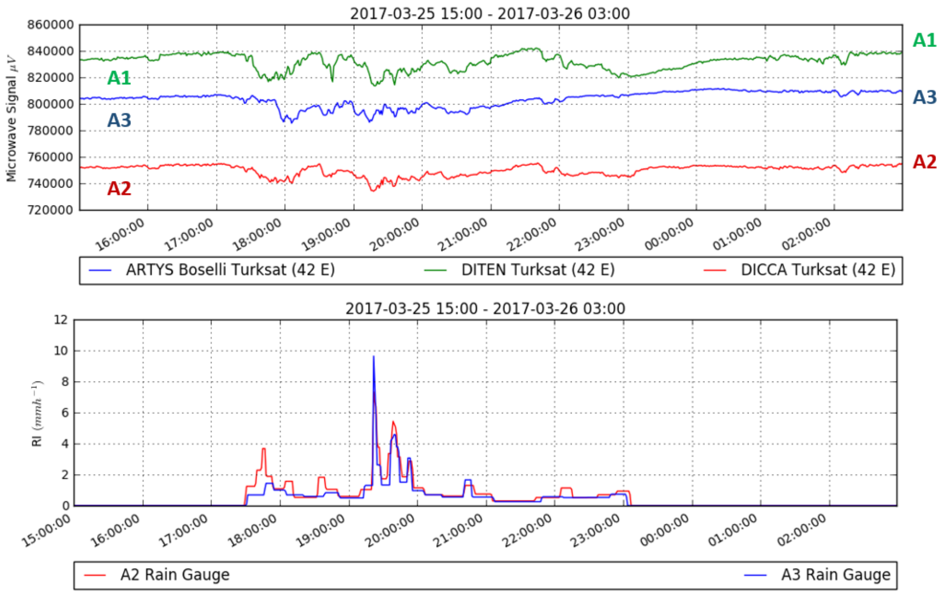

Figure 5. Top panel: Voltage levels [μV] measured by three different antennas (A1, A2, and A3). Bottom panel: The one-minute rainfall intensity RI [mm h^{-1}] measured by calibrated tipping bucket rain gauges (located in the A2 and A3 sites).

A brief comparison between the time series of Fig.5 shows an evident correlation between the SRS signal attenuation and the RI measured by the rain gauges. The time and spatial variability of the precipitation event must be taken into account when evaluating the differences between the signal of non co-located antennas and TBRGs. Currently, the RI measurements made by the SRS antennas are based on the solution of Eq.1 and the accuracy of the intensity maps obtained by interpolating such measurements is under evaluation as the main objective of the experimental campaign.

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