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Performance comparison of different types of broadcast satellite receivers for opportunistic rain estimation

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Abstract

Rainfall monitoring plays a key role in many disciplines dealing with environment, social activities, and business. Moreover, the temporal and spatial variability of precipitation and the need for a dense network of measuring devices, make the rainfall estimation a complex task from both scientific and economic point of view. In recent years, the use of "opportunistic" sensors has been investigated as an alternative to the conventional devices, aiming to expanding available measurements without adding new infrastructures, thus also containing costs and maintaining the necessary measurements accuracy. In the framework of exploiting opportunistic sensors, this paper has investigated the rainfall estimation performance of two different types of receivers for direct-to-home satellite TV, a high-quality product, named IoT First, and a more conventional and cheaper LNB. The analysis shows better performance of the IoT First in terms of noise and rain estimate accuracy w.r.t. conventional weather sensors.

1. Introduction

The geostationary satellites (GEOs) are widely used for TV broadcasting and this encouraged the commercial diffusion of a huge amount of products for direct-to-home (DTH) reception. Consider, for instance, that the number of pay satellite television (TV) subscribers worldwide is estimated to be around 1 billion by 2027 [1]. In recent years, satellite terminals for DTH have received further attention also as opportunistic rain sensors [2]. In this case, satellite receivers are used to estimate the rain intensity starting from the precise measurement of the signal strength, or the signal-to-noise ratio (SNR), which is received on ground. This sets more stringent specifications for the receiving devices, particularly regarding the amount of internally-generated electronic noise. In this paper we consider two types of DTH receivers, a high-quality product and a more conventional (and cheaper) one, and we evaluate their performance in terms of estimation accuracy of rainfall intensity when used as opportunistic satellite-based sensors (OSSs).

2. Measurement System

The two commercial-grade satellite receiving devices considered in this study were part of the OSS network deployed in Central Italy (Tuscany region and Rome city) during NEFOCAST [3] and INSIDERAIN [4] projects, both funded by Tuscany regional administration, which produced satellite data from 2017 to 2022. In particular, the measurement data presented in this comparative study were taken by the OSS at CNR-ISAC, Rome, Italy (41.8400°N, 12.6472°E).

2.1. IoT First Terminal

The first type of device considered in this study consists of an interactive satellite terminal (IST), called IoT First Terminal (formerly, SmartLNB) and produced by AYECKA Ltd., Israel [5]. Thanks to its optimized form-factor, this device can be mounted in the focus of a conventional offset dish for DTH satellite TV reception, with typical diameter 80 cm (Figure 1). The IoT First Terminal is a two-way satellite device, which enables the following links: i) forward link (FL) reception, i.e., satellite to ground down-link in the $10-13$ GHz Ku-band with digital video broadcasting - satellite 2nd gen. (DVB-S2) receiver; ii) return link (RL) transmission, i.e., ground to satellite up-link in the 14 GHz Ku-band, with low-power transmitter. Thanks to its two-way capability, the IST device targets both mass-market applications, where it can be used for connected TV and home automation, and professional applications, such as machine-to-machine (M2M) and Internet of things (IoT) backhauling, or low-cost Internet Access. Note that the IoT First device is a complete receiving system as it takes the radio frequency (RF) signal from the satellite, performs frequency down-conversion to intermediate frequency (IF), followed by signal demodulation and data decoding, and eventually outputs the information-carrying bits, also providing SNR readings. This paper analyzes SNR readings on the FL from Eutelsat 10A satellite in 10°E orbital position, with effective isotropic radiated power (EIRP) 48 dBW, taken twice per minute by NEFOCAST-ITA-RM-001X station. The SNR readings are eventually sent through the RL to a remote data collection and fusion center via the IoT First satellite platform, which exploits the same Eutelsat 10A satellite. The main technical specifications of the device are summarized in Table 1. In 2023, the former IoT FIRST service via Eutelsat 10A, became EUROBIS, provided by MBI Srl, Pisa, Italy, via Eutelsat 36E, in 36°E orbital position.

Table 1. IoT First technical specifications (PHY: physical layer; DLL: data link layer; V: vertical; H: horizontal; IP-MPE: multi protocol encapsulation; F-SIM: fixed-interactive multimedia services)

Feature	**Value**
FL receive frequency	Ku-band: 10.7 – 12.75 GHz
FL receive polarization	Linear H/V, Switchable
FL protocols	PHY: DVB-S2; DLL: IP-MPE
RL transmit frequency	Ku-band: 13.75 – 14.5 GHz
FL transmit polarization	Linear H/V, Switchable
RL transmit power	1 W
RL protocols	PHY: F-SIM; DLL: F-SIM
Noise figure	0.2 dB
Operating temperature	−33°C to 55°C
Cost	A few hundred €

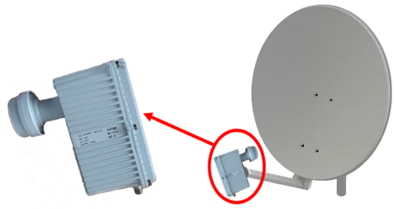

Figure 1. The IoT First terminal and the 80 cm offset satellite dish.

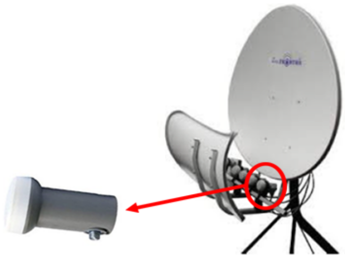

Figure 2. A conventional LNB and the 90 cm (actual size, height×width: 96.7 cm×108.6 cm) Wave-Frontier T90 dual reflector toroidal antenna for multi-sat reception [6].

2.2. Conventional Low-Cost Universal LNB

The other type of device considered in this study consists of a conventional low-cost, single universal low-noise block converter (LNB) for DTH satellite reception in Ku-band (marketed with P/N 80185KL and shown in Figure 2), whose main technical specifications are summarized in Table 2. Note that, unlike the more expensive IoT First device, the low-cost universal LNB outputs an IF signal after frequency down-conversion. Therefore it needs to be paired with an external terminal, developed by Egatel S. L. [7] and suitably customized to read the SNR measurements (taken every minute), collect them with a datalogger (a Linux code in this study), and send them via a 4G modem (at a typical rate of one sample per minute). All these add-ons, however, appreciably raise the overall cost of the receiving station. In the project INSIDERAIN, some of these devices have been used with the multi-LNB Wave-Frontier T90 dual reflector toroidal antenna [8].

Table 2. Conventional LNB technical specifications (LB: low-band; HB: high-band; n.a.: not available).

Feature	**Value**
Receive frequency	Ku-band: 10.7 – 12.75 GHz
Receive polarization	Linear H/V, Switchable
Local oscillator	9.75 GHz, LB 10.6 GHz, HB Switchable
Output IF range	950 – 1950 MHz, LB 1100 – 2150 MHz, HB
Noise figure	0.1 dB
Gain	57 dB
Operating temperature	n.a.
Cost	Around 5 €

3. Rain Estimation Algorithm

The block diagram of the algorithm for retrieving the rain rate from the received signal strength is illustrated in Figure 3.The SNR measurements provided by the satellite receivers, expressed as the ratio $\eta = E_s/N_0$, between the energy at RF per symbol E_s and the one-sided noise power spectral density (PSD) N_0, are suitably processed by Kalman filtering [9] to make a classification between "rain" and "no rain" conditions. In case of "rain", the signal "baseline", i.e., the reference level is derived from the most recent "no-rain" data statistics, and is used for the evaluation of the excess attenuation due to the rain A. This represents the total attenuation along the wet path (i.e., the slanted radio signal path across the rainy system) and is processed according to a layered tropospheric model, which includes the heights of rain, of 0°C isotherm, and melting layer, the length of the wet path, and some empirical coefficients. The rainfall rate R (in mm/h) is eventually obtained from a relationship between A and R, which is a sort of extension of the well-known power law model specified in ITU-R recommendation P.838-3 [10].

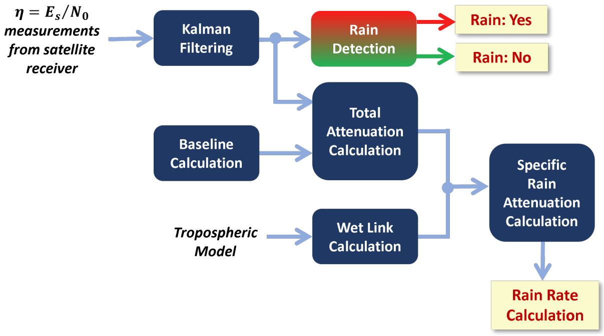

Figure 3. Block diagram of the rain rate estimation algorithm [9].

4. Experimental Results

In this section, we numerically evaluate the performance of the two different satellite receiving devices described in Sect. 2, when used as rain sensing devices. In particular, among the many low-cost universal LNBs that are used on the Wave-Frontier T90 multi-satellite receiving antenna at CNR-ISAC, Rome, Italy, we have focused on the one pointed at Eutelsat 10A satellite, the same satellite pointed by the IST IoT First terminal.

4.1. Noise

We first evaluate the amount of internal electronic noise that affects the measurements provided by the two satellite receivers. To this end, we select for both the devices a 24h time series characterized by clear sky conditions. Figure 4 depicts the SNR measurements (in dB) as a function of time, collected by both the IoT First and the conventional LNB, from 00:00:00 UTC to 23:59:59 UTC, on May 30, 2022. The long-term fluctuations of the SNR trajectories in the graph are produced by a combination of the residual movement of the GEO in the sky (due to orbit perturbations) and the actual aiming of the broadside of the receiving antenna patterns towards the satellite.

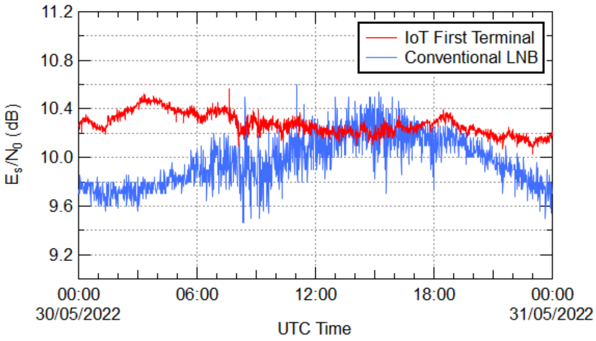

Figure 4. SNR from Eutelsat 10A measured by the two receivers of the station NEFOCAST-ITA-RM-001X, over 24 hours in clear sky conditions, on May 30, 2022.

Denoting now with $t_n = n\tau$ the nth sampling instant of the receiver, where τ is the sampling interval, we can then extract from the SNR measurements the zero-mean process $\Lambda(t_n)$ responsible for the rapid fluctuations (in dB), termed SNR noise (SNRN), as follows:

$$\Lambda(t_n)|_{\text{dB}} = \left.\frac{E_s}{N_0}(t_n)\right|_{\text{dB}} - W(t_n)|_{\text{dB}} \tag{1}$$

where

$$W(t_n)|_{\text{dB}} = \left.\frac{1}{K}\sum_{i=0}^{K-1}\frac{E_s}{N_0}(t_{n-i})\right|_{\text{dB}} \tag{2}$$

is the moving average calculated over a window of K samples. We selected a window length of $K = 15$ samples which, for a rate of 1 sample per minute, corresponds to 15 minutes. As shown in Figure 5, the SNR measurements collected by the conventional LNB (blue) are affected by a higher noise w.r.t. those collected by the IoT First device (red). Figure 6 plots the environmental temperature measured from 00:00:00 UTC to 23:59:59 UTC, on May 30, 2022, at the station NEFOCAST-ITA-RM-001X, which shows a thermal excursion of about 10°C. As apparent, the noise level that affects the SNR measurements provided by the conventional LNB: *i*) is strongly influenced by the environmental temperature and significantly increases during daytime; *ii*) is always higher than that affecting the IoT First receiver, even during nighttime. Contrarily to the nominal specifications, the low-cost device is therefore much noisier than the IoT First, and is also poorly shielded from external heat sources.

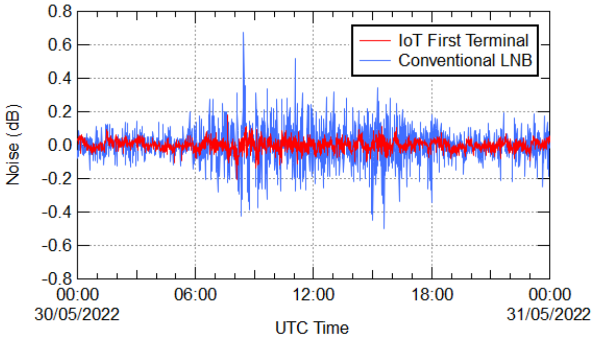

Figure 5. SNRN from Eutelsat 10A measured by the two receivers of the station NEFOCAST-ITA-RM-001X, over 24 hours in clear sky conditions, on May 30, 2022.

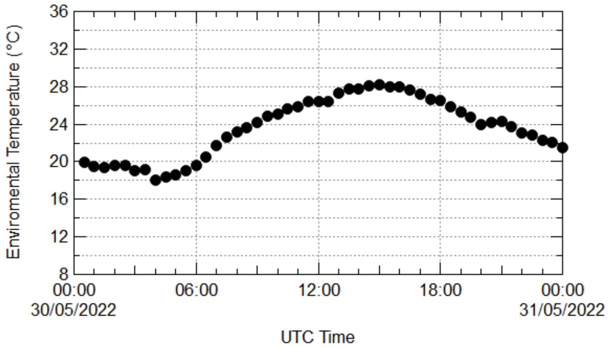

Figure 6. Environmental temperature vs. time at the station NEFOCAST-ITA-RM-001X, over 24 hours in clear sky conditions, on May 30, 2022.

4.2. Rain Estimate Accuracy

For both satellite receivers, we consider and analyze the SNR samples collected during a rain event occurred between April 21 and 22, 2022. In Figure 7, the solid red line reports the measurements of $\eta = E_s/N_0$ collected by the Iot First, while the solid blue line depicts those collected by the conventional LNB. The dashed lines represent the corresponding rain rate estimates (in mm/h), obtained by processing the SNR records with the algorithm sketched in Sect. 3. The results in Figure 8 show the estimate of the cumulative rainfall (in mm) provided by both the satellite receivers, and compared with those provided by co-located conventional rain sensors: *i*) a disdrometer, which is a laser-based Thies Clima optical device, manufactured

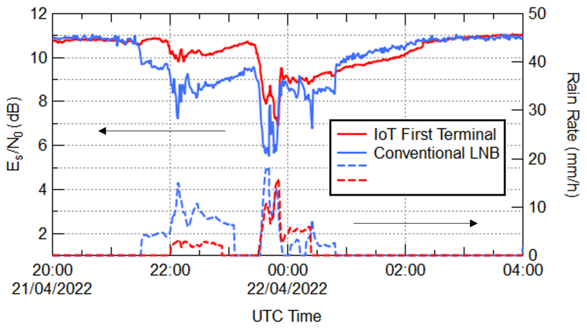

Figure 7. SNR from Eutelsat 10A measured from the two receivers during a rain event (solid lines) and the corresponding estimates of the rain rate (dashed lines).

by Adolf Thies GmbH & Co., Göttingen, Germany [11]; *ii*) a tipping bucket rain gauge, developed by ETG s.r.l., Florence, Italy [12], which provides measurements of the water amount every minute with a resolution of 0.2 mm. As apparent, the estimate of the cumulative rainfall provided by the IoT First reveals in good agreement with the measurements of both the reference weather instruments, whereas the conventional LNB provides a grossly over-estimate. This poor accuracy can be attributed to the high level of electronic noise of the device, but also a wet antenna effect could be presumed to justify the exaggerated attenuation from 21:00 to 24:00. For the sake of brevity, only a specific example is reported in this work. However, similar results can be obtained for rain events with medium or high precipitation intensity.

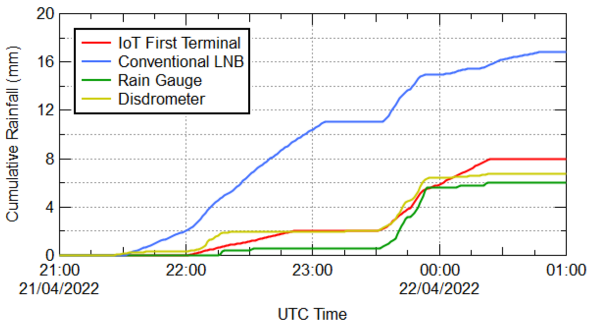

Figure 8. Cumulative rainfall estimates provided by the two OSSs, compared to the measurements by co-located conventional weather instruments.

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5. Conclusions

Recently, the use of satellite TV terminals as “opportunistic” satellite-based sensors for precipitation estimation has been investigated as an alternative, or a complement, to conventional techniques, with the aim to expand available devices without adding new infrastructures, containing the costs and maintaining the necessary accuracy. In this paper, two different types of DTH receivers are examined in terms of noise and rain estimate accuracy. Both instruments are located at the CNR-ISAC in Rome, Italy. The analysis has highlighted better performances of the IoT First, while the conventional (and cheaper) LNB appears much noisier, revealing poorly shielded against external heat sources, and providing a grossly over-estimate of the cumulative rainfall.

Acknowledgements

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References

[1] Worldwide pay TV subscriber industry report. (accessed Jan. 20th, 2024). [Online]. Available: https://www.prnewswire.com/news-releases/

[2] F. Giannetti and R. Reggiannini, “Opportunistic rain rate estimation from measurements of satellite downlink attenuation: A survey,” *Sensors, 2021*, vol. 21, no. 17, Aug. 2021.

[3] NEFOCAST project. (accessed Jan. 20th, 2024). [Online]. Available: https://www.nefocast.it/

[4] INSIDERAIN project. (accessed Jan. 20th, 2024). [Online]. Available: https://www.insiderain.it/

[5] Ayecka Satellite Technol. (accessed Jan. 20th, 2024). [Online]. Available: https://www.ayecka.com/

[6] WAVEFRONTIER Co., Ltd. (accessed Jan. 20th, 2024). [Online]. Available: https://wavefront.en.ec21.com/

[7] Egatel S. L. (accessed Jan. 20th, 2024). [Online]. Available: https://www.egatel.es/producto/iot-first-terminal

[8] F. Giannetti, A. Vaccaro, F. Sapienza, G. Bacci, V. Lottici, and L. Baldini, “Multi-satellite rain sensing: Design criteria and implementation issues,” in *Proc. URSI Atlantic and Asia Pacific Radio Science Meeting (AT-AP-RASC)*, May 2022.

[9] F. Giannetti, M. Moretti, R. Reggiannini, and A. Vaccaro, “The NEFOCAST system for detection and estimation of rainfall fields by the opportunistic use of broadcast satellite signals,” *IEEE Aer. Electr. Syst. Mag.*, vol. 34, no. 6, pp. 16–27, 2019.

[10] International Telecommunication Union (ITU), “Specific attenuation model for rain for use in prediction,” ITU-R, Geneva, Switzerland, Tech. Rep. Recommendation P.838-3, 2005.

[11] Thies CLIMA. (accessed Jan. 20th, 2024). [Online]. Available: https://www.thiesclima.com/

[12] ETG. (accessed Jan. 20th, 2024). [Online]. Available: https://www.etgsrl.it/en/