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The NEFOCAST project: A nowcasting weather platform based on dual-frequency interactive satellite terminals

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Abstract

In this paper, we present a research project named NEFOCAST, that targets a very-short-term forecasting platform with high accuracy and small-scale spatial resolution. The innovative solution lies in adopting a new generation of interactive satellite terminals, called SmartLNB, that serves both as a weather sensor and the transceiver for the forecasting platform. Throughout the paper, we highlight the main features of the system, including the advantages compared to state-of-the-art solutions, the expected results, and the market perspectives.

1 Introduction

Accurate weather forecasting, with updated information on a very short-term scale in time and space domains (the so-called *nowcasting*), is playing a dramatic role in many important aspects of everyday's life. Nowcasting is particularly relevant for public safety, business-oriented services, and personal services, just to mention a few. For instance, the availability of reliable real-time forecast for hazardous and extreme weather conditions, such as cloudburts and thunderstorms, may effectively reduce the threat to life and property, thanks to tempestive emergency rescue operations. Similarly, it can have a positive impact on the food chain, as it improves the supply chain and enables precision agriculture, thanks to hyperlocal information that optimizes yield and soil conditions [1].

This branch of meteorology has been made possible by a combination of factors, including the availability of low-cost and low-consumption sensors, and the proliferation of new information and communication technologiess (ICTs), which made the distribution and the application of real-time weather information possible at nearly any location [2].

Currently, short-term weather forecasting can be obtained by using different technologies. The most common solution is provided by modern weather stations, which are equipped with a number of different sensors, that measure, among the others, parameters such as temperature, air pressure, humidity, wind speed, wind direction, rain intensity, and solar radiation. Other solutions are offered by weather surveillance radars (WSRs), used to detect hydrometeors based on the Doppler effect, and by radio-frequency (RF) receivers, that operate in the very-high frequency (VHF) and ultra-high frequency (UHF) frequency ranges to measure the received signal power attenuation and thus to estimate the intensity of precipitations. However, to transform these frequent measurements into valuable inputs for real-time weather prediction algorithms, all these solutions must be equipped with a data distribution and collection platform. Furthermore, the installation and operation costs of each measurement station often prevent the deployment of a highly dense grid of sensors, thus reducing the resolution (and hence the accuracy) of the prediction algorithms.

In this paper, we present NEFOCAST, a research project funded by Tuscany region (Italy), started in September 2016 for a duration of 24 months, which is based on an alternative solution: it uses a population of interactive satellite terminals (ISTs) that serve both as *weather sensors* and as *modems* to send the measurements to a dedicated nowcasting platform and to receive potential alerts. Since these ISTs are are low-cost and low-power RF transceivers which are also equipped with a traditional satellite television (TV) decoder, they can replace the current population of direct-to-home (DTH) receivers, thus providing a capillary network of sensors with integrated bidirectional communication towards a fusion center (the NEFOCAST nowcasting platform).

The remainder of the paper is structured as follows. Sect. 2 describes the main drivers of the project, including the the advances with respect to the state of the art (SoA), whereas the main objectives and the market perspectives are detailed in Sect. 3. The key players, including the stakeholders, and the expected results are presented in Sects. 4 and 5, and Sect. 6 concludes the paper.

2 The project idea

As anticipated in Sect. 1, the solutions currently adopted to provide measurements for accurate, real-time, and hyperlocal weather forecasting show some significant limitations. The first impairment is represented by the need for a *dense grid* of such data collection points. Modern weather stations, albeit very rich in terms of variety of equipped sensors and accuracy of the measured parameters, cannot be located everywhere, due to the installation costs and the site requirements and size [3]. Similarly, WSRs, which are customarily employed in nowcasting scenarios thanks to the fine discrimination across the different types of hydrometeors, are heavily limited by the cost, which makes a sensor network equipped with many of these devices impractical.

A way out of this impasse is provided by weather satellites, that offer multi-range scanning of the weather conditions across different frequency bands, with wide continental beams. The downside of an extended coverage is a *poor resolution*, which has a negative impact on the forecast localization. As an example, the second-generation Meteosat satellites, operated by the European Organisation for the Exploitation of Meteorological Satellites (EUTMETSAT), are able to gather real-time information with a maximum resolution of 3×3 km^2 [4]. To obtain a finer resolution, we can resort to RF receivers that estimate weather conditions based on the link attenuation. While being attractive due to the relatively low costs, RF receivers require a specific installation campaign, thus limiting the *scalability* of the system, similarly to weather stations and WSRs. Furthermore, they operate in frequency ranges (e.g., VHF and UHF) which show a *scarce sensitivity* to rain conditions [5].

Another common drawback of all above-mentioned terrestrial technologies is the need for a *communication channel* between the measurement sensors and a common fusion center, which is able to collect all data and to apply the weather forecast algorithm. Although data-oriented wireless communications are widely available worldwide, this calls for equipping the sensors with a dedicated interface, thus increasing system design complexity, installation expenses, and operating costs.

To overcome all these shortcomings, NEFOCAST proposes a different solution based on a novel generation of an IST, called *SmartLNB* [6]. The SmartLNB technology belongs to bidirectional satellite communications, in which the IST is a transceiver providing Internet and broadcasting services. In the context of NEFOCAST, it also adopts an indirect estimation of the rain conditions, thus using the same principle adopted by RF receivers, but at more suitable frequencies. Designed by Eutelsat S.A. in collaboration with the European space agency (ESA), the SmartLNB is a low-cost, low-power low-noise block converter (LNB), that, in addition to standard video broadcasting services, is able to offer a two-way data communication channel, using the existing coaxial cabling (including the satellite dish) at the DTH premises.

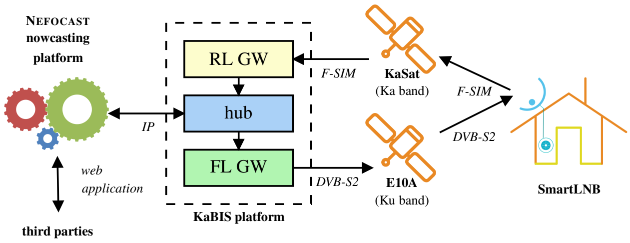

Figure 1. Architecture of the NEFOCAST platform.

Thanks to these features, a large penetration in the households is expected in the next few years, targeting a million terminals by the end of 2019 [6], and thus supporting the large scalability which is required for an effective nowcasting platform with real-time and high-density capabilities. The coexistence among a large population of SmartLNBs is made possible by selecting edge-cutting multiple-access technologies and adopting SoA signal processing techniques at the SmartLNB satellite platform [7], whose design and implementation has been mainly carried out by M.B.I. srl, the prime contractor of the NEFOCAST project (please see Sect. 4 for further details). Since the SmartLNB is already equipped for data delivery, it also solves the problem concerning the communication with a data collection platform: it is in fact able to send weather estimates with a very dense granularity in the time domain (e.g., sub-second measurements) and to simultaneously receive feedback from the nowcasting platform, such as weather alerts. This significantly simplifies and optimizes the nowcasting network architecture, as the SmartLNBs can simultaneously serve both as dense and scalable weather sensors, and as communication nodes.

In addition to these distinguishing features, the experimentation campaign selected for NEFOCAST (detailed in Sect. 5) adopts the dual-frequency version of the SmartLNB, in which the received and transmitted signals take place in the Ku and Ka bands, respectively. This has a two-fold impact on the accuracy of the hydrometeor detection: not only Ku (measured at the SmartLNB terminal) and Ka (measured at the SmartLNB platform) bands are particularly sensitive to rain events, especially compared to VHF and UHF, but the combination of the two measurements allows us to better identify the nature of the atmospherical event affecting the RF communication [8].

More in detail, the architecture of the NEFOCAST nowcasting platform is reported in Figure 1. As can be seen, the communication between the data collection point (the nowcasting platform) and the population of SmartLNBs, using standard Internet protocol (IP) protocols, is provided by Ka-band broadband interactive system (KaBIS), the satellite platform that supports the SmartLNB technology in the Ku/Ka band, whereas the interface towards third parties is done via web applications. Figure 1 also shows the main building blocks of KaBIS: the return link (RL) gateway (GW), the forward link (FL) GW, and the hub. The FL uses a satellite link (using E10A, a high-capacity satellite placed at 10° East) based on the digital video broadcasting - satellite (version 2) (DVB-S2) standard. The RL uses a satellite link (using KaSat, a multi-spot satellite placed at 9° East) based on the enhanced spread-spectrum Aloha (ESSA) protocol [9] – more specifically, an evolved version called fixed satellite interactive multimedia (F-SIM). In particular, the F-SIM protocol is the key factor that enables all the advantages listed above, including the large scalability of the system and the low cost of the SmartLNB terminals.

3 Main objectives and market perspectives

The main objective of the NEFOCAST project is the implementation of an *integrated platform* aimed at the analysis of the weather parameters (in particular, rain retrieval based on RF signal power attenuation) and at the provisioning of accurate weather information (e.g., precipitation fields). To this aim, the project activities target the design and the implementation of all required subsystems, including:

- modification to the current F-SIM protocol, implemented at both the SmartLNB and the KaBIS side, in order to optimize the transport layer between the SmartLNBs (as weather sensors) and the NEFOCAST platform;
- integration of additional weather sensors (that use the SmartLNB as the satellite modem) to increase the availability and the diversity of measurements;
- definition of a suitable rain retrieval algorithm that exploits the dense map of weather sensors, also using a dedicated WSR for validation purposes; and
- presentation of the results via a dedicated web application, designed to serve a wide number of third parties, including public safety and business-oriented players.

To meet all the goal listed above, the project is also supported by two major players, Eutelsat S.A. and Météo-France. Eutelsat is one of the three major satellite operators worldwide, covering Europe, Middle East, Far East, Africa, India, Northern and Southern America. Moreover, it owns the SmartLNB technology, and thus plays a key role in supporting the innovation required by NEFOCAST to the ISTs.

Météo-France, the French national weather service, is one of the leading national meteorological organizations worldwide and one of the founders of EUTMETSAT. Its support is thus significant to foster the exploitation of NEFOCAST nowcasting, in order to prevent natural disasters in rural areas and flash floods in urban areas. In line with the motivations presented in Sect. 1, NEFOCAST in fact aims at offering valuable services for a large number of business-oriented fields, such as precision agriculture, ground and air transportation, logistics, insurance companies, and media. The natural outcome of the project is finally the formation of an independent business entity, specialized in the provisioning of weather nowcasting services to third parties.

4 The project consortium

The NEFOCAST consortium is entirely composed by Tuscan partners: two small and medium enterprises (SMEs), M.B.I. srl and Pro.Ge.Com. srl, and three research centers, the Department of Information Engineering of the University of Pisa, the Radar and surveillance system (RaSS) laboratory of the Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT), and the Institute of Biometeorology (IBIMET). Each partner's expertise and role within the project is described in the following:

- M.B.I. srl, the prime contractor, is an ICT integration company, which is also the official provider of satellite platforms that adopt the SmartLNB technology. The main role is the design and the implementation of the hardware (HW) and software (SW) architecture of the NEFOCAST platform, including the interface with KaBIS.
- Pro.Ge.Com. srl, a consulting company whose core business is communication service provisioning, including web applications for public safety, is in charge of the implementation of the nowcasting data presentation.
- The Department of Information Engineering of the University of Pisa is an academic institution with expertise in the broad field of ICT, including satellite communications. The main task is to derive the analytical models that characterize the rain precipitation based on the RF measurements provided by the SmartLNB.
- The RaSS laboratory of the CNIT, a no-profit organization that groups 37 Italian universities, and the IBIMET, an institute of the Italian national research council operating in the broad field of climate-related solutions, cooperate to study the physical models behind the precipitation events, and to design a novel algorithm for rain retrieval.

5 Expected results and experimentation

The expected results of the project can be summarized into two aspects: the technical side, and the commercial side. The major scientific contribution is represented by a novel *rain retrieval algorithm*, which is able to fuse the measurements from a large number of dense weather sensors in both time (in the order of seconds and below) and space (in the order of few hundreds of meters) domains. For the preliminary outcomes of the NEFOCAST project, please see the companion paper [10], containing a first set of results of an inversion algorithm based on the received RF power from SmartLNBs already deployed on KaBIS.

From the commercial point of view, the outcomes of NEFOCAST are attractive for two different fields of application: institutional bodies and business services. In the first case, the target is to supply nowcasting information for public institutions at regional, national, and European levels (thanks to the support of organizations like EUTMETSAT). In the

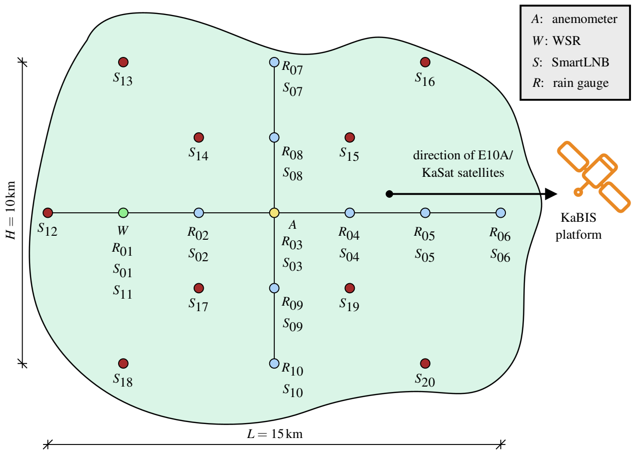

Figure 2. Map of the NEFOCAST experimentation site.

second case, the goal is nowcasting service provisioning to professional customers, such as the ones listed in Sect. 3.

To achieve these ambitious results, NEFOCAST also encompasses an extensive experimentation campaign, used to validate the proposed SmartLNB technology, combined with the derived rain retrieval algorithm. To this aim, a pilot system will be installed in the metropolitan area of Florence, Italy, following the map illustrated in Figure 2, in which each colored dot represents a weather station, possibly equipped with multiple sensors: S and P denote the SmartLNBs and the rain gauge, respectively (with the subscript reporting the sensor identifier), whereas R and A represent the WSR and the anemometer, respectively. As can be seen, the proposed experimentation site will take advantage of 20 SmartLNBs, 10 rain gauges, one WSR and one anemometer, arranged in an area of 15×10 km^2, also considering the direction of location of the KaSat and E10A satellites used by KaBIS (which is nearly the same thanks to the close orbital position), in order to optimize the performance of the nowcasting algorithm.

6 Conclusion

This paper described a recently launched research project named NEFOCAST, that aims at building a real-time weather forecast platform based on the usage of dual-frequency ISTs, using Eutelsat's SmartLNB technology. The advantages of the proposed solution compared to existing alternatives are multifold: *i*) increased spatial resolution, thanks to the IST, installed on a household basis, serving as the weather sensor; *ii*) increased coverage map, thanks to the usage of continental-based satellite beams; *iii*) increased frequency update of the measurements, thanks to rain retrieval based on RF power estimates, that are performed on every data packet transmitted and received by the IST, and that can be directly accessed by the nowcasting platform (via the IST, also acting as part of the communication infrastructure); *iv*) scalability of the platform, thanks to the penetration in the satellite TV market, with every subscribers being a potential weather station; and *v*) reduced deployment and operation costs, thanks to low-cost ISTs with integrated bidirectional communication.

7 Acknowledgement

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References

[1] C. Magnin, "How big data will revolutionize the global food chain," McKinsey & Co., Tech. Rep., Aug. 2016.

[2] C. Mass, "Nowcasting: The promise of new technologies of communication, modeling, and observation," *Bulletin of the American Meteorological Society*, vol. 93, no. 6, pp. 797–809, Jun. 2012.

[3] D. Cesarini, L. Cassano, M. Kuri, V. Bilas, and M. Avvenuti, "AENEAS: An energy-aware simulator of automatic weather stations," *IEEE Sensors J.*, vol. 14, no. 11, pp. 3932–3943, Nov. 2014.

[4] EUTMETSAT, Meteosat Design. [Online]. Available: http://www.eumetsat.int/website/home/Satellites/CurrentSatellites/Meteosat/MeteosatDesign/index.html

[5] J. S. Seybold, *Introduction to RF Propagation*. Hoboken, NJ: J. Wiley and Sons, 2005.

[6] Eutelsat SA, SmartLNB website. [Online]. Available: http://www.eutelsat.com/en/services/broadcast/direct-to-home/SmartLNB.html

[7] M.B.I. srl, Starfish website. [Online]. Available: http://www.mbigroup.it/en/starfish-platform/

[8] T. Teramoto, S. Chihara, W. Chujo, T. Manabe, S. Yamamoto, and A. Tsuzuku, "Ka- and Ku-band satellite availability and frequency diversity characteristics during rain using state transition matrix," in *Proc. Asia-Pacific Microwave Conf. (APMC)*, Yokohama, Japan, Dec. 2010.

[9] R. De Gaudenzi, O. del Rio Herrero, and G. Gallinaro, "Enhanced spread aloha physical layer design and performance," *Int. J. Satell. Commun. Network.*, vol. 6, no. 32, pp. 457–473, Nov.-Dec. 2014.

[10] E. Adirosi *et al.*, "Exploiting satellite terminals in Ka and Ku bands for the real-time estimation of rain intensity," in *URSI General Assembly and Scientific Symposium*, Montréal, Canada, Aug. 2017, submitted.