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Environmental Monitoring Network Applied to Propagation Studies at Millimetre Wavelengths

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Abstract

Wireless access networks based in millimetre wavelength technologies are mainly impaired by rain. To evaluate the rain effects over a communication system, it is essential to know the temporal and spatial evolution of rainfall rate. For this reason it is necessary to develop an experimental network which provides the adequate data to study, prevent and compensate the rain fade. In this paper, an experimental rain gauge network is presented. This network comprises weather stations capable of measuring rainfall rate, temperature and humidity. The paper describes first the experimental network for automatic data acquisition as a system based in a distributed process. The design of the experimental network is explained in detail and finally the interest for millimetre wavelength applications is pointed out.

Keywords: wireless technologies, telemetering, millimetre wavelengths, acquisition systems.

1 Introduction

The space-time variability of rain intensities at local scale is an essential input for a number of studies, including the planning and management of drainage [1, 2] and telecommunications networks [3, 4, 5].

In the field of meteorology and hydrology for urban areas, the requirements are for rainfall data with very fine time and space resolution. For this reason, a number of experimental campaigns to obtain data from weather radars and rain gauge networks have been developed in the past. The analysis of these data contributes to a better knowledge about the local distribution of precipitation [1, 3, 6, 7]. In some cases, it is possible to take advantage of these networks and use their data for studies in the field of telecommunications [8]. In addition, the availability of similar networks placed in different climatic regions will permit the cross comparison of the results about the spatial structure of rain, and its influence in the performance of radio telecommunication networks.

In the field of telecommunications, recent studies have shown the suitability of using weather radars to predict the impairments caused by rain over satellite or terrestrial links [9, 10]. Moreover, in Europe there are about 80 weather radars for meteorological purposes. Images from weather radars have also been used for the characterization of the spatial properties of rain [11].

The rainfall rate can change dramatically along space and time particularly during convective events [3]. Because of this, the rain fade suffered by a terrestrial or satellite link can not be exactly predicted from the point rainfall rate recorded, for example, at the receiver site. Since the link has a certain path length that could be partially or totally immersed within the rain, the attenuation series can be calculated more accurately if information about the rainfall rate along the path is provided, for instance, by a weather radar or a rain gauge network.

For the experiment described in this paper both data sources are considered, a weather radar which belongs to the Spanish Meteorological Office (SMO) and a rain gauge network consisting in 20 tipping bucket gauges located within the radar coverage.

Current advances in electronic and communication technologies have permitted the development of multifunctional sensor nodes with enhanced wireless communication capabilities [12]. These nodes sense, process and transmit the data, enabling the development of automatic sensor networks, which nodes are accessible from a wide area. These communication capabilities allow the system data to be remotely monitored and consulted. The implementation of a warehousing approach, allows data to be stored in a centralized database system that is responsible for query processing [13, 14]. The stored data will be used in the future to analyse the spatial and temporal variability of the rainfall rate.

The paper describes first the different elements employed in the experiment. These included (i) the meteorological sub-network, (ii) the propagation sub-network and (iii) the data management. The paper progresses towards the application of these data to performance studies of radio networks allocated in the millimetre wavelengths.

2 Data acquisition system

The Weather station data Acquisition System (WAS) structure for meteorological variable measurement is based on the mobile telephony network GSM, for communications between control station (CS) and weather stations (WS), and on Internet for communications with the weather radar (WR) and the central wireless node (CWN) (Fig. 1).

In this system the following physical and logical elements have been designed: twenty weather stations with all their sensors, networks access points (GSM, Internet and LAN),

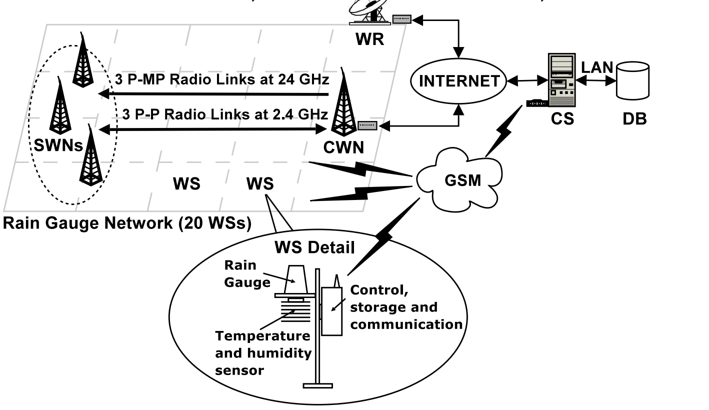

Figure 1: Weather station data Acquisition System (WAS) structure for the rain gauge network.

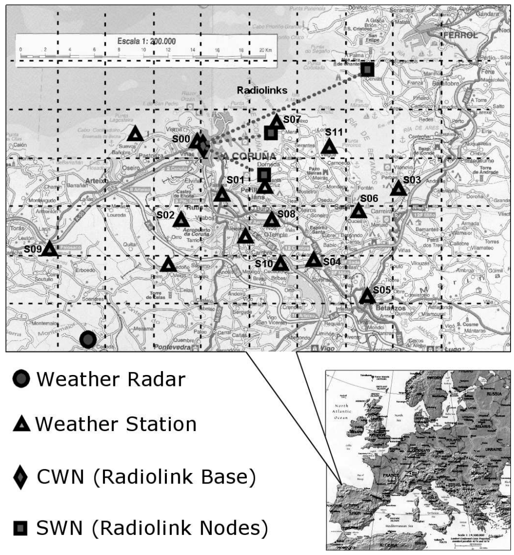

Figure 2: Weather station grid and weather radar location map.

the communication and data processing control station (CS) and the database (DB).

A second communication network has been superimposed to the weather stations experimental network, to study the precipitation impact on millimetre wavelength communication system. This second network comprises the following physical and logical elements: three broadband radio links in a point-to-multipoint (P-MP) configuration at 24 GHz, formed by three Secondary Wireless Nodes (SWN), and one Central Wireless Node (CWN) with Internet connection, and three WLAN based point-to-point links at 2.4 GHz between the CWN and the SWNs.

Each weather station comprises a GSM modem that transmits the meteorological information to the CS through a data call. In order to reduce costs, the CS makes a call to all the WSs every 24 hours by means of a polling procedure. During these calls the WSs send all the information that has been stored during that period. On the other hand, the collected data from the WR (radar images) and the CWN (radio links state) are sent through direct connections to Internet, under CS request. Therefore the CS periodically executes the reading data process and later database storage of the received information, through an Ethernet local area network.

The Territorial Meteorological Centre, which belongs to the Spanish Meteorological Office (Fig. 2), queries the database by Internet. Therefore, it is possible to calibrate and compare the data from the weather radar connected to the SMO, with the weather station data from the experimental rain gauge network. This allows to execute different applications whose meteorological impact can be relevant (section 4).

2.1 Meteorological data

The meteorological data sub-network consists in a C-band weather radar and a rain gauge network composed by 20 tipping-bucket gauges, located within the radar coverage and in the surroundings of the city of A Coruña (Northwest of Spain).

The weather radar belongs to the Spanish Meteorological Office and it is located on a hill at 600 m above the sea level. The radar can operate in two modes: (i) normal mode which provides a horizontal resolution of 2 Km and (ii) Doppler mode with 1 Km resolution. It performs twenty down-up scans resulting in a total time interval between two successive volumetric scans of 10 minutes. The reflectivity data recorded by the radar are then sent to the Regional Meteorological Office through a radio link at 10 GHz.

The chosen topology for the rain gauge network was a uniform grid of square cells. The cells have a dimension of 3x3 Km. Following this regular topology, one weather station has been installed within each cell to complete a total of 20 rain gauges (Fig. 2).

A weather station (WS) is the basic acquisition system and carries out the data registration (measurements and processing), and the communication with the control station (CS). In this way, each WS comprises an automatic measurement unity with data transfer capacity. Each WS is located within one of the squares of the grid shown in figure 2.

The data acquisition process is carried out inside the weather station, by the sensors and the console. Each WS comprises the rain gauge, an internal and external temperature sensors and an internal and external humidity sensors which are integrated in the console.

The rainfall rate measurements are carried out by an electronic tipping-bucket gauge with 0.1 mm tip size. The rain drops are captured by a collector and sent to a small bucket. When this bucket is full, it tips out, closing an electronic circuit and sending an impulse to the console.

The console is the system nucleus, it captures the data from each sensor, automates the measurements, synchronises the data and manages the communications. The data transmission is carried out by means of the data logger and the GSM

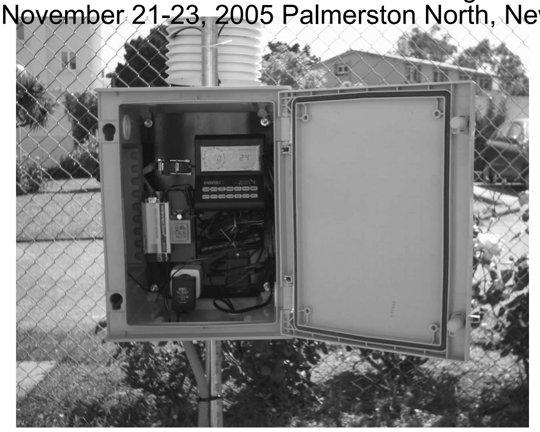

Figure 3: WS data acquisition and communications system assembled in the protection box.

modem connected to the console. Next, the data captured by the console is sent to the storage system where they are saved. The communication process setting, through the GSM modem connected to the data logger, permits the control and programming of several tasks in the console as well as the acquisition of the stored data.

The data captured by the console are organised in registers. The registers comprise the sensor outputs as well as the time and date. These registers are then sent to the storage system where they are saved for a future access. The console is programmed for capturing and storing the sensors information each minute. Due to the limited capacity of the storage system integrated in the WS, the data can only be stored during a day (24 hours).

Figure 3 illustrates the console, the storage system, the GSM modem and connections with the sensors and the electrical supply. All these elements are placed inside a box which protects them from the weather conditions. This box as well as all the sensors are fixed to a metallic base located at the site (Fig. 4).

2.2 Propagation data

The second part of the experiment comprises the study of the impairments caused by rain, in the radio communications systems working in the millimetre wavelengths. For this reason a sub-network comprising three radio links at 24 GHz has been installed, within the area covered by the meteorological data network (Fig. 2). The topology was chosen to be point-to-multipoint (P-MP) or divergent in order to take advantage of the spatial structure of rain and the path length is about 4 Km. Consequently, the links reproduce a network configuration which benefits from angular diversity. With this particular configuration, it is possible to study the relationship or dependence between the three attenuation series in terms of correlation, angular-diversity improvement, etc. The radio links are unidirectional from the CWN to the SWNs. The attenuation data registered at 24 GHz is sent through a signalling channel at 2.4 GHz employing WLAN

Figure 4: Final assembly and WS installation.

technology. The signalling channel is not affected by rain and sends the attenuation registered by the three links to the CWN, where it is again sent to the CS through the Internet.

2.3 Global data management

The information obtained from the data acquisition system (meteorological and propagation data) is collected by the control station and stored in the database for later process, analysis and query.

The CS requests and compiles the data from the different elements of the developed system (Fig. 5) to store them in the database. Thus the CS is provided with a GSM modem to make the polling query of each experimental WS in the network, and with an Internet connection to check the radio link state from the CWN, get the radar images from the WR and communicate with the DB.

Therefore the CS is a PC connected to GSM network and Internet that executes the developed program to perform its operations flowchart. The figure 6 shows this flowchart detailing the three basic tasks of system data query: WSs, CWN and WR query.

Since all the measured data must have the same time reference for its later process, the control station obtains the system reference clock from a real time network server by the NTP synchronization protocol (*Network Time Protocol*). So after the data have been obtained, a time synchronization test is verified for the WSs, the CWN and the WR clocks, to determine if the collected data can be considered valid. If this is the case, the information is stored directly in the DB. In the opposite situation, the problem is corrected (if it is possible), it is notified by email and/or a SMS message, and finally the data and the error information are stored. This way it is possible to known exactly when and what type of errors took place and, depending on this information, weather data

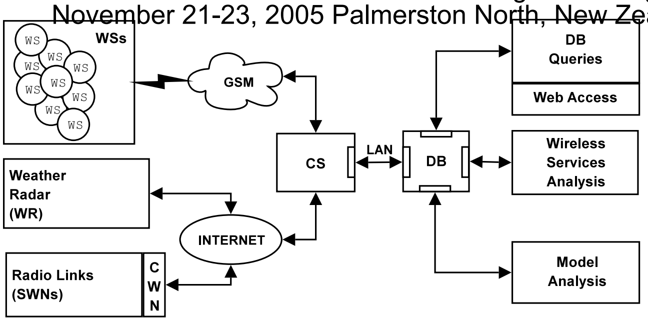

Figure 5: WAS architecture and database interfaces.

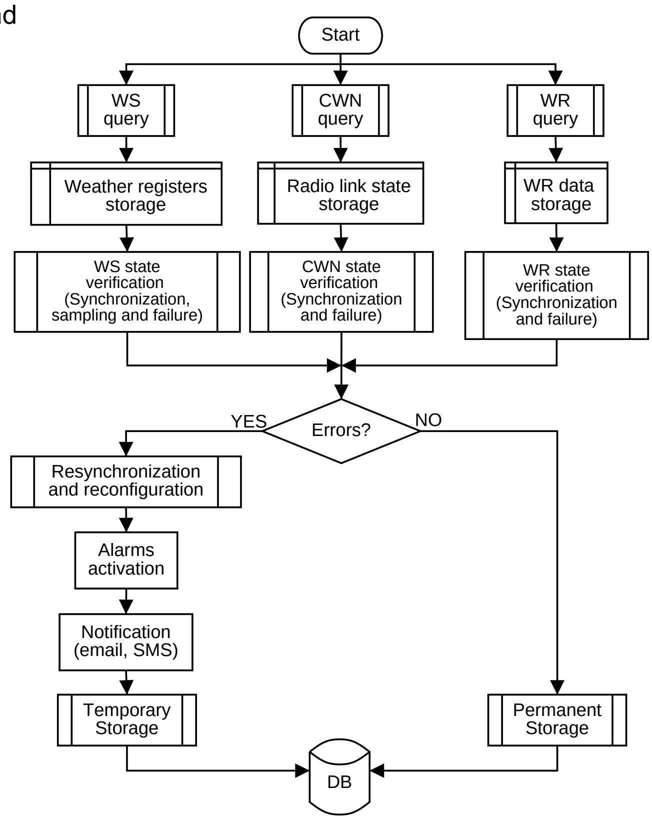

Figure 6: CS operations flowchart.

can be corrected.

The data from the weather stations network, the radio links and the WR are centralized in a relational database. This DB presents one interface with the CS, through which all the system information is introduced, and three interfaces to access this information: general data accesses, access to interesting data to analyse the wireless services, and query of data to obtain models (Fig. 5).

Since this system do not have the restrictions (sample rate and data volume) imposed to other acquisition systems [14], the interface between CS-DB and queries-DB are executed directly by means of ODBC (*Open DataBase Connectivity*). The general data access will directly take place through an Internet accessible web page. Whereas for queries related to the analysis of wireless services and models, the access is made through specific views for each type of study [15]. These views (*virtual cards*) considerably facilitate the services and models analysis.

Figure 7 shows an example of the WS data management. This figure illustrates the structure of communications between elements, interfaces and layers.

3 Application to broadband radio technologies in millimetre wavelengths

It was already pointed in the introduction the suitability of employing weather radars for propagation studies in the millimetre wavelengths. Nevertheless, weather radar accuracy is mainly limited by two factors. First, the transformation of radar reflectivity (Z) into rainfall rate (R) involves the assumption of a certain Raindrop Size Distribution (RSD). Although there are some well-known experimental RSD such as the Marshall-Palmer or the Joss distributions, it has been found that the RSD changes with the type of storm [16]. The usual process to obtain the rainfall rate consists in assuming a certain RSD and obtaining the relation between Z and R. This process may not be correct since it is based on the RSD assumption which can not validated in practice.

Because of the availability of a rainfall rate database provided by the rain gauge network, it is possible to "calibrate" the radar images with real rainfall rate data.

The second radar limitation that must be taken into account is the spatial and temporal resolution. The weather radar used in this research provides a horizontal resolution of 2 Km when it is operating in normal mode and 1 Km when it operates in Doppler mode. The time interval between two successive radar volumes is 10 minutes. The resolution can be improved if a rain gauge network complements the radar images because (i) the sensors are easy to install which permits to get the desired spatial resolution and (ii) in contrast with the radar images, the rain gauges provide instantaneous rainfall rate data.

Weather radar limitations can then be reduced if data from a rain gauge network is used. In addition, the radar provides coverage in places where the installation of a rain gauge network is not feasible.

Attending the reasons above, the design of a rain gauge network has been carried out as it was explained in section 2. The cells size was chosen to be 3x3 Km because of the similarity with previous experiments [1, 8]. Nevertheless, the rain gauges are not uniformly arranged due to the difficulties to find the ideal sites, and the distances between them are, in some cases, smaller or bigger than 3 Km. In any case, the average distance provides a ratio of at least one rain gauge every two radar pixels. In addition, recent studies have shown that this distance is enough to distinguish and extract the structure and movement of the rain cells [17].

Some previous studies about the spatial distribution of rain-

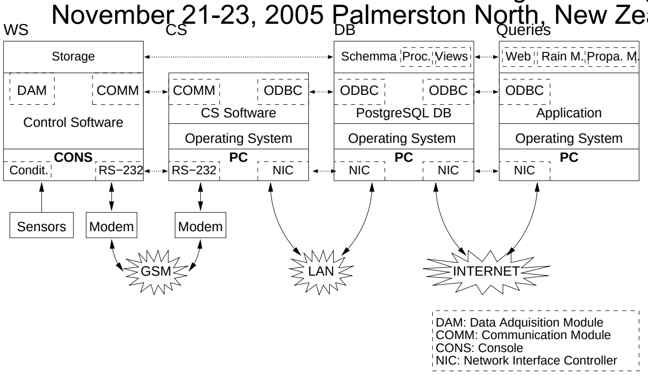

Figure 7: Communication example between elements, interfaces and layers.

fall rate have illustrated the significance of using spatial data for the analysis/prediction of the behaviour of the telecommunications systems. Figure 8 shows an illustrative example of a measured attenuation series carried out with the ITALSAT satellite at 39.6 GHz and the series calculated using rainfall rate data from a dense rain gauge network [8].

The characterisation of the spatial distribution of rainfall rates can be obtained from the radar images, once calibrated using the rain gauges information. Radar images can then be applied to the simulation and analysis of the performance of communication systems, fixed terrestrial or satellite, in the millimetre wavelengths. This analysis will permit the design and evaluation of numerous ways of optimising the communications by adapting the transmission parameters such as the transmitted power, coding or modulation.

The spatial and temporal characterisation of rainfall rates is also useful for the development of microscale/mesoscale precipitation models. These models can then be applied to a number of systems including hydrology or communications. The analysis of the spatial data provided by the radar-gauges network will complement the available information obtained from similar experiments [1, 8]. This fact will help to reduce the lack of results about the time-space structure of rainfall rate at local scale.

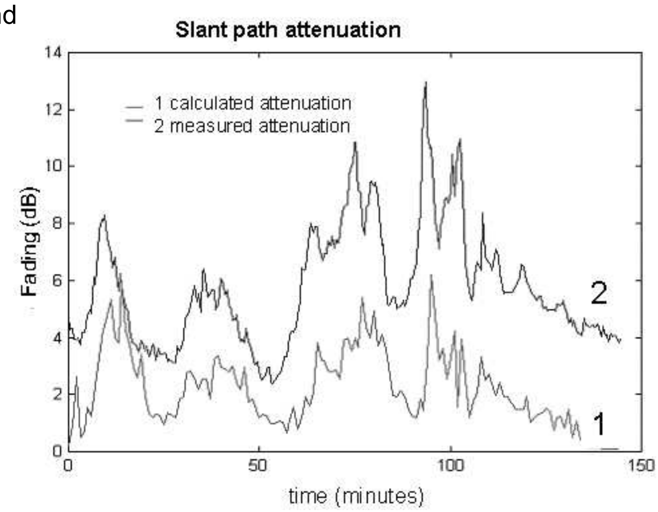

Figure 8: Comparison between measured and computed attenuation for the same radio link. Barcelona ITALSAT. 41^o elevation, 39.6 GHz.

4 Conclusions

The authors have designed a meteorological and propagation data acquisition and storage system (WAS) based on GSM network and Internet. This system has been developed within the area covered by the weather radar of the SMO, located in the neighbourhood of A Coruña (Spain). The WAS comprise a meteorological data sub-network formed, in addition to the WR, by a grid of 20 weather stations within 3 Km cells, and a propagation data sub-network formed by three radio links at 24 GHz and the signalling channel at 2.4 GHz (Fig. 2).

The aim of the WAS experiment is not exclusively limited to the field of telecommunications and the evaluation of the impairments caused by rain within broadband wireless networks, like the studied one in this article (section 3). For this reason the extension to the general meteorology scope is taken into account, providing a web service where meteorological data are available to all the users, and national or international agencies related to environmental studies in meteorology, hydrology, communications, natural disasters prevention, etc.

In the scope of wireless optical technologies applications, also it is interesting the evaluation of optics based services in free space (FSO) [18].

Also, in the radio communications scope, it is predicted to extend the study to other radio networks services such as: satellite distribution networks, satellite data networks with small aperture antennas (VSAT), stratospheric platforms (HAPs) [19], aeronautical services, fleets radio communication (TETRA), mobile networks without infrastructure (MANET), etc.

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