Rainfall Retrieval Through Commercial Microwave Links in Valmalenco (North Italy)

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Abstract

The signals transmitted across commercial microwave links used for cellular base station backhauling can be opportunistically processed to retrieve rainfall. In this work, we assess the potential and limitations of this technique when applied in a particularly hostile Alpine environment (Valmalenco, northern Italy). To this purpose, we exploit time series of transmitted and received power gathered by a network of operational links and compare the results with measurements performed with rain gauges and disdrometers and assumed here as the ground truth.

1 Introduction

It is well known that point-to-point microwave links can be used to retrieve the average rainfall intensity across the propagation path [1][2]. The pervasive growth of cellular mobile networks over the past two decades has made this technique attractive [3][4], especially where conventional rain gauges are scarce and weather radars are either not available or not effective.

Raw data, i.e. time series of transmitted and received power across each link are by-products of Commercial Microwave Link (CML) networks. However, as they are generated for link quality verification rather than for rainfall measurements, they have a number of limitations, such as rough temporal resolution, gross quantization and format of the available data (e.g. min/max rather than instantaneous power measurement). These add to the inner drawbacks of the technique: a non-linear and non-univocal relationship between rain attenuation and rainfall rate, the spatial inhomogeneity of rain across the path and unwanted attenuation components due to other atmospheric effects, multipath, wet antennas and water diffusing into the antenna feed and the waveguides, among others. For the above reasons, CML data must be thoroughly processed and, when possible, calibrated against reliable benchmarks (rain gauges, disdrometers or radars).

The objective of this paper is to assess the potential of using CMLs to estimate rainfall in a particularly hostile Alpine environment; the chosen area is Valmalenco, located in the Sondrio province, about 100 km North-East of Milan, Italy. The area is of great hydrological and geological interest, since it is a narrow, steep valley that is prone to floods and landslides. This area was already addressed during the MANTISSA project [5]. However, the dual-frequency microwave link used in that occasion was designed and installed purposely for the experiment, and it had the characteristics of a measurement instrument (i.e. high accuracy, stability and resolution). The operational CMLs used in this work, on the contrary, are not optimized for this application and have all the limitations discussed above.

This paper reports preliminary results of the experimental campaign carried out in the frame of the MOPRAM (Monitoring of PRecipitation through A network of Microwave radio links) project. Specifically, the rainfall amount estimated from CMLs will be compared with that obtained from co-located rain gauges and disdrometers; preliminarily, we will describe the procedure adopted for the estimation of rainfall from power data. To the authors' knowledge, this work is one of the first attempts to measure rainfall by CMLs in a mountainous area.

2 Experimental Set-Up

Measurements were carried out in an Alpine area of particular interest from the hydrological and geological point of view, where the Mallero torrent flows through the narrow and steep Valmalenco valley, before joining Adda river, one of the biggest watercourses in northern Italy. The CML data used in this work are owned by Vodafone Italia S.p.A. and were generated by a network monitoring tool implemented by SIAE Microelettronica S.p.A. The available data are the minimum and maximum values of the transmitted and received power across each (two-way) link, measured during 15-min time slots. The quantization step is 1 dB.

Figure 1 shows the location of the links (black solid lines). An overall 13 CMLs are operational in the area of Valmalenco as well of Valtellina (the major valley in the area), with transmission frequency comprised between 10.74 GHz and 23.03 GHz and path length between 2.7 and 14.0 km, respectively. Link elevation angles are as high as 20°, because antennas are often located on the top of high mountains. The altitude of link terminals is between 300 m and more than 2200 m a.m.s.l. Four operational rain gauges of the network owned by the regional environmental protection agency of Lombardy (ARPAL) are shown as well (red triangles labelled as CAI, LAG, LAP and SFF, respectively). Moreover, two disdrometers were deployed as part of MOPRAM experimental activity (blue circles labelled as CAG and PRI, respectively). The rain gauges and the disdrometers are used here as the ground truth against which to validate rainfall estimates gathered from link data.

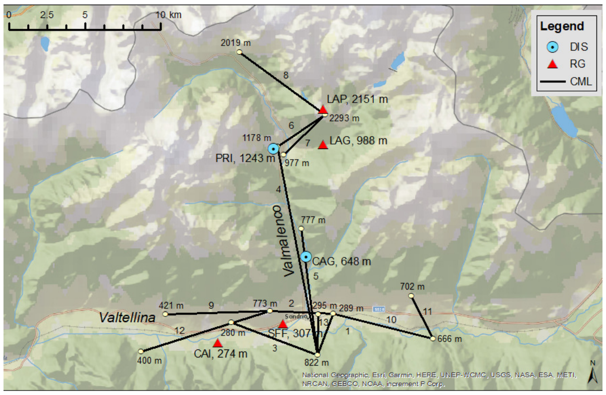

Figure 1. Location of 13 CMLs, four rain gauges and two disdrometers in the Alpine area of Valmalenco and Valtellina (northern Italy).

3 Methods

Several authors have proposed methods for extracting rainfall intensity from the time series of received power across a microwave link [6][7]. Here, we use an approach similar to the one discussed in [6] for a network of CMLs in the Netherlands. The procedure described in the following relies only on CML data and goes through five steps:

1. Identify outliers.
2. Identify wet and dry periods of time.
3. Build the baseline.
4. Calculate rain attenuation.
5. Calculate rain intensity.

Outliers are defined here as occasional spikes in the time-series of receiver power, which are not caused by rain. They are identified by a simple threshold-based algorithm. Besides outliers, other anomalous signal patterns are detected by visual inspection.

Subsequently, every 15-min slot of each link is flagged as wet or dry. To classify the slot t of link i, the following test is carried out over i and the N_i nearby links, by taking advantage of the spatial correlation of rain: if the difference between the minimum received power and the above reference power level exceeds a given threshold, a binary flag B_k is set to 1, otherwise it is set to 0, where k=1,2, …, N_i +1. The slot is wet if the following condition holds:

$$c_i(t) = \frac{\sum_{k=1}^{N_i+1} W_k B_k(t)}{\sum_{k=1}^{N_i+1} W_k} > 0.5 \qquad (1)$$

where W_k is the weight of the k-th link, which is inversely proportional to the minimum measurable rain intensity across k. The procedure is iterated over all the links moving from the one with the maximum number of neighbors.

Third, a reference level of received power, namely the baseline (bl), is identified for each link. The baseline $P_{bl,i}$ represents the received power level in the absence of rain. It is calculated by averaging minimum and maximum received power over a dry period at least two-hours long immediately preceding a wet period.

Fourth, the rain attenuation across link i at the slot t, $A_{rain,i}(t)$, is estimated by the following formula:

$$A_{rain,i}(t) = P_{bl,i}(t) - P_{rx,i}(t) \qquad (2)$$

where $P_{rx,i}(t)$ is the received power. Last, the rainfall intensity (averaged over the propagation path) at the slot t, $R_i(t)$, is obtained by inverting the power-law relationship provided by ITU-R P. 838-3 recommendation [8]:

$$A_{rain,i}(t) = L_i k_i R_i(t)^{\alpha_i} \qquad (3)$$

where L_i is the path length, whereas k_i and α_i are coefficients dependent on frequency, polarization and link elevation. For instance, k_i =0.0156 and α_i= 1.1741 at 10.74 GHz (link 4), whereas k_i = 0.1287 and α_i= 0.9628 at 23.03 GHz (link 8).

If only min-max measurements are available, an average R value can be calculated every 15-min as a weighted sum of the corresponding minimum and maximum rain attenuation values [6]. Moreover, the received power-to-rain rate conversion model should take into account the wet antenna effect and other biasing factors. It can be done, for instance, by subtracting an extra attenuation term from the first factor of (3). The parameters of (3) are usually optimized by comparison with rainfall estimates provided by rain gauges, disdrometers or weather radars. However, because of the relatively small amount of precipitation data collected so far in this experiment, a reliable model calibration procedure could not be carried out. Sample data available over few links at a 0.1 Hz sampling rate (not shown here) highlight a marginal overestimate of the arithmetic average between maximum and minimum power with respect to the actual average in a 15-min slot. The wet antenna effect is observed after rain has ceased (according to nearby rain gauges), but it is not easy to quantify due to the rough quantization step. In this preliminary work, the average rain rate is calculated as the arithmetic average of min-max rain attenuation (on a dB-scale) whereas wet antenna attenuation is not considered.

4 Results

Concurrent CML, disdrometer and rain gauge data were collected during two 48h rainy periods in July 2019 (see Table I). Four major episodes were detected, one in the first period and three in the second one.

Table 1 Rain events considered in this study. The rainy time is averaged over all the six precipitation sensors.

Start	*End*	*Max. intensity*	*Max. rainfall depth*	*Rainy time*
14-Jul	15-Jul	17 mm/h	28 mm	393 min
25-Jul	26 Jul	125 mm/h	35 mm	195 min

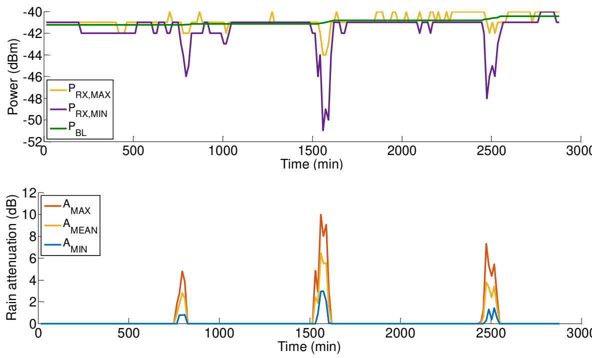

Figure 2 Example of CML data (link 6). Top panel: time series of minimum and maximum transmitted and received power during a 48h period including three rain episodes; bottom panel: corresponding rain attenuation derived through (2).

The top panel of Figure 2 shows an example of raw power data (link 6 of previous Figure 1) collected on 25-26 July. Three rain events are visible. Only the received power time series are shown as the transmitted power was very stable and equal to 20 dBm. During extreme events, an Adaptive Power Control (APC) system increases the transmitted power. In such a case (2) should be modified, including the term relative to the transmitted power. The bottom panel has minimum, maximum and average rain attenuation as calculated by the procedure described in Section 3. The maximum attenuation peaks to almost 10 dB across a 4.0 km path at the link frequency of 18.09 GHz.

Figure 3 shows the time series of 60-min accumulated rainfall (i.e. rainfall depth) gathered from the six rain sensors on 14-15 July. The top panel has the four sensors in Valmalenco (LAP, LAG, PRI and CAG), whereas the bottom panel reports the rain gauges in Valtellina (CAG and SFF). Both the northern and southern part of the measurement area were interested by the major precipitation event between 1230 and 1950 min at the same time, accumulations being higher in the North.

The terminals of link 6 are located close to three rainfall sensors (LAP, LAG and PRI), hence it has been chosen to compare rainfall estimates. Please note that the propagation path goes through Valmalenco from SW to NE, path elevation being around 15°. The SW terminal is located at 1273 m a.m.s.l., whereas the NE one is at 2271 m a.m.s.l. As the time stamps of disdrometer, rain gauge and link data are rather different (1-min, 10-min and 15-min, respectively), the comparison is carried out between the time-series of 60-min accumulated rain as shown in Figure 4. The three-time series are in rather well agreement. The

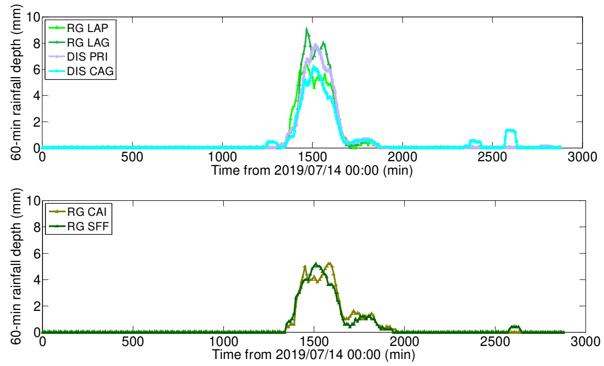

Figure 3 60-min accumulated rainfall on 14 and 15 July 2019, as measured by the six rainfall sensors deployed in the measurement area.

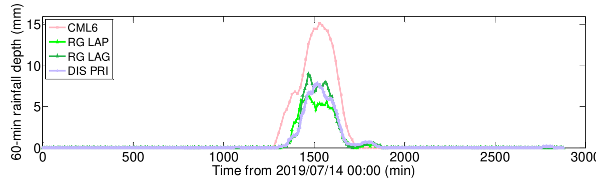

Figure 4 30-min accumulated rainfall on 14 and 15 July 2019: comparison between link 6, and the two rainfall sensors located close to its terminals.

accumulated rainfall collected by LAP, LAG and PRI during the event are about 26, 24 and 37 mm, respectively.

The spatial distribution of rain on 25-26 July was rather inhomogeneous (Figure 5) and rainfall sensors recorded much higher accumulations than in the previous case. The first event was detected only by PRI (western side of Valmalenco), whereas the last two events involve the entire measurement area, even though there are large differences in the amounts of rain collected. The second event has a peak hourly accumulation of almost 19 mm (at PRI) and much lower in the other sites. The third event has peak accumulations of 21 mm in Valtellina (CAI).

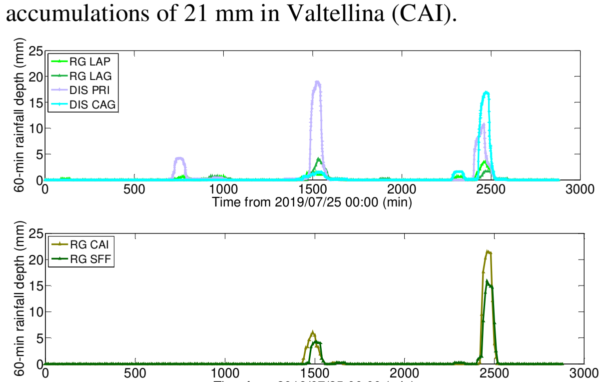

Figure 5 60-min accumulated rainfall on 25 and 26 July 2019, as measured by the six rainfall sensors deployed in the measurement area.

Figure 6 shows the hourly rainfall depth as observed by LAG, LAP, PRI and CML 6. The correlation between the occurrence of rain is good, even though the magnitude of the accumulation is much different due to the high spatial variability of the event. As expected, the curve of rainfall depth obtained from CML data is between PRI and LAP. The accumulation over the entire 48h period are 9, 8, 35 and 34 mm, respectively.

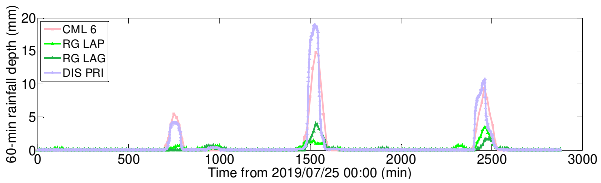

Figure 6 60-min accumulated rainfall during three rain episodes occurred on 25 and 26 July 2019: comparison between link 6 and the three rainfall sensors located close to its terminals.

Figure 7 shows a comparison of the 48h accumulated rainfall on 25-26 July across every link against the one measured by the nearby rainfall sensors, i.e. the ones at a distance less than 1 km (if any). Eight links are within 1 km from the closest rainfall sensor, however link 8 has too many invalid data and it is not considered. Even though in a majority of cases (links 4, 6, 7 and 12) there is one nearby rainfall sensor with small differences in rain accumulation, the discrepancies increase when one considers the average of the nearby sensors. The rainfall estimated by link 4, which follows the SN course of Valmalenco and it is very long (14.0), and by link 6 are between the minimum and maximum measured by the nearby sensors, whereas link 5 and 7 exceed the maximum. A similar comparison for the event of 14-15 July (not shown here), where rain is rather uniformly distributed throughout the measurement area, confirm that CMLs tend to overestimate rainfall depth with respect to rain gauges and disdrometers. Possible explanations are: a) a wrong baseline calculation due to clear-air effects, such as an increase in water vapor absorption just before an event (due to an abrupt increase in the relative humidity), b) wet-antenna effects, and c) the actual drop size distribution results in different k and α coefficients then those predicted by ITU-R.

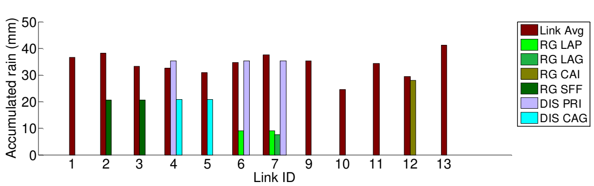

Figure 7 Rainfall accumulated during 25 and 26 July. Comparison between CML estimates (maroon bars) and nearby rainfall sensors (if any).

5 Conclusions

The experimental campaign carried out in the frame of the MOPRAM project aims, among others, at assessing the potential of CML data for rainfall estimates and rainfall field retrieval in an Alpine area of hydrological interest (Valmalenco, northern Italy). Despite the geomorphology of the measurement area is challenging and the link approach is not optimized due to lack of measurements, preliminary results highlight a fair agreement between accumulated precipitation estimated by the CML and conventional rainfall sensors. However, CMLs tend to overestimate the rainfall depth values with respect to rain gauges and disdrometer measurements. Future work will focus on implementing procedures to calibrate model parameters in order to reduce potential biases.

6 Acknowledgments

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7 References

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