Empirical Study of the Quantization Bias Effects in Commercial Microwave Links Min/Max Attenuation Measurements for Rain Monitoring

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Abstract

The potential of commercial microwave links to be used as sensors for rain monitoring depends heavily on the availability of the links attenuation measurements. The cellular operators which provide the majority of these measurements usually make use of the standard Network Management Systems (NMS), which log only a quantized version of the minimum and the maximum attenuation values (usually in 15-minute intervals). The non-linear min/max transformation and the quantizer, which are implemented on the channel attenuation measurements, should be considered during the rain-estimation procedures. In this paper, we examine actual NMS produced attenuation measurements taken from a commercial microwave link during multiple rain events. Using observations from rain-gauge and weather radar, we experimentally demonstrate that the output of the NMS includes bias, which in turn interferes with the rain-estimation process. We show that the detection and the compensation of this bias has the potential to increase the microwave links rain-estimation accuracy dramatically.

Keywords: Quantization Bias, Microwave Links, Precipitation Attenuation

1. Introduction

The potential of using standard Commercial Microwave Links (CMLs) which are part of the infrastructure of modern Microwave Communication Networks (MCNs) for rain monitoring purposes was suggested a decade ago (Messer *et al*, 2006). Since that time, the capability to use the available CMLs as remote sensors for the environment was studied by many researchers, and many achievements have been made. It has been shown that CMLs can be used to detect and classify rainy periods from dry periods (Schleiss *et al*, 2010; Chwala *et al*, 2011; Overeem *et al*, 2011) and to measure the rainfall accurately in various scenarios (Overeem *et al*, 2011; Rayitsfeld *et al*, 2012). Algorithms for creating 2-Dimensional rain maps were presented (Goldstein *et al*, 2009), and country-wide rain mapping using CMLs was demonstrated (Overeem *et al*, 2013). In addition, example of dynamic rainfall monitoring was recently demonstrated (Roy *et al*, 2016). Furthermore, the integration of rain measurements taken by CMLs with standard radar and rain-gauges measurements was discussed (Bianchi *et al*, 2013; Liberman *et al*, 2014), and a survey integrating three years of rain monitoring using CMLs was recently presented (Overeem *et al*, 2015). Recent cooperation between several research groups in Europe and Africa presented the potential to use CMLs in Africa, where no other observation tools are available, and thus, standard rain-monitoring capabilities are not-existing (Doumounia *et al*, 2014; Gosset *et al*, 2015). Despite the advances achieved in the last decade, the fact that the major part of the available CMLs measurements are produced by the MCNs Network Management Systems (NMS), and thus, contain only a quantized version of the minimum and the maximum values of the Received Signal Level (RSL) and the Transmitted Signal Level (TSL), usually in 15-minute intervals, remains challenging. Although various methodologies for treating the min/max transformation were presented (Overeem *et al*, 2011; Ostrometzky *et al*, 2014, 2016), the fact that the available RSL and TSL measurements pass a quantizer was generally ignored. These errors were considered to be unavoidable (Kollar, 1994), and relatively small for the purpose of rain monitoring using CMLs attenuation measurements, and thus, did not attract special interest. Nonetheless, we have recently shown that the quantization process, in combination with the min\max transformation, may introduce a high bias into the measurements (Ostrometzky *et al*, 2017). This bias cannot be neglected, as it can affect the rain-estimation accuracy dramatically. In this paper, we present for the first time an experimental demonstration designed to show how this bias affects accumulated rainfall estimations. The results validate the theory that this bias should be detected and subtracted from the available measurements prior to the estimation process in order to increase the rainfall estimation performance. The rest of this paper is organized as follows: In Section 2, the methodology is described. Then, the experimental setup and results are presented in Section 3. Lastly, Section 4 concludes this paper.

2. Methodology

The relationship between the rain-intensity at a given time t, $r(t)$ (in *mm/h*), and the CML path induced attenuation at that time, *A(t)* (in *dB*), can be expressed by the well-known *Power-Law* equation (Olsen *et al*, 1978):

$$A(t) = a[r(t)]^b L \quad (1)$$

where *L* (in *km*) is the CML path-length, and *a* and *b* are coefficients which depend on the CML specific signal frequency, polarization, and the drop-size-distribution of the rain. Their values are considered to remain relatively constant, and are published in the technical literature (ITU, 2005). For the experimental purposes of our research, we obtained the NMS produced logs from the Israeli cellular operator *Cellcom*™, which utilizes NMS that sample the TSL and the RSL values every 10-seconds, but produce an output log with only the observed minimum and maximum TSL and RSL values within 15-minute intervals (defined for the *i^th^* interval by TSL_i^{min}, TSL_i^{max}, RSL_i^{min}, and RSL_i^{max} respectively). The TSL measurements are quantized by a quantization level of $\pm 1dB$, and the RSL measurements are quantized by a quantization level of $\pm 0.3dB$. From these available quantized extreme measurements, the maximum and the minimum attenuation which occurred within each interval can be approximated by:

$$A_i^{min} = TSL_i^{min} - RSL_i^{max} \quad (2a)$$

$$A_i^{max} = TSL_i^{max} - RSL_i^{min} \quad (2b)$$

where A_i^{min} (in *dB*) is the minimum observed attenuation value within the i^{th} interval, and A_i^{max} (in *dB*) is the maximum observed attenuation value within the i^{th} interval.

Based on equations (2a) and (2b), the attenuation caused by the maximal observed rain-intensity in the i^{th} interval, defined by $A_i^{r\_max}$ (in *dB*), can be directly extracted (Ostrometzky and Messer, *in review*):

$$A_i^{r\_max} = A_i^{max} - \min(A_{i-1}^{min}, A_i^{min}) \quad (3)$$

from which, the averaged rain-intensity in the i^{th} interval, defined by r_i^{avg} (in *mm/h*), can be calculated using an adaptation of the Power-Law's *a* coefficient (Ostrometzky *et al*, 2016):

$$r_i^{avg} = \sqrt[b]{\left(\frac{A_i^{r\_max}}{\tilde{a}L}\right)} \quad (4a)$$

$$\tilde{a} = a \cdot [\ln(90) + 0.57722]^b \quad (4b)$$

On the other hand, as we claim that $A_i^{r\_max}$ includes bias which is to be considered, we suggest to rewrite eq. (4a) as follows:

$$r_i^{avg} = \sqrt[b]{\left(\frac{\max(A_i^{r\_max} - B, 0)}{\tilde{a}L}\right)} \quad (5)$$

where *B* (in *dB*) is the induced bias due to the combination of the quantizer and the min\max transformation. Negative values of ($A_i^{r\_max} - B$), if exist, were accounted as zeros.

Next, an experiment which emphasizes the effects of this bias, *B*, is presented.

3. Experimental Setup

An experiment was designed based on a real operational CML. The specific CML was chosen based on the availability of the NMS measurements (provided by the Israeli cellular operator *Cellcom*™), and the availability of a nearby Rain-Gauge (RG) and weather radar coverage, both controlled by the Israeli Meteorological Services (IMS). The experiment details are as follows:

- The minimum and the maximum TSL and RSL measurements in 15-minute intervals were logged by a CML located near the city of *Arad, Israel.* The CML path-length is *16km,* and it operates at a frequency of *18.6GHz*, using *Horizontal* polarization. Thus, based on the literature, the corresponding Power-Law coefficients for this specific CML are *a=0.077;b=1.074*. From which, the value of $\tilde{a}$ is directly derived using equation (4b): $\tilde{a} = 0.44$.
- An IMS controlled RG located near the CML base-station in the city of *Arad*, (roughly *3km* from the CML path) was monitored to observe the amount of rainfall.
- Unlike the RG, which provides point measurements, the CML is affected by rain throughout its path L (see eq. (1)). Due to the difficulties in comparing point to path-integrated rainfall measurements, a weather radar was also used. Data were derived from the IMS controlled Radar, located in Beit-Dagan (central district, roughly 85km from the CML), from which the radar cells covering the path of the CML were used in order to approximate the average rainfall along the CML path, as demonstrated in an earlier study (Eshel *et al*., *In Review*).

4. Results

Three rain events were analyzed in order to compare the performance of the CML, with and without the subtraction the bias, *B* (of eq. (5)), with the different instruments. The specific events occurred on 06-Nov-2015, 01-Jan-2016, and 25-Jan-2016. The duration and the total rain depth for each event are summarized in Table 1. For each event, the available TSL and RSL data-series were used to calculate the minimum and the maximum attenuation values (of eq. (2a) and (2b)), from which, the averaged rain intensities for each 15-minute interval within the events, r_i^{avg} of eq. (5), were derived for the durations of the events, twice:

- No Bias Subtraction, $r_i^{avg}(B = 0)$, defined by NBS: *B* of eq. (5) was put to zero (i.e., no bias consideration was taken).
- Bias Subtraction, $r_i^{avg}(B = 1.6)$, defined by BS: *B* of eq. (5) was taken as *1.6dB* for the calculation of r_i^{avg} for all events. The value of *1.6dB* was found during dry periods prior to each event (and was found to remain constant at *1.6dB*). This value is based on the quantization levels and the specific CML additive noise (Ostrometzky et. al, 2017).

The cumulative CML rain depth throughout each event was also calculated twice. In addition, for comparison, the cumulative rain depth for each event was derived both from the RG, and from the radar. It is worth noting, that comparing the monitored rain from the different sensors (i.e., CML, RG, and radar) is inherently challenging, as each sensor has different spatial and calibration properties. Thus, in order to reduce errors regarding instrumental

Table 1. Experimental Results. The details of each rainy event (as observed by Arad rain-gauge), and the normalized Root Mean Square Error (RMSD) between the radar (RAD) and the CML, and between the Rain-Gauge (RG) and the CML are detailed.

Event	Duration (hours)	Total Rain Depth (mm)	RMSD (RAD)		RMSD (RG)	
			BS	NBS	BS	NBS
06-Nov-15	7	20.8	0.0529	0.1065	0.1241	0.1366
01-Jan-16	28	24.1	0.1194	0.1174	0.0749	0.0727
25-Jan-16	20	16.9	0.0772	0.0942	0.0727	0.1072

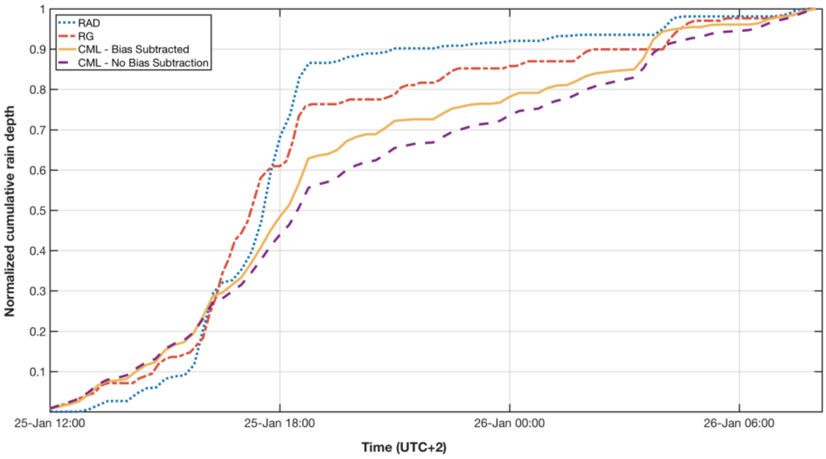

Figure 1. Normalized accumulated rain depth for a chosen event- 25-Jan-2016, monitored by: radar (RAD), rain gauge (RG), and CML with and without bias subtraction.

adjustments, and to confine ourselves to comparing only the effects of the aforementioned bias, each cumulative rain depth data series was normalized to its total accumulated value. An example of the four (normalized) calculated cumulative rain depths (throughout the event of 25-Jan-2016), can be seen in Figure 1. In addition, the Root Mean Square Difference (RMSD) between the two CML based cumulative rain-depth plots (BS and NBS) and both the RG and the radar based plots were performed for each event. The specific RMSD calculations are detailed in Table 1. From Figure 1, it is easy to see that the subtraction of the bias indeed reduced the gap between the CML based cumulative rain estimate and that of the RG and the radar, throughout the presented event. Furthermore, as can be seen in Table 1, the benefit of subtracting the bias is not unique to this specific example: Examining the resulted RMSD presented for the three different events, shows that the subtraction of the bias could indeed be a contributing factor to CML based rain estimation accuracy. Indeed, in one case, the bias did not affect the RMSD of the CML based estimate (during the event which occurred on 1-Jan-2016). However, even in this case, subtraction of the bias did not harm the calculated RMSD.

5. Conclusion

In this paper, we examine the bias which affects the min/max quantized Received Signal Level and Transmitted Signal Level measurements, used for rain monitoring. Using a specially designed experiment, we show for the first time that this bias indeed interferes with CML based rain estimation methodologies. We believe that the empirical results and conclusions presented in this paper should be used as a basis for future research, both for better understanding the effects of this bias in regard to different climates and rain physical properties, and for the implementation of new modules for bias compensation in current and future CML based rain estimation algorithms.

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