Statistical Signal Processing Approach for Rain Estimation Based on Measurements From Network Management Systems

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Outlines

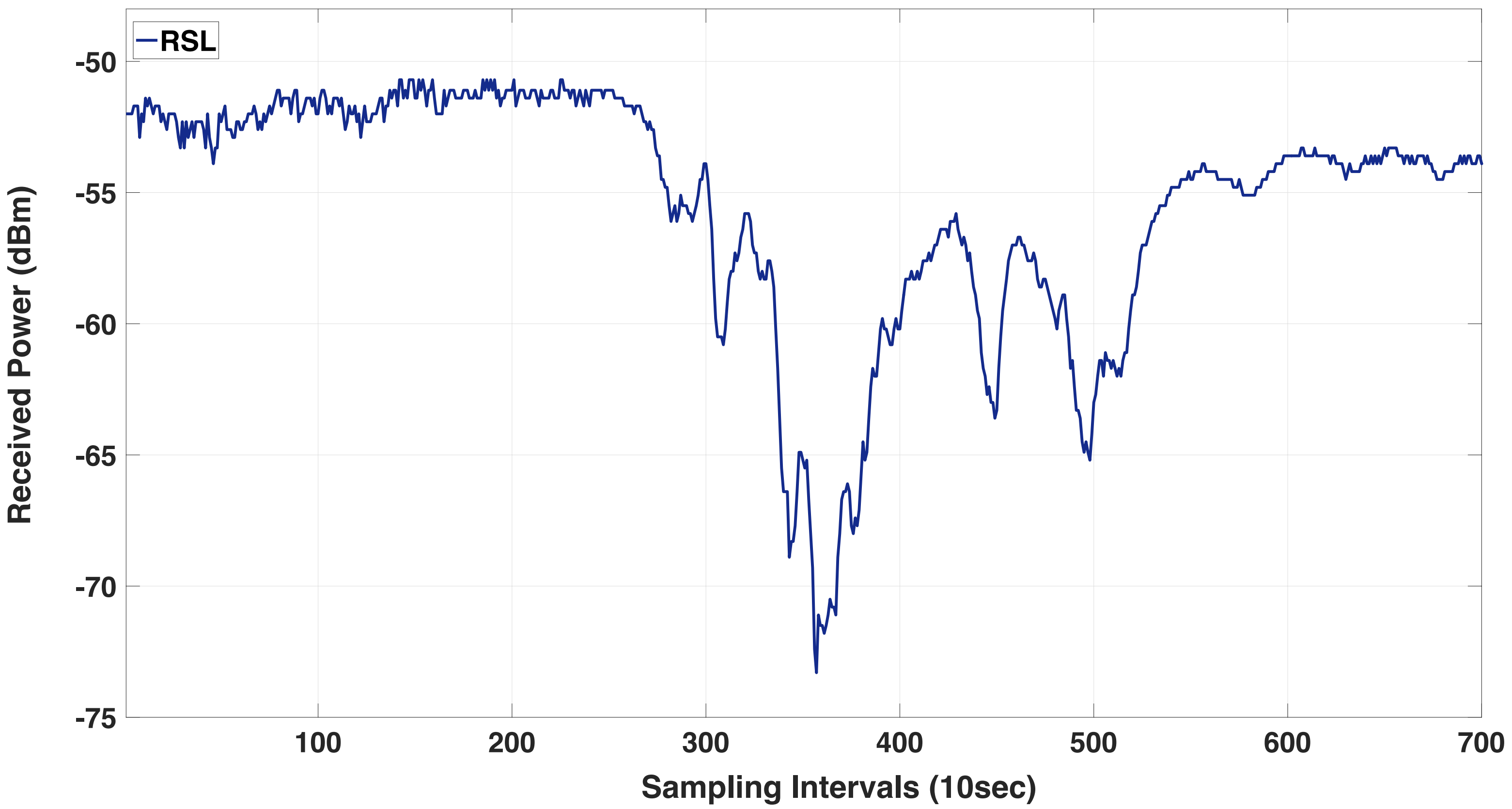
- The Challenge
- The Idea
- Pre-Processing
- Rain Estimation
- Demonstration

The Challenge

SNMP access
– The ”**Active**” Approach

- ✓ Instantaneous Measurements
- ✓ High Temporal Resolution (10-second)
- • Variable dynamic range
- • Variable base-line attenuation
- – Rough quantization
- – **Complicated and hard to get**

~2 hours of Received Signal Level (RSL) data-series (taken from a commercial microwave link near Gothenburg) during a rain event in summer 2015



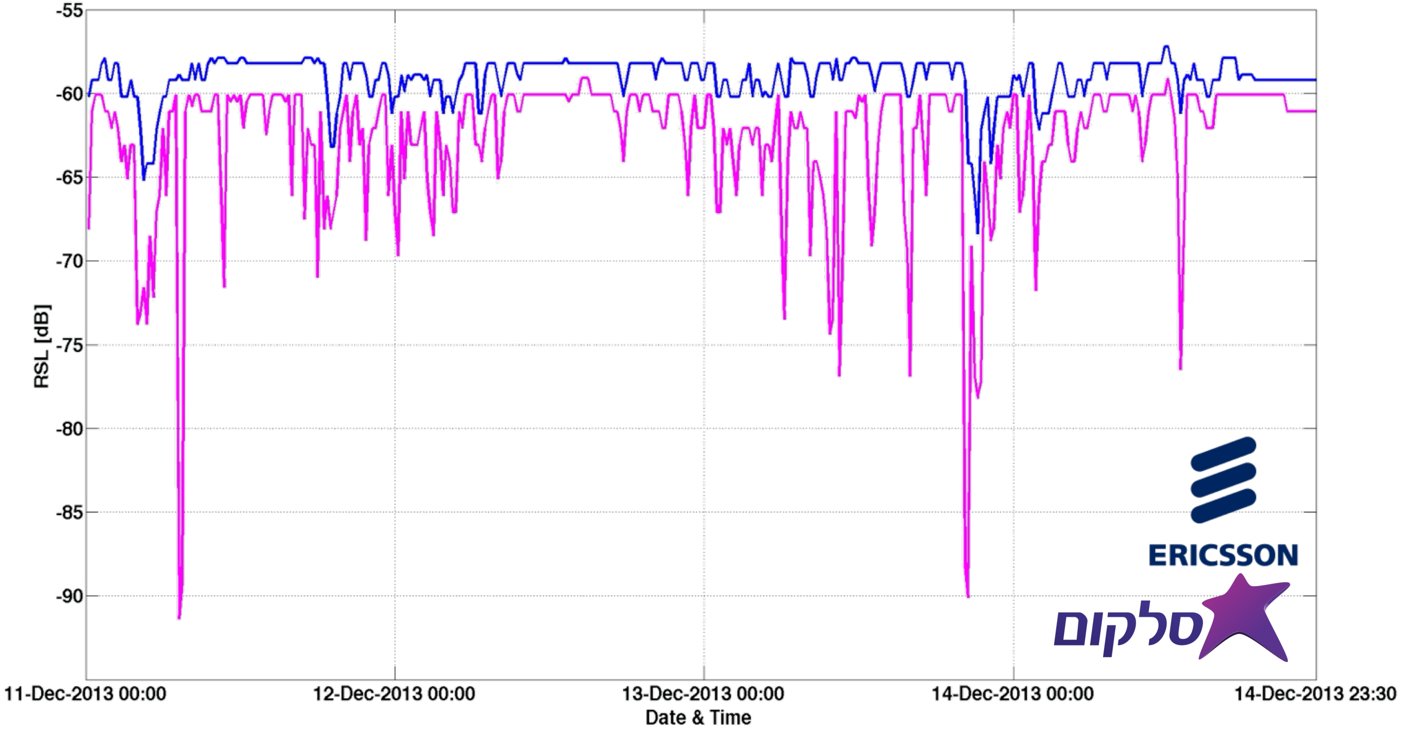
By Ericsson AB

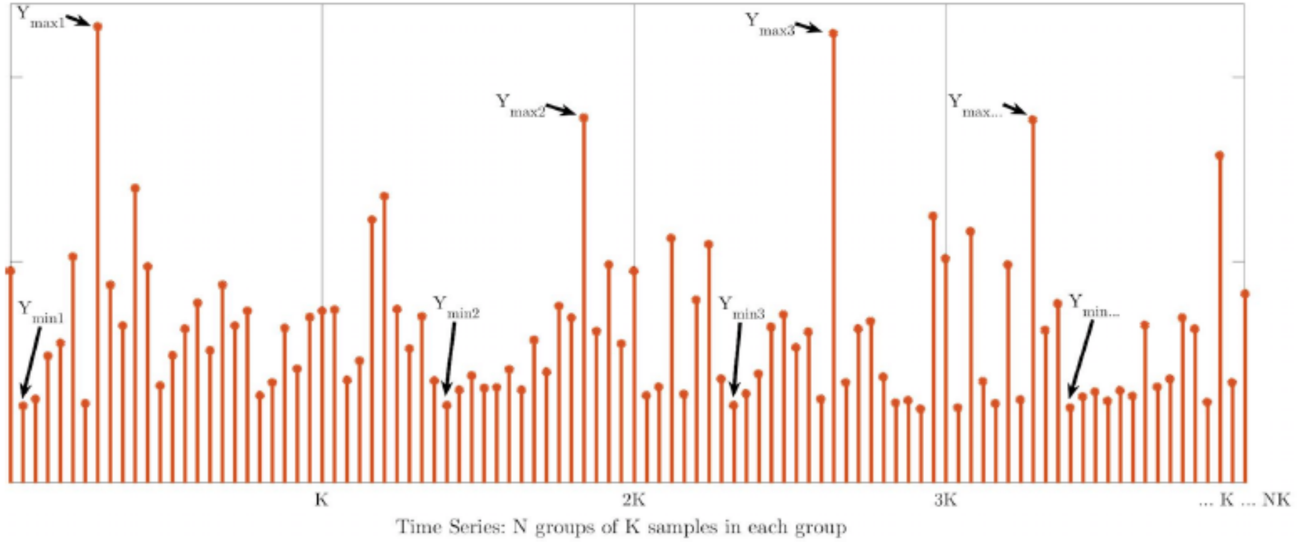
Available measurements collected by the standard NMS –
The ”Passive Approach”

- Variable dynamic range
- Variable base-line attenuation
  – Low temporal resolution (15-minute)
  – Rough quantization
  – Non-linear min/max transformation

✓ **Widely accessible**

72 hours of Min/Max RSL data-series (taken from a CML near Netanya) during a rain event in winter 2013





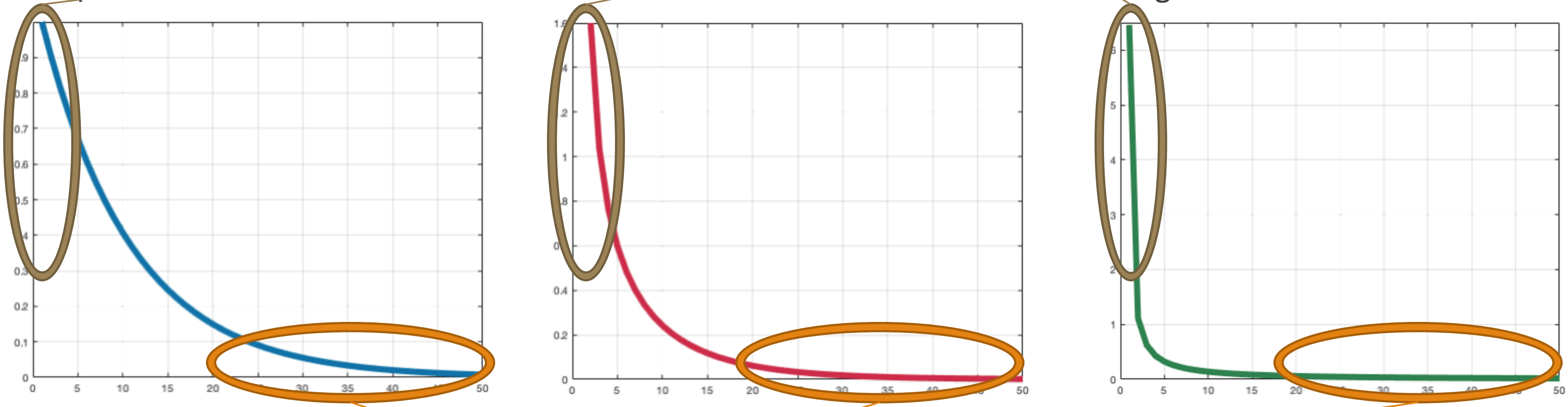
The Idea

The rain statistics

$\Pr\{r(t) \leq r\} = F_R(r; t, \underline{\theta})$, where $f_R(r; t, \underline{\theta})$ is:

The minimum is bounded (> 0)

Exponential? Gamma? Log-Normal?



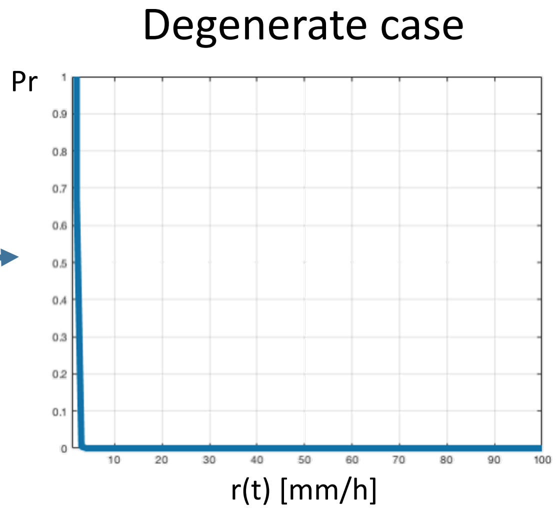
The maximum follows an Exponential tail

Statistics of Extreme Values

MINIMUM FROM K OBSERVATIONS*

$$f_{Y_{min}}(z;\underline{\theta},K) = K\left[1 - F_X(z;\underline{\theta})\right]^{K-1} f_X(z;\underline{\theta})$$

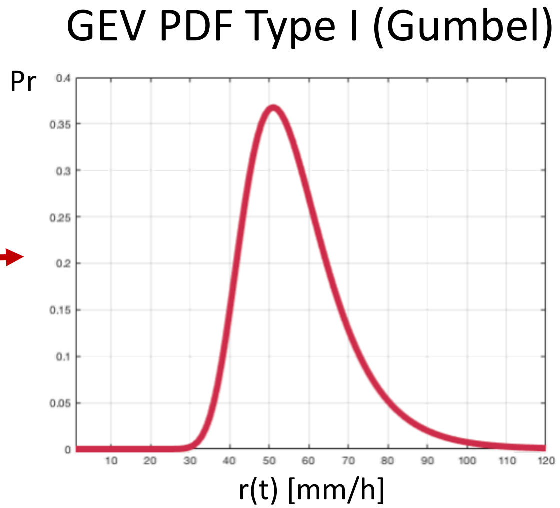
$K \to \infty$



MAXIMUM FROM K OBSERVATIONS*

$$f_{Y_{max}}(z;\underline{\theta},K) = K\left[F_X(z;\underline{\theta})\right]^{K-1} f_X(z;\underline{\theta})$$

$K \to \infty$



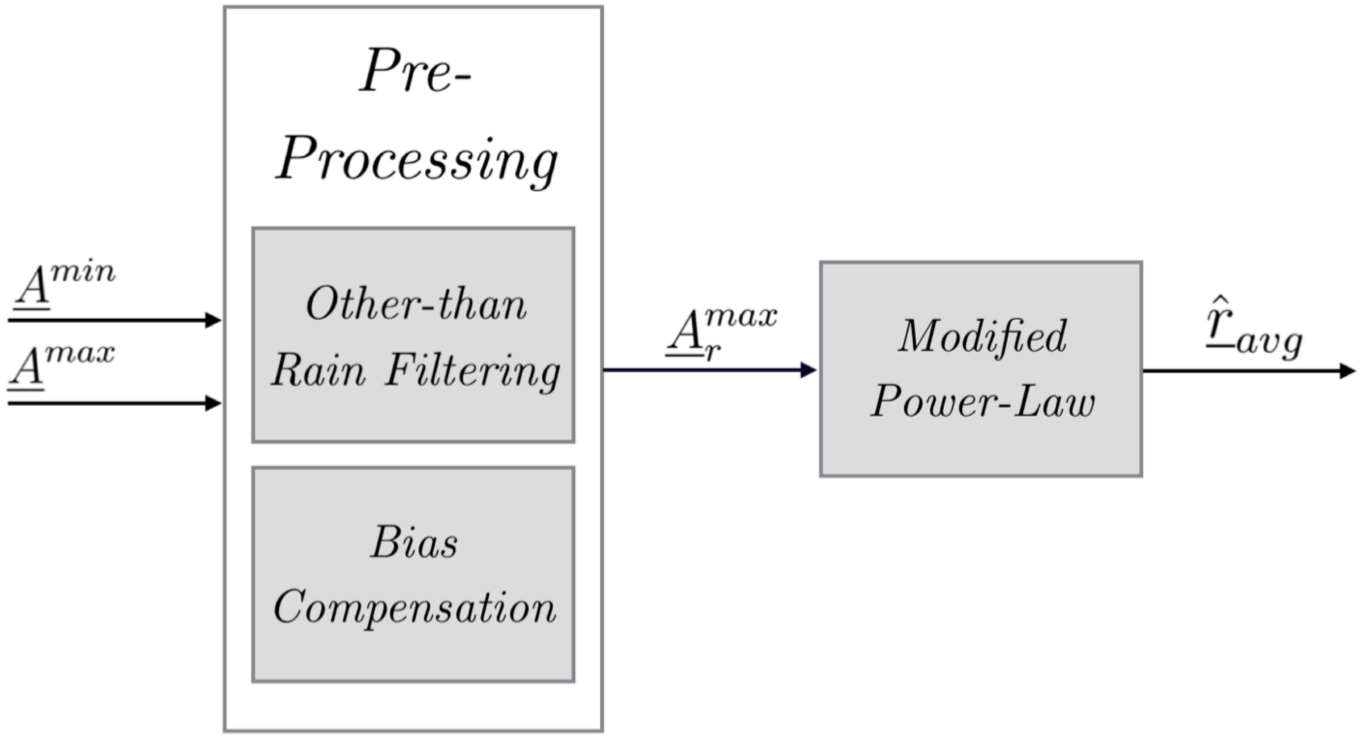
$$F_{Y_{max}}\left(y_{max};\underline{\varphi}\right) = \\ = e^{-e^{-(x-\mu)/\beta}}$$

$$\underline{\varphi} = [\mu, \beta]^T$$

* Ostrometzky, J., & Messer, H. (2020). On the information in extreme measurements for parameter estimation. Journal of the Franklin Institute, 357/1. pp. 748-771.

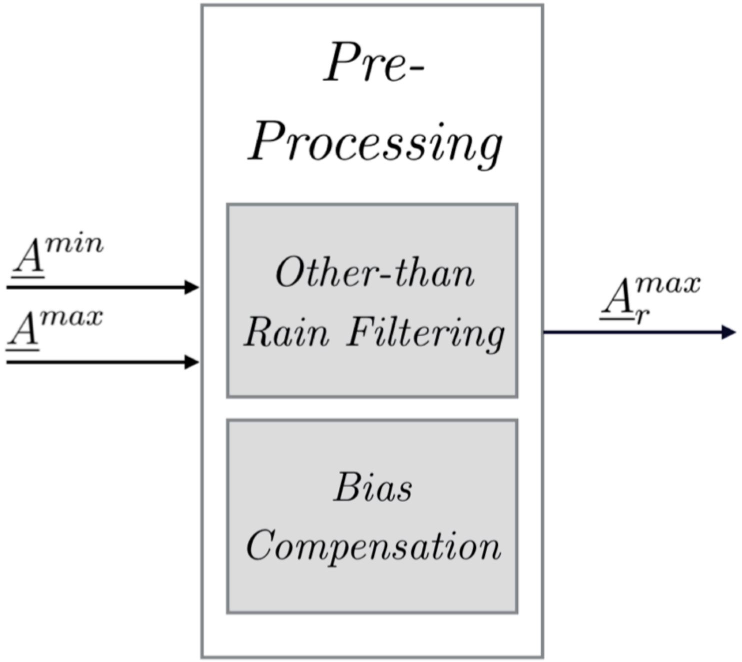
* Assuming iid

Estimation Workflow

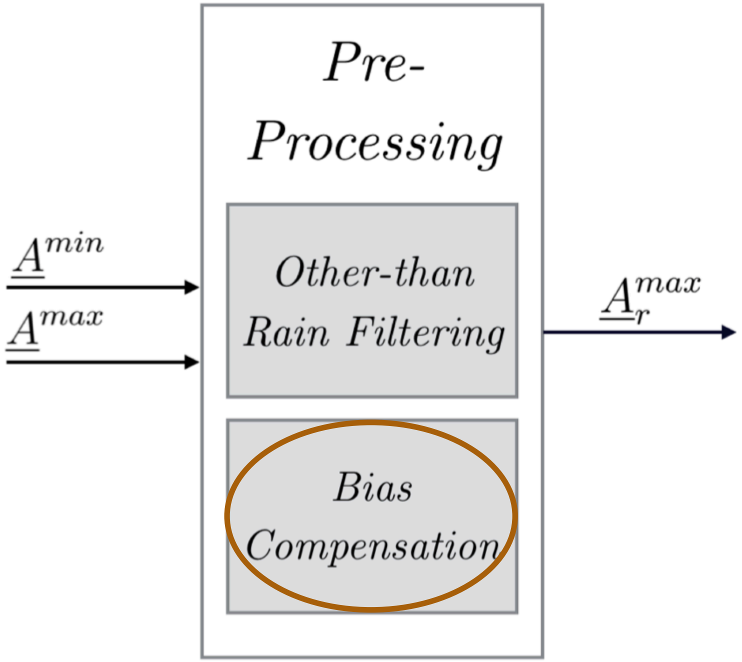


Pre-Processing

Two Pre-Processing Stages

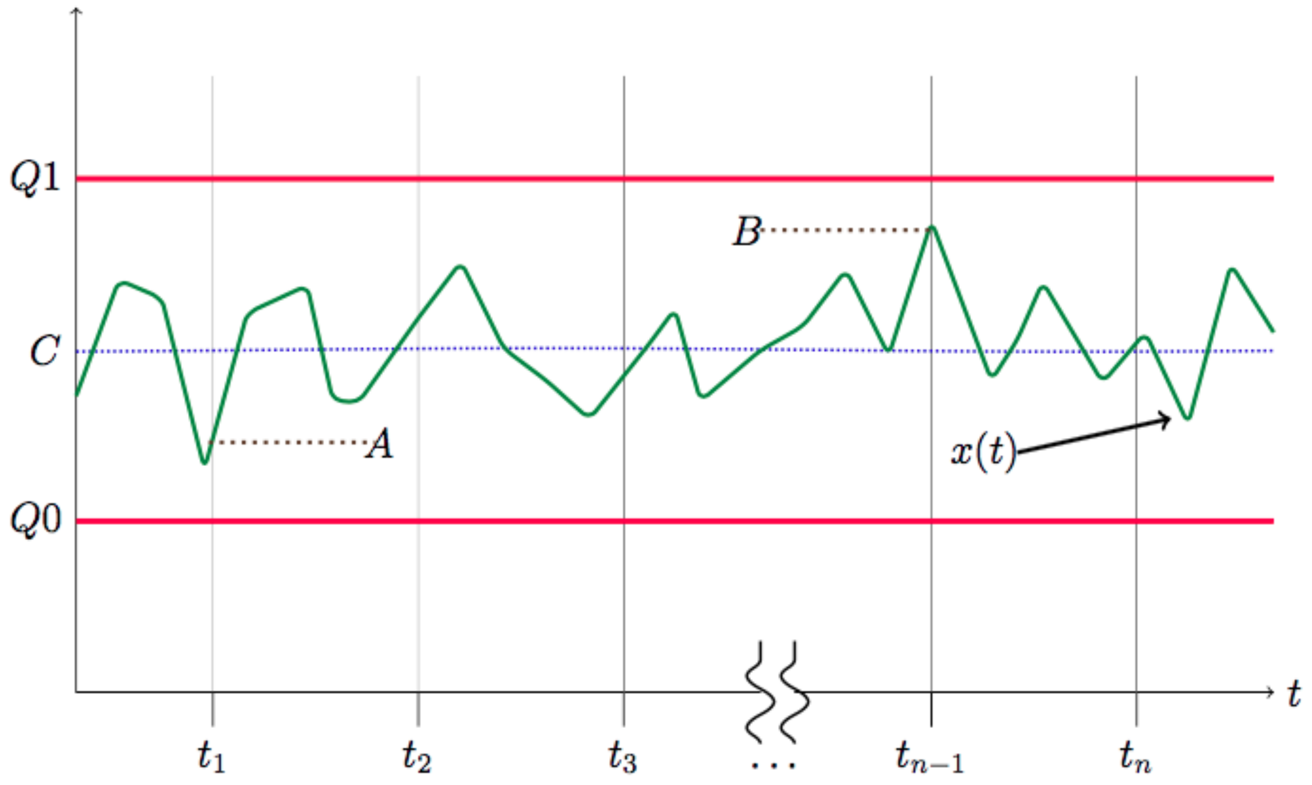


Two Pre-Processing Stages



The nearest-neighbour (or a *"round"*) quantizer $q(x)$ is defined by:

$$y = q(x) = L \cdot round\left(\frac{x}{L}\right)$$



L=Q1-Q0 (and is called the quantization interval)

- A is the actual minimum observed value.
  - However, the quantizer will output Q0.
- B is the actual maximum observed value.
  - However, the quantizer will output Q1.

* **Ostrometzky, J.**, Eshel, A., Alpert, P., & Messer, H. (2017, March). Induced bias in attenuation measurements taken from commercial microwave links. In Proc. *IEEE ICASSP'17,* pp. 3744-3748.

For Ericsson Systems, Usually:

$$g_T = L_T = 1 \quad (dB)$$

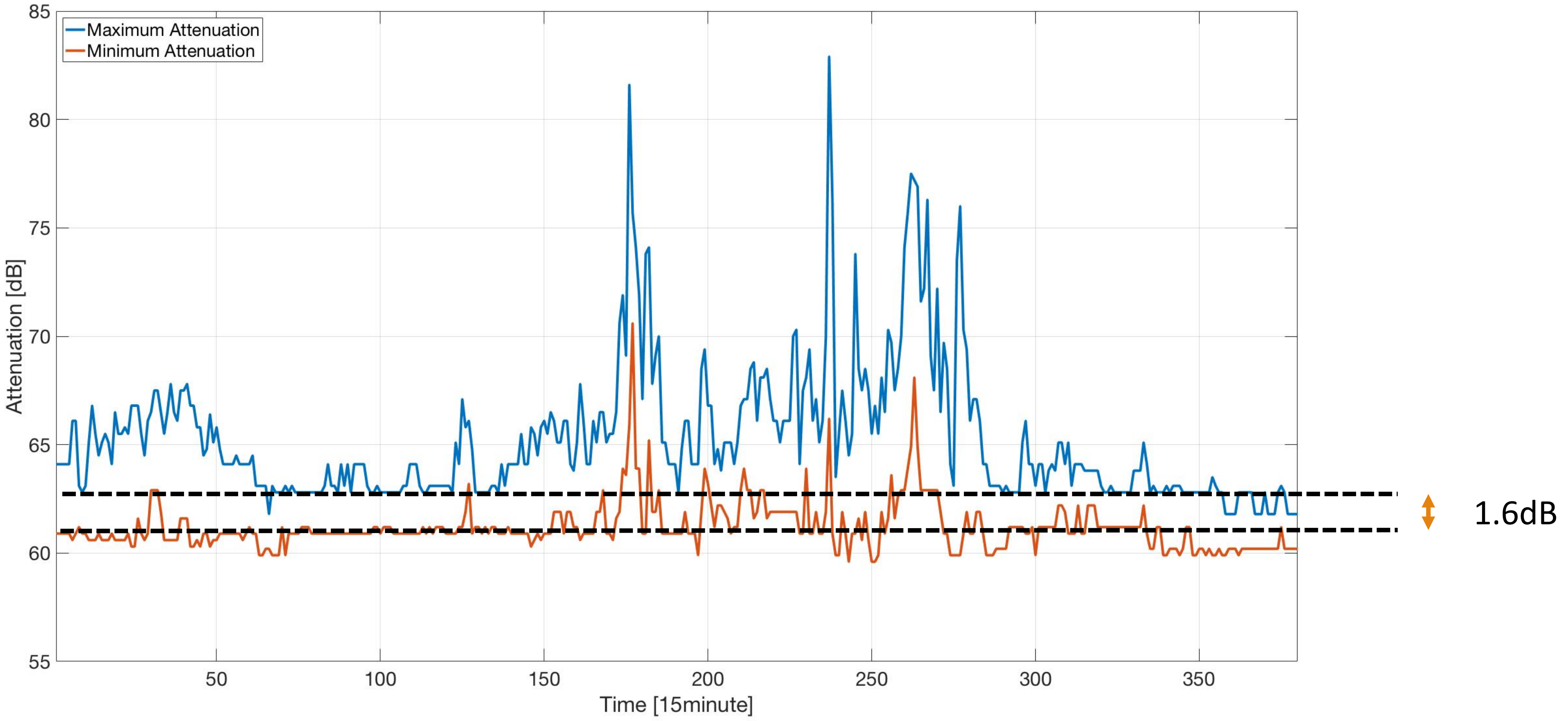
$$g_R = 2 \cdot L_R = 0.6 \quad (dB)$$

Meaning that a bias of 1.6dB is induced:

$$\underline{A}_{diff} = \underline{A}^{max} - \underline{A}^{min} \quad = \underline{1.6}\text{dB}$$

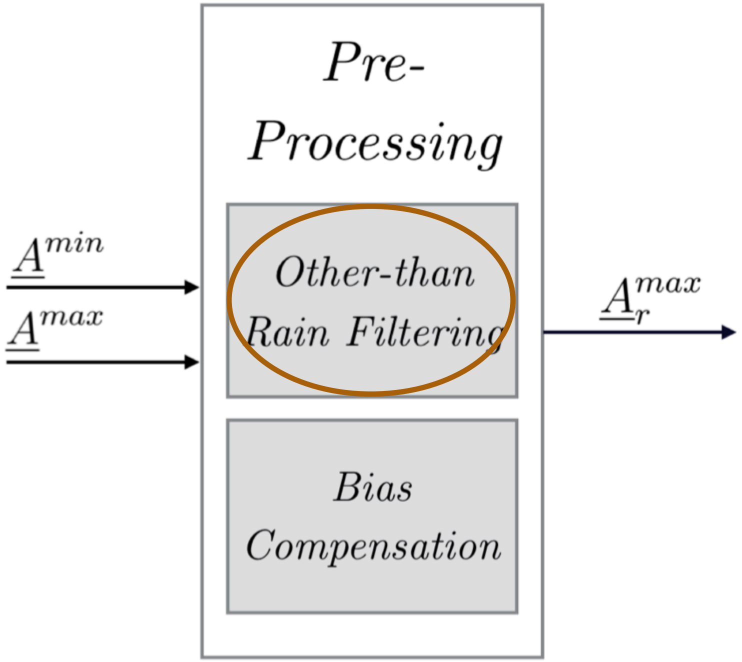
where g_T is the quantization gap of the TSL values, and g_R is the quantization gap of the RSL values.

g_T and g_R equal to L (which is the base quantizer gap for the Tx (L_T) and Rx (L_R)), or multiplications of L, depending on the amount of the additive noise



Maximum Attenuation
Minimum Attenuation
Attenuation [dB]
85
80
75
70
65
60
55
50
100
150
200
250
300
350
Time [15minute]
1.6dB

Two Pre-Processing Stages



Other-than Rain Filtering

$$A_t(t_i) = A_r(t_i) + \Delta(t_i) = a \cdot r(t_i)^b \cdot L + \Delta(t_i)$$

↓

$$\min\left(A_t(t_1), A_t(t_2), \cdots, A_t(t_n)\right) = \Delta_n$$

$$\text{where } \Delta_n \approx \Delta(t_i) : \forall i = [1, 2, \cdots, n]$$

assuming that $\Delta(t_i)$ changes slowly compared to the rain

Which yields:

$$A_r(t_j) = A_t(t_j) - \Delta(t_j) \approx A_t(t_j) - \Delta_n =$$
$$= A_t(t_j) - \min\left(A_t(t_1), A_t(t_2), \cdots, A_t(t_n)\right)$$

* Ostrometzky, J., & Messer, H. (2017). Dynamic determination of the baseline level in microwave links for rain monitoring from minimum attenuation values. IEEE Jour. Sel. Topics in Applied Earth Observations and Remote Sensing, 11/1, pp. 24-33.

Practical Use

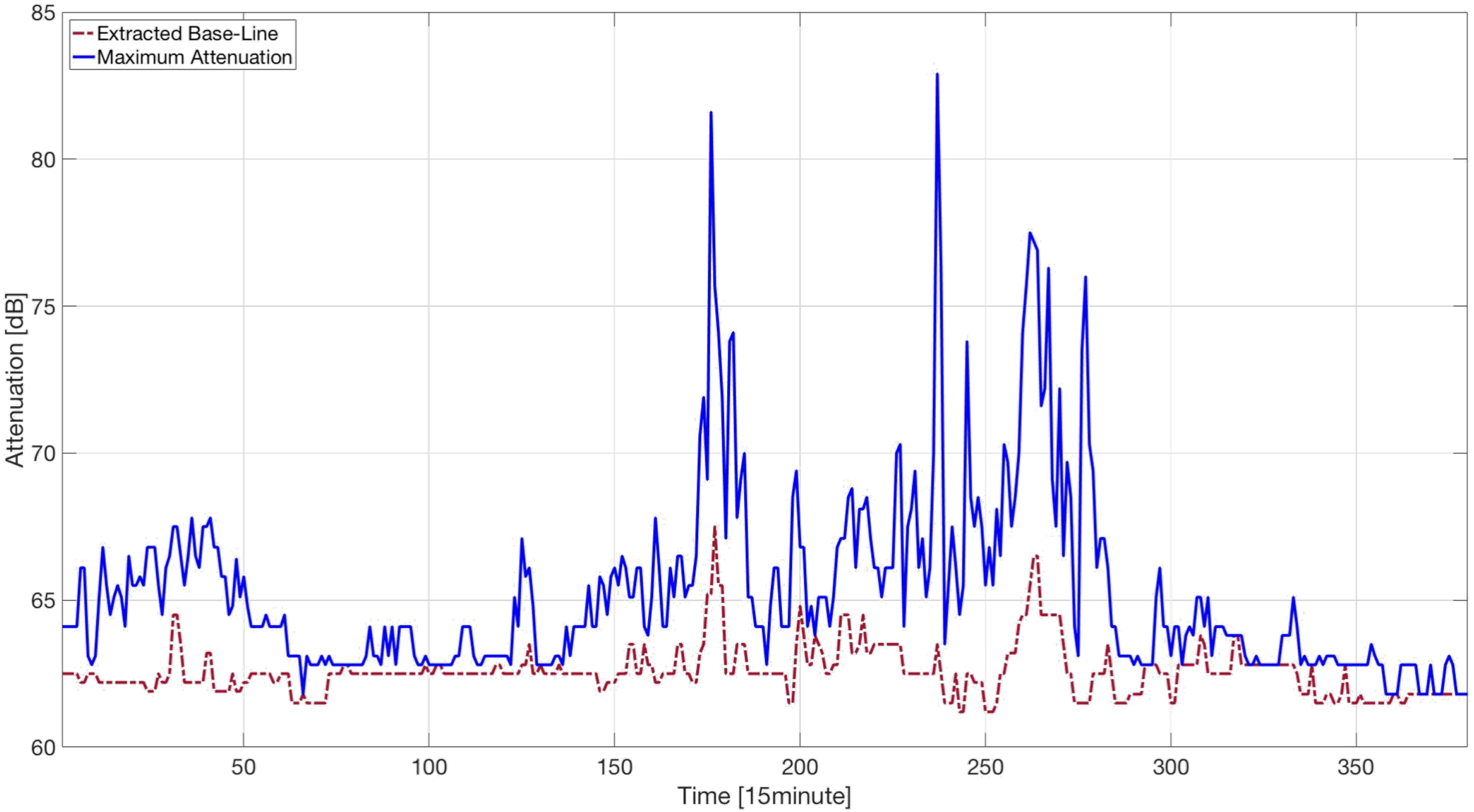
Quantization induced bias

$$A_{\mathbf{r}}^{max}[\mathbf{j}] = A^{max}[\mathbf{j}] - \min(A_{\mathbf{j-7}}^{min}, \cdots, A_{\mathbf{j}}^{min}) \; - \mathbf{1.6dB}$$

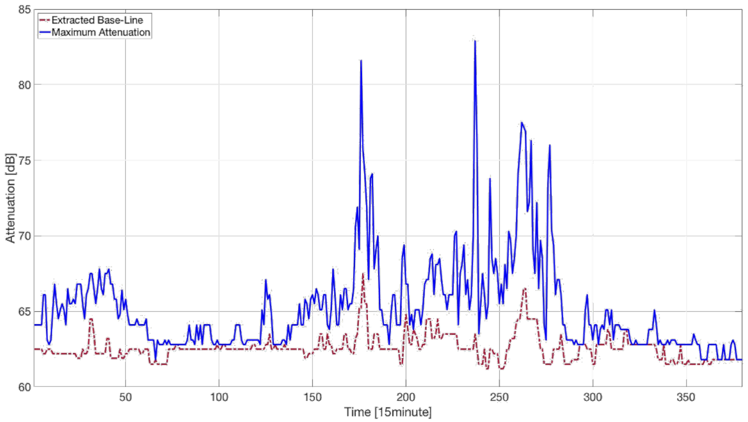
Extracted Base-Line for the j^{th} group

- j is the group number.
  - Usually, (i.e., for Ericsson systems), each group contains 90 observations (sampled at 10s-interval).
    - The extreme values are reported every 15 minute.

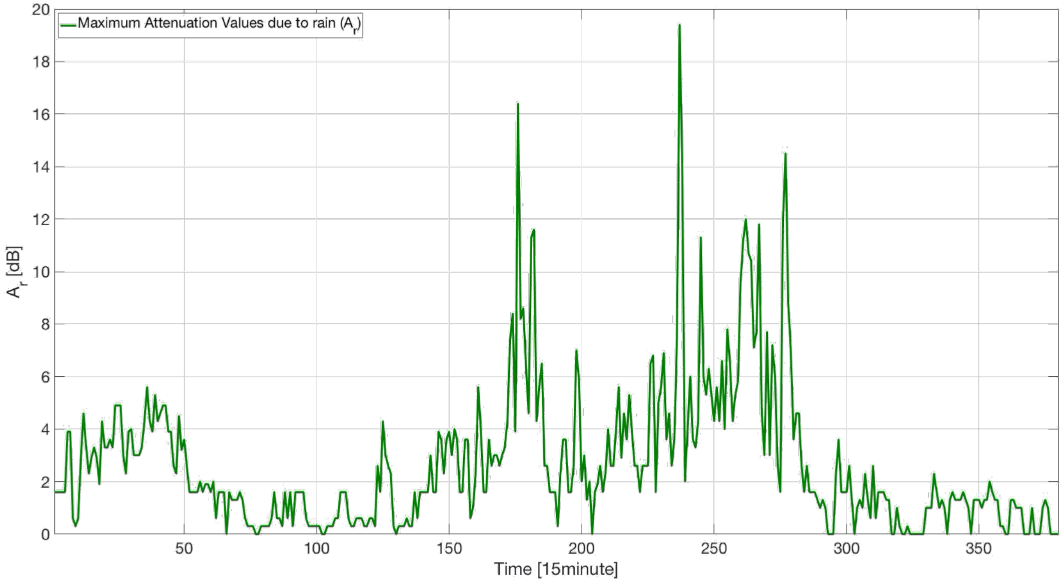
Example – The Pre-Process Output



Example – The Pre-Process Output



$$\underline{A}_r^{max} = \underline{A}^{max} - \underline{A}_{BL} \quad \text{(dB)}$$



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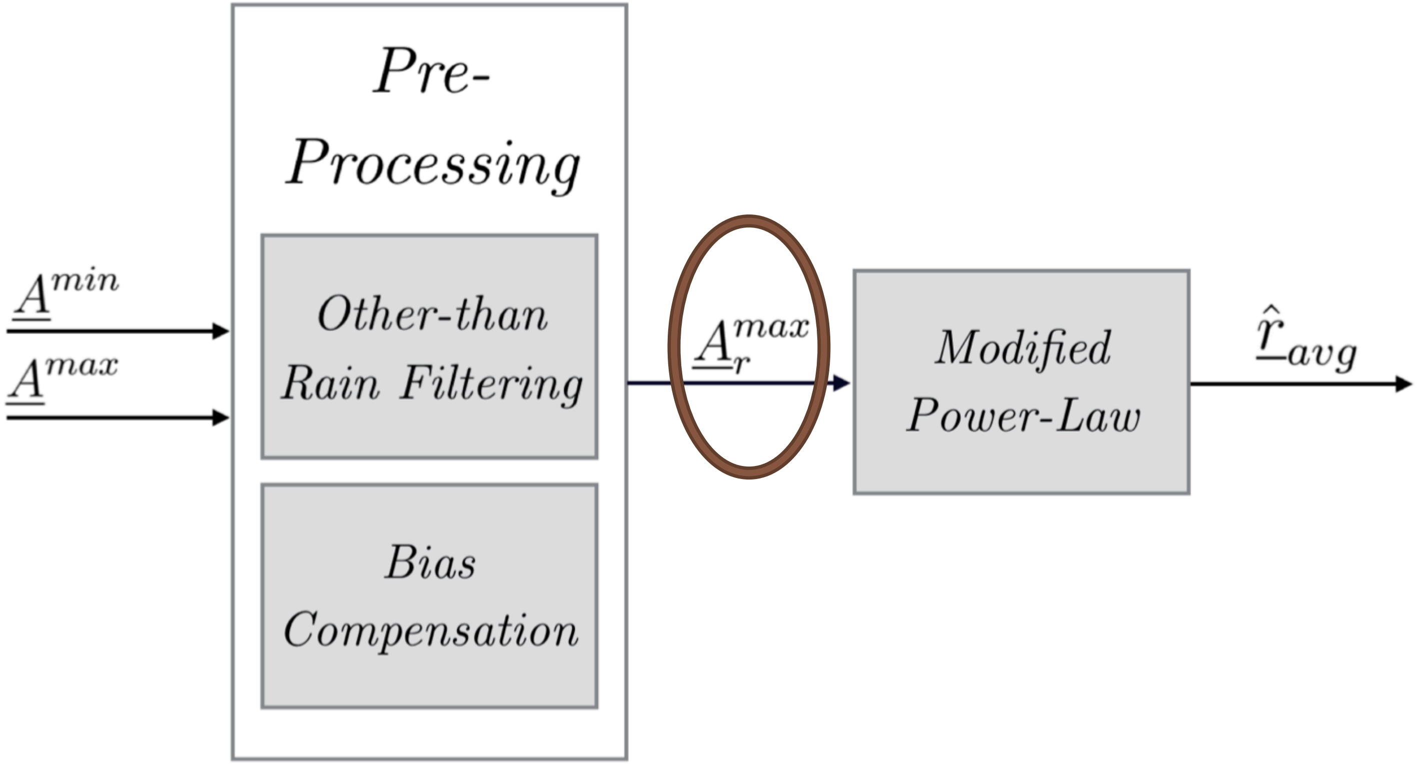

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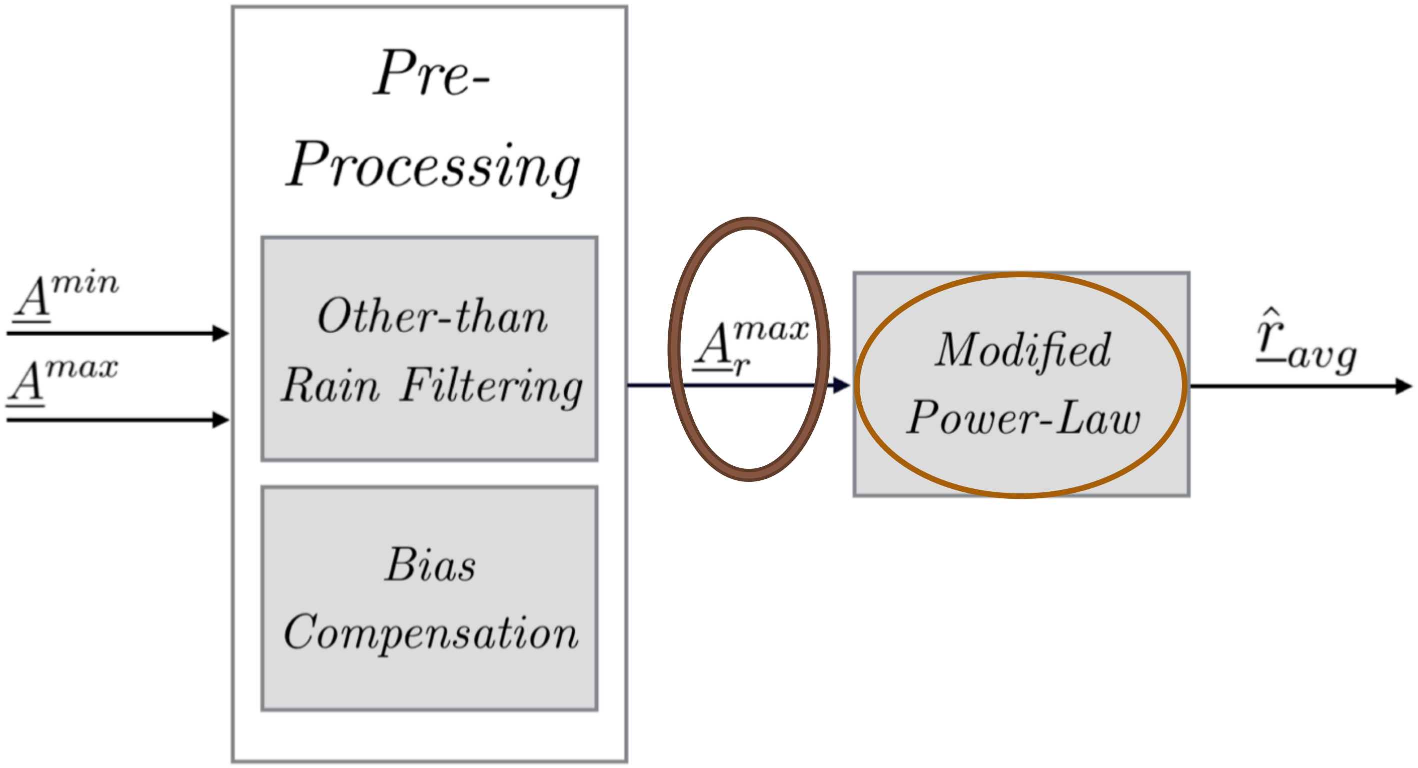
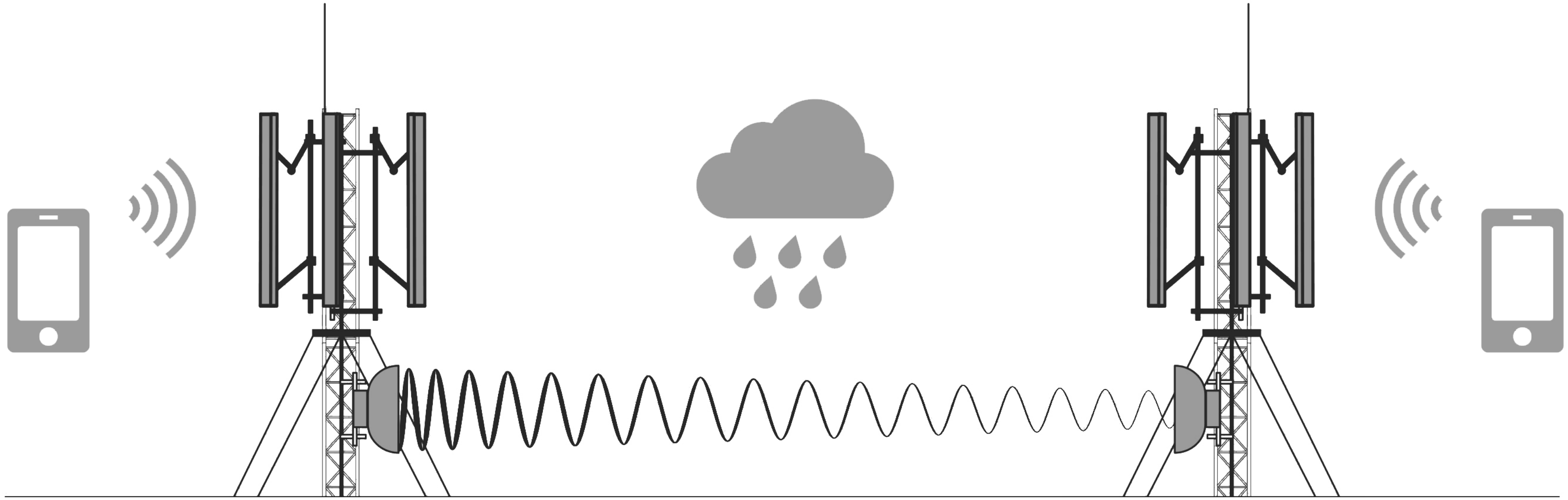


Rain Estimation

Modified Power-Law

Reminder – The standard Power-Law



$$\rightarrow \quad r(t) = \left(\frac{A_r(t)}{aL}\right)^{1/b} \quad \left(\frac{mm}{h}\right)$$

Modified "Power-Law"

Based on the statistical modelling of the rain, we have shown that the relationship between the maximal attenuation value and the averaged rain-rate within each group is given by a scaling of the standard Power-Law:

$$r_{avg} \xrightarrow{K\to\infty} \left(\frac{A_r^{max} + \mathcal{O}(1)}{a_{cal}^{max} \cdot L}\right)^{\frac{1}{b}} \approx \left(\frac{A_r^{max}}{a_{cal}^{max} \cdot L}\right)^{\frac{1}{b}}$$

where

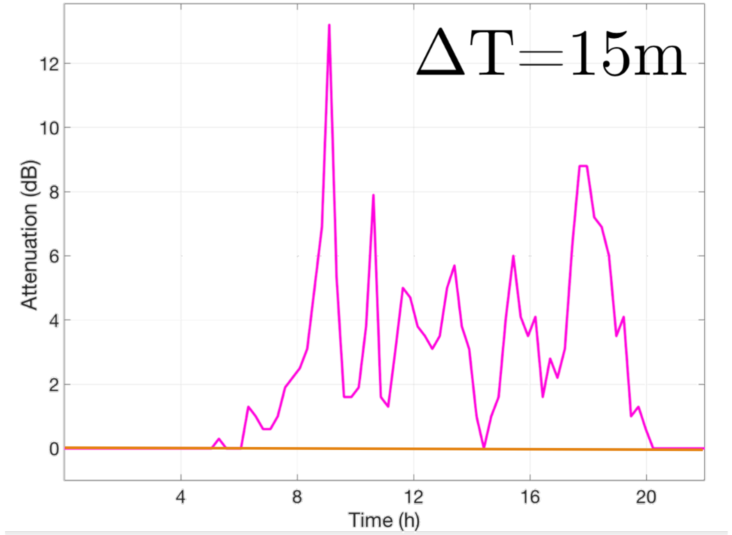
$$a_{cal}^{max} = a \cdot (\ln(K) + \gamma)^b$$

K is the number of original samples within the 15-minute intervals. For Ericsson MINI-LINK, K=90, which result in high accuracy

$\gamma = 0.57722$

* **Ostrometzky, J**.,Raich. R., Eshel, A., & Messer, H. (2016, March). Calibration of the attenuation-rain rate power-law parameters using measurements from commercial microwave networks. In Proc. *IEEE ICASSP'16,* (pp. 3736-3740).

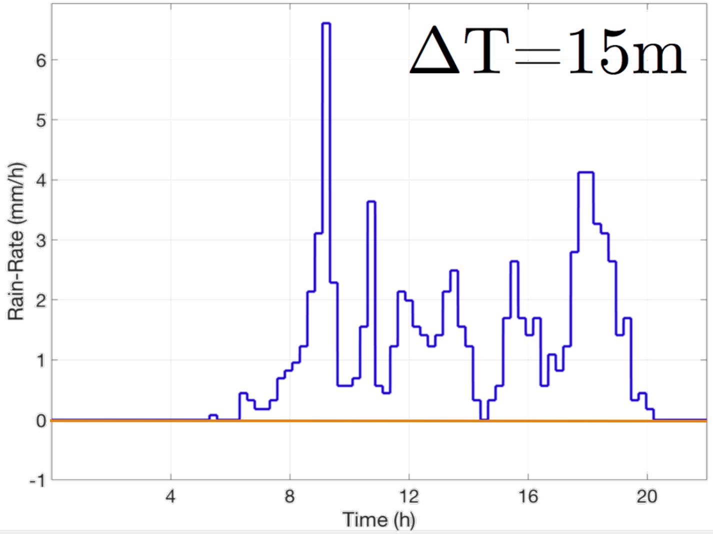
Modified “Power-Law”



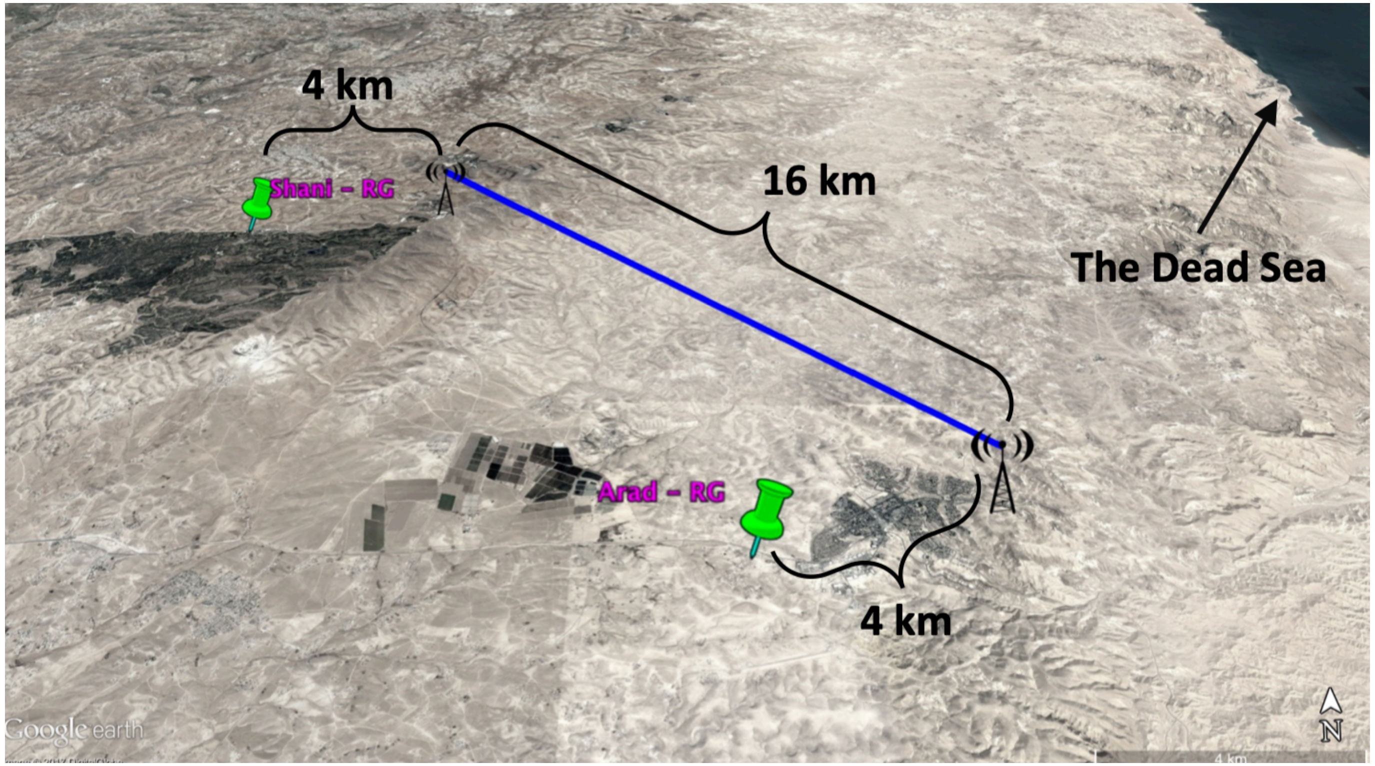
Rain Induced
Maximal Attenuation

Modified Power-Law

$$r_{avg} \approx \left(\frac{A_r^{max}}{a_{cal}^{max} \cdot L} \right)^{\frac{1}{b}}$$

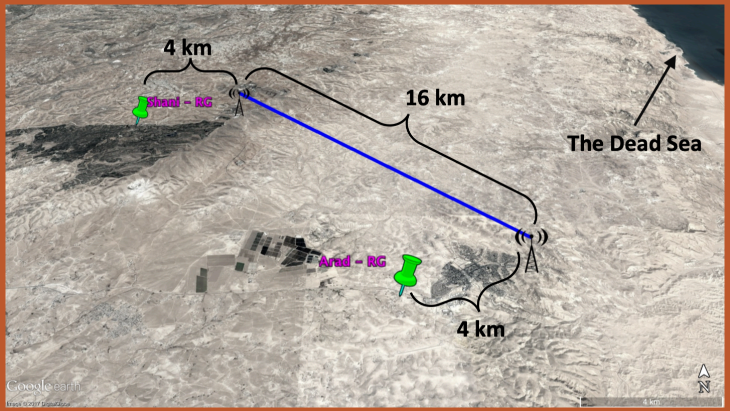


Averaged rain-intensity
for each 15 minute interval



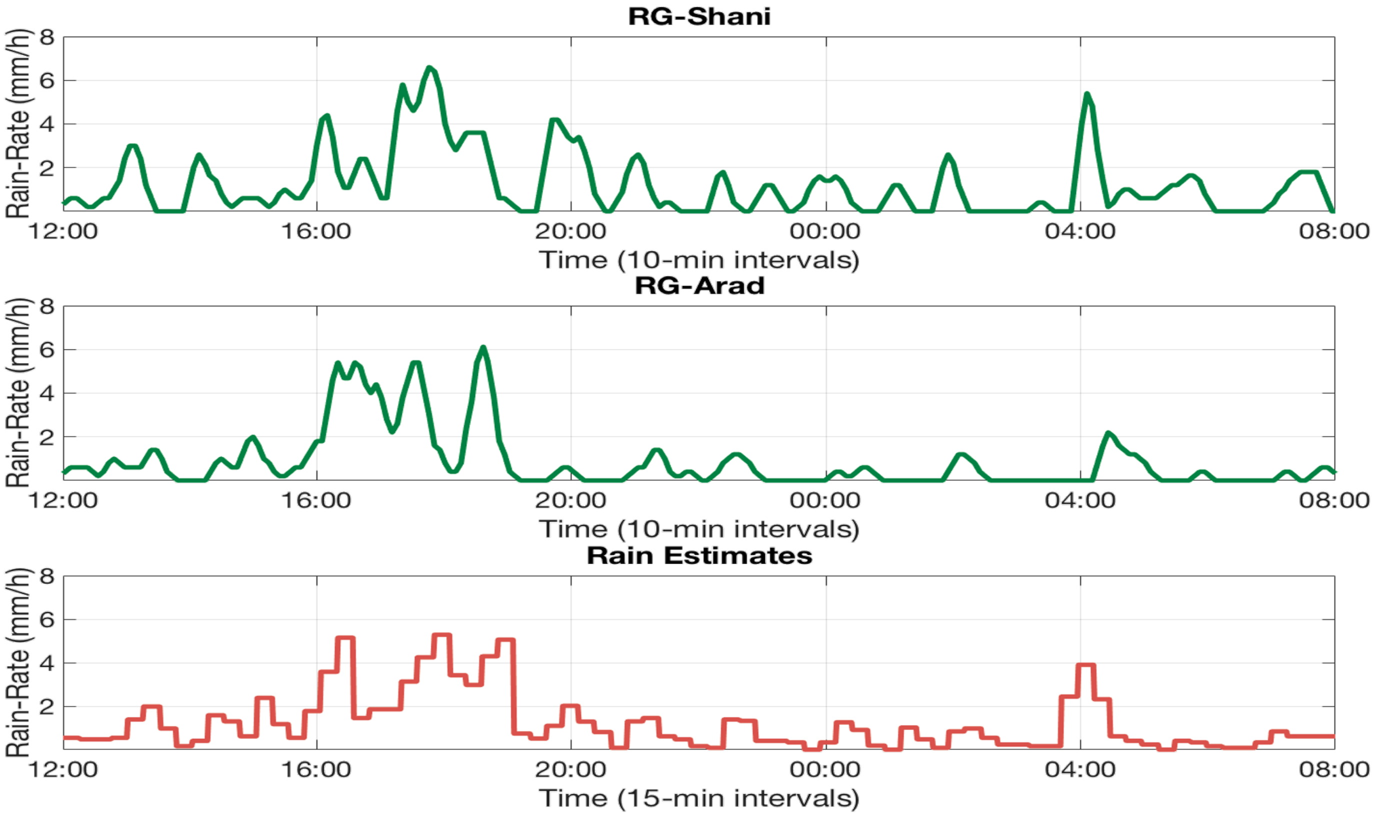
Test Case – Demonstration

Results



Event No. Date Duration	RG	RG-RD (mm)	CC
1	Shani	**24.7**	0.715
25-Jan-2016	Arad	**16.9**	0.655
20 h	$\hat{R}_c$ **(mm):**	**23.9**	–
2	Shani	**57.3**	0.548
31-Dec-2015	Arad	**24.1**	0.223
28 h	$\hat{R}_c$ **(mm):**	**36.6**	–
3	Shani	**6.2**	0.546
06-Nov-2015	Arad	**2.9**	0.367
22 h	$\hat{R}_c$ **(mm):**	**7.13**	–

Example – Time Series



RG-Shani Cumulative:
24.7 mm

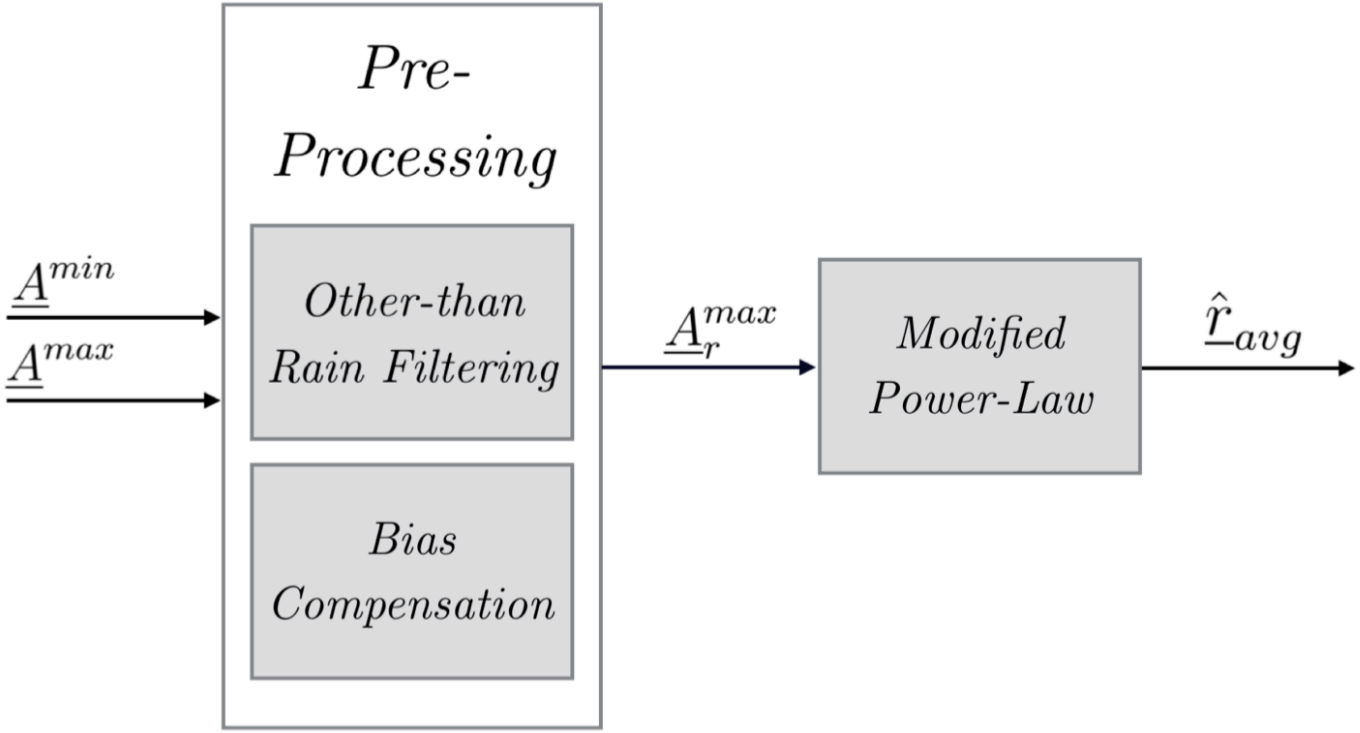
RG-Arad Cumulative:
16.9 mm

CML Cumulative:
23.9 mm

Corr (vs RG-Shani): 0.715
Corr (vs RG-Arad): 0.655

*The Power-Law coefficients were taken based on a past study

Conclusion



We have established an estimation process which takes the standard NMS output, extract the rain induced attenuation components (using the minimum attenuation values), and successfully estimates the averaged rain intensity (per interval) using the maximum attenuation values.

This approach produces high spatial-resolution rain-intensity samples, does not require any prior knowledge or pre-calibration or training, and can be implemented in real-time.

Acknowledgments

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In *Pelephone*, we would like to thank: N. Dvela, A. Hival and Y. Shachar.

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Thank You!

Ostrometzky, J., & Messer, H. (2020). Statistical signal processing approach for rain estimation based on measurements from network management systems. In Proc. *IEEE ICASSP'20*, https://ieeexplore.ieee.org/document/9054652.

Ostrometzky, J., & Messer, H. (2020). On the information in extreme measurements for parameter estimation. Journal of the Franklin Institute, 357/1. pp. 748-771.

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