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# New Empirical Conversion Technique for 1-minute Integration Time of Precipitation Intensity in Malaysia

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**ABSTRACT**

**Background:** The suitability of previously proposed techniques claim to be able to accurately convert precipitation intensity statistics at longer integration times into 1-minute integration time statistics has been of great interest to many wireless propagation researchers. Measured data of precipitation intensity collected in Kuala Lumpur, Malaysia had enabled the production of statistics at various integration times of interest**. Objective:** An investigation has been embarked with the aim to devise a new empirical technique that capable to generate a more precise statistic at 1-minute integration time. **Results:** The study outlines the use of polynomial relationship in the process of converting statistics of longer integration time to 1-minute integration time. The generated 1-minute statistics using the new method were then compared with those of measured statistics in order to assess the technique's effectiveness. **Conclusion:** It can be suggested that the new conversion technique appears to be capable of producing consistent statistics for 1-minute integration time from various other integration times.



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## INTRODUCTION

Rapid expansions of centimeter wave frequency in earth-to-satellite communication links have pushed satellite operators to use frequencies higher than 10 GHz. But the progression of above 10 GHz frequency spectrums implicates larger fading due to precipitation as the raindrops absorb and scatter the radio wave energy. This will lead to longer outage periods and therefore adequate fade margin is required to mitigate such circumstances. To determine the suitable fade margin, researchers and scientists had proposed various rain attenuation prediction models (ITU-R P.618-11, 2013) (Dissanayake *et al.*, 1997) (Crane, 1980) (Crane and Shieh, 1989) for earth-to-satellite communication links. These prediction models require 'exclusive' information gathered from precipitation intensity annual statistic at 1-minute integration time. Unfortunately, the 1-minute integration time data are not likely to be available as most of the data are collected at longer integration period, e.g. hourly or daily basis especially data obtain from meteorological department. Extensive efforts have been attempted by researchers in developing reliable methods to convert statistics acquired at various integration times into statistics of 1-minute integration time. Empirical conversion is the most widely proposed by past researchers. Researchers (Segal, 1986) (Burgueno *et al.*, 1988) (Lavergnat and Golé, 1998) (Ismail *et al.*, 2011) had suggested the use of a power law relationship in converting statistics of longer integration time to 1-minute integration time. Chebil and Rahman (1999) did propose an alternative empirical conversion technique that involved combination of power and exponential law relationship. Another conversion method developed by Joo *et al* (2000) using rain data measured by optical rain gauge in 2000. In 2009, Capsoni and Luini (2009) had developed and proposed a physically based procedure, claimed to be capable of converting statistics of precipitation intensity at different integration times into a reliable 1-minute integration time statistic. Nevertheless, some of the methods have been identified as incompatible by local researchers (Mandeep *et al.*, 2007) (Mandeep, 2011) (Chun and Mandeep, 2013). An investigation has been embarked in generating a new empirical technique in developing the most precise generated statistic at 1-minute integration time that suit Malaysian local climate. The study incorporates the exploitation of polynomial relationship in the attempt to convert statistics of longer integration time to 1-minute integration time.

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### ***Local Data And Measurement Set-Up:***

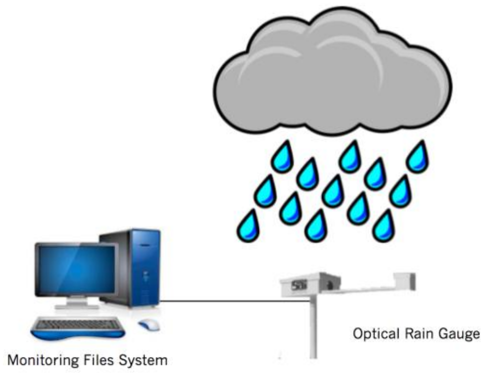



**Fig. 1:** Measurement setup.

Fig. 1 shows an illustration of measurements set-up. A measurement campaign was carried out at Bukit Jalil, Kuala Lumpur, Malaysia, latitude 3°08' N and longitude 101°32'E (Ismail and Watson, 2000). The data collection period lasted for almost 2 years. An optical rain gauge was used to accumulate the rain event data. The optical sensor of the rain gauge determined precipitation intensity by providing an analogue voltage equivalent to "measured" precipitation intensity. The equipment employed the focusing and defocusing of an optical beam principle to estimate precipitation intensity. It computed the precipitation intensity by detecting the optical irregularities induced (also known as scintillation) within the sample volume by precipitation particles falling through the beam of partially coherent infrared light. The measurement system sampled the precipitation intensity at every 10 seconds interval during rainy condition. During non-rainy events, the system intelligently switched the data storing to be at every 10 minutes sampling time. All collected data were stored in monitoring files on daily basis. In the study, time-series plot for every measured event was produced using plot-generating software, Matlab. Fig. 2 shows one of examples of time-series plot for measured event on July 4 1997. Measurements at every 10-second interval enable the computations and generation of precipitation intensity statistics at 1, 5, 10, 30 and 60-minutes integration time. Fig. 3 shows the plotted graphs for precipitation intensity statistics obtained (10-seconds, 1, 5, 10, 30 and 60-minutes). From the figure, comparisons can be made between the precipitations intensity statistics acquired using the selected integration times. It can be observed that there appears to be a reasonable good agreement among all plotted statistics for percentage of time exceedance greater than 0.2%. Plotted statistics of 10-seconds, 1-minute and 5-minutes integration time exhibit reasonably good agreement for percentage of time exceedance greater than 0.02%. Plotted statistics of 10-second and 1-minute integration time display almost good agreement for all time percentages.

### ***Description of new technique:***

In the pursuit of developing a more precise technique capable of generating precipitation intensity statistics of 1-minute integration time that suit Malaysian climate, a new relationship for the conversion from longer integration times to 1-minute integration time are proposed. The suggested technique presented in this paper involves the following three steps:

a) Compilation of precipitation data
b) Plotting the precipitation data
c) Identifying best fit relationship of the plotted data

### ***A. Compilation of precipitation data:***

The first step in developing the relationship is by compiling each precipitation intensity statistics data for 1-, 5-, 10-, 30- and 60-minutes at the same percentage time exceedance value. Table 1 below lists example of precipitation data with the same percentage time exceedance value. Note that all of the precipitation data are in mm/hr. The data that use in this step are from the generated precipitation intensity statistics.

**Table 1:** Example of precipitation values.

| Percentage Time Exceedance | 1-min | 5-min | 10-min | 30-min | 60-min |
|---|---|---|---|---|---|
| 0.01% | 4 mm/hr | 4 mm/hr | 4 mm/hr | 5 mm/hr | 5 mm/hr |
| 0.05% | 65 mm/hr | 52 mm/hr | 54 mm/hr | 48 mm/hr | 50 mm/hr |
| 0.10% | 84 mm/hr | 80 mm/hr | 78 mm/hr | 67 mm/hr | 59 mm/hr |
| 0.80% | 161 mm/hr | 151 mm/hr | 148 mm/hr | 116 mm/hr | 67 mm/hr |

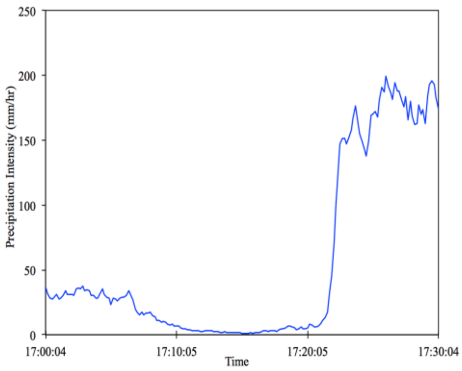



**Fig. 2:** Example of time-series plot for measured event on July 4 1997.

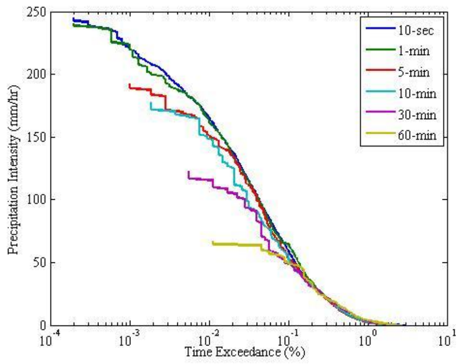



**Fig. 3:** Plotted graphs for precipitation intensity statistics obtained

***B. Plotting the precipitation data:***

The next step is to plot the compiled precipitation intensity statistics data. The 1-minute precipitation intensity statistics data is plotted against the desired precipitation intensity statistics data (in this case 5, 10, 30 and 60-minute) with the same percentage time exceedance value. Fig. 4 (a) – Fig. 4 (d) show the plots of the 1-minute precipitation intensity statistics data against the desired precipitation intensity statistics data.

***C. Identifying the best fit relationship of the plotted data:***

The new proposed technique encompasses relationship that utilized polynomial equation. The general form of polynomial equation is shown in (1):

$$f(x) = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + ... + a_j x^j \quad (1)$$

The final stage involved configuring the most relevant relationship of the plotted graphs. Curve fitting was used to uncover the relationship between the plotted data. By applying the data in the matrix form (2) (3) (4) below and solving the matrix equation (5) by attaining the X values, the relationship of the plotted graphs were then managed to be obtained:

In the equations, *x* is the precipitation intensity statistics data at various integration times (in this case 5-, 10-, 30- and 60-minute). *y* on the other hand is the desired 1-minute precipitation intensity statistics data with both have the same percentage exceedance value. Subsequently, *i* is the number sequence of the precipitation data and *j* is the order of the polynomial. The procedures of deriving the relationship involved the use of MATLAB software. Fig. 5 (a) – Fig. 5 (d) show the graphs and the curve-fitting process execute by the software.

By performing all the above-mentioned steps, new relationship to convert statistics from longer integration times to that of 1-minute integration time was achieved. The equation for the conversion technique is given as (6). The associate empirical constants are listed in Table 2.

$$R_1(P) = aR_t(P)^4 + bR_t(P)^3 + cR_t(P)^2 + dR_t(P) + e \quad (6)$$

where *a, b, c, d* and *e* are empirical constant and $R_t(P)$ is the input precipitation intensity data for *t* integration of time.

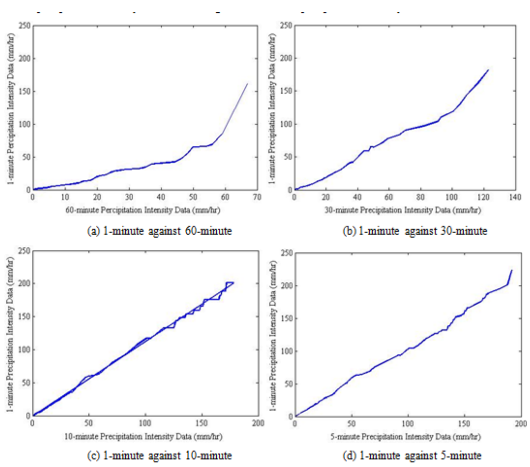



**Fig. 4:** Plots of the 1-minute precipitation intensity statistics data against the desired precipitation intensity statistics data.

$$A=\begin{bmatrix} n & \sum x_i & \sum x_i^2 & \cdots & \sum x_i^j \\ \sum x_i & \sum x_i^2 & \sum x_i^3 & \cdots & \sum x_i^{j+1} \\ \sum x_i^2 & \sum x_i^3 & \sum x_i^4 & \cdots & \sum x_i^{j+2} \\ \vdots & & & & \vdots \\ \sum x_i^j & \sum x_i^{j+1} & \sum x_i^{j+2} & \cdots & \sum x_i^{j+j} \end{bmatrix} \quad (2)$$

$$X=\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ \vdots \\ a_j \end{bmatrix} \quad (3)$$

$$B=\begin{bmatrix} \sum y_i \\ \sum (x_i y_i) \\ \sum (x_i^2 y_i) \\ \vdots \\ \sum (x_i^j y_i) \end{bmatrix} \quad (4)$$

$$A = XB \quad (5)$$

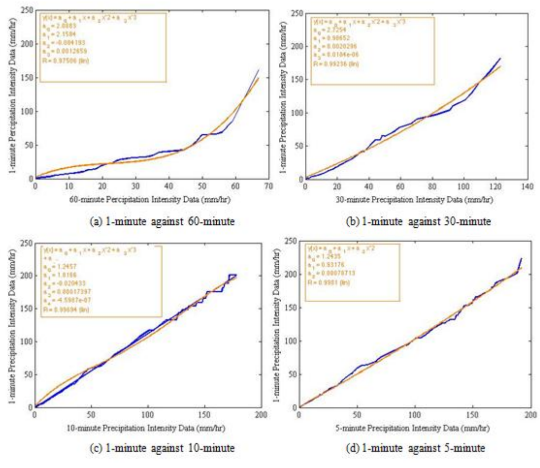



**Fig. 5:** Graphs and the curve-fitting process execute by the software.

**Table 2:** Empirical Constant Values.

| t(min) | a | b | c | d | e |
|---|---|---|---|---|---|
| 5 | 0 | 0 | 7.8713E-4 | 0.93176 | 1.2345 |
| 10 | 4.5987E-7 | 1.7397E-4 | -0.020433 | 1.8166 | 1.2457 |
| 30 | 0 | 8.0184E-6 | 2.0296E-3 | 0.98652 | 2.7254 |
| 60 | 0 | 1.2659E-3 | -0.084193 | 2.1584 | 2.0883 |

***Result Analysis:***

The precipitation intensity statistics of 5, 10, 30 and 60-minutes integration times were then converted to the 1-minute integration time by using the new conversion formula to test the applicability of technique. Fig. 6 (a) – Fig. 6 (d) show the comparison between the results of the conversion technique and the of measurements data of 1-minute integration time.

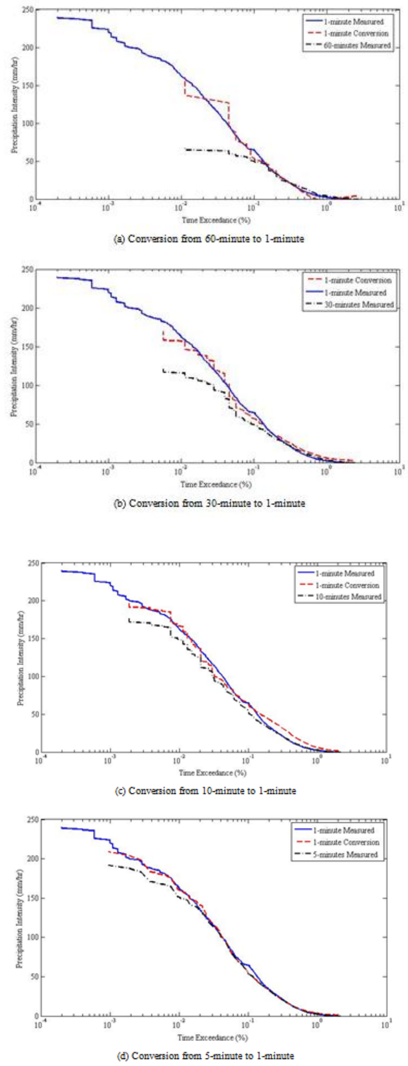
From the observation of Fig. 6 (a) – Fig. 6 (d), the newly recommended conversion technique appears to present very encouraging outcomes. The assessments on the applicability of the new technique were further investigated by determination of the root mean square error (RMSE). In addition, the percentage errors of precipitation intensity values between measured data and empirical conversion technique at 0.01% time exceedance were also identified. The RMSE in this study can be defined as (7):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(ECD_i - MD_i)^2} \qquad (7)$$

where $n$ is the number of data, $ECD$ is the empirical conversion data and $MD$ is the measurement data. The root mean square error and percentage errors of precipitation intensity at 0.01% time exceedance for each of the conversion are listed in Table 3.

**Table 3:** Root mean square error and percentage errors of precipitation intensity at 0.01% time exceedance.

| t(min) | RMSE (%) | Percentage Error (%) |
|---|---|---|
| 5 | 3.9758 | 2.0370 |
| 10 | 6.1345 | 2.4691 |
| 30 | 5.6705 | 3.0864 |
| 60 | 9.1293 | 8.2822 |




(a) Conversion from 60-minute to 1-minute

(b) Conversion from 30-minute to 1-minute

(c) Conversion from 10-minute to 1-minute

(d) Conversion from 5-minute to 1-minute

**Fig. 6:** Comparison between the results of the conversion technique and the of measurements data of 1-minute integration time.

From Table 3, it is evident that the new conversion technique is capable of offering a reasonable RMSE (less than 9.1293%) and percentage error of less than 8.2822% for the selected integration of times of interest. It can also be implied that the conversion technique is dependable and consistent to be used for Malaysian tropical climate.

### *Conclusions:*

The statistics of precipitation intensity is indeed very dependent on the integration time used, as it will evidently determine the accuracy of rain attenuation prediction. In this paper, new conversion technique has been proposed where it utilizing polynomial relationship. From observation of graphs, comparisons against measured statistical data at 0.01% time exceedance do show reliable agreements. Immediate ensuing research work of the study will entail determination how well the new technique fare against previously proposed techniques.

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