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Spatio-Temporal Rainfall Estimation from Communication Satellite Data using Graph Neural Networks

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Accurate precipitation estimation with high spatial and temporal resolution is key to many applications including weather forecast, flood monitoring and the prediction of natural hazards such as the recent extreme weather events around the world. While weather radars are able to monitor the spatio-temporal dynamics of precipitation, they are expensive and sparsely deployed around the world.

Alternatively, existing ground terminals used in satellite communication services (e.g. broadband internet) have shown the potential to function as accurate rain sensors. By analyzing the carrier-to-noise (C/N) data between the satellite and ground terminal, the rain-induced signal attenuation is estimated. The relationship between the attenuation and rain rate at millimeter-wave then allows computation of the latter. To tackle the difficulty of detecting rainy events and rain-induced attenuation, machine learning approaches are often used to learn from measurements of co-located rain gauges. These methods utilize dense or long short-term memory networks taking a temporal sequence of C/N values from one terminal as input to obtain the local rain rate. So far, most approaches have investigated each ground terminal as an independent sensor, fusing them only after rain rate estimation in order to create two-dimensional (2-D) rain maps. Since neighboring terminals are not considered, the rain estimates suffer from local inconsistencies and malfunctioning terminals are harder to detect which further impacts the accuracy.

In this work, to achieve spatio-temporal consistency, we propose to estimate rainfall from a dense grid of ground terminals using graph-neural networks (GNN). By including neighboring terminal information directly in the estimation, rain rates are more consistent and malfunctions are easier to detect. We model local terminal neighborhoods in a GNN combined with one-dimensional convolutional neural networks taking the temporal sequence of C/N values of each terminal as input. The neural networks directly map C/N values to rain rates that are supervised during training using external rain gauge and weather radar data. After estimating rain rates for all terminals, 2-D rain maps are created by using ordinary kriging interpolation.

Initial results for January 12, 2021 storm event across the entire French metropolitan regions using 8000 active ground terminals indicate an improved average rain rate accuracy in comparison to

weather radars. Furthermore, the resulting rain maps are significantly more spatio-temporally consistent compared to independent terminal approaches. These promising results allow rainfall estimation from satellite communication data to strongly complement the weather radar data or become a viable alternative in areas not covered with radars.