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Investigating the Effects of Precipitation on the Reliability of Lossy LoRaWAN Links

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***Abstract*—The effects of climate change on the planet have become more and more noticeable in the last decades. An increase in extreme weather events, such as flooding and droughts, can be observed all around the world. The usage of monitoring systems can help to understand, analyze, and ultimately predict such weather extremes, e.g., by reliably monitoring important indicators like precipitation, river levels, and soil moisture. Since these parameters often exhibit strong variations, even within small geographical boundaries and short time intervals, monitoring must be done at a high spatial and temporal resolution. This poses a significant challenge, because an accurate monitoring requires sensors to be deployed in a large area, which might furthermore be inaccessible or hard to reach, mandating the use of wireless devices. Wireless link reliability can be additionally aggravated by harsh weather events like heavy rainfall, even though monitoring is particularly crucial during such extreme weather events. The relation between the prevailing weather conditions and the corresponding link quality has only been researched to a limited extent so far. We thus analyze long-term link quality data from a Long Range Wide Area Network (LoRaWAN)-based sensor network in the German Harz mountain range, in order to assess the relation between precipitation events and the reliability of links. Our evaluation indicates that lossy links indeed suffer from precipitation, and packet loss is indeed greater during rain events.**

***Index Terms*—LoRa, LoRaWAN, Weather events, Reliability**

I. Introduction

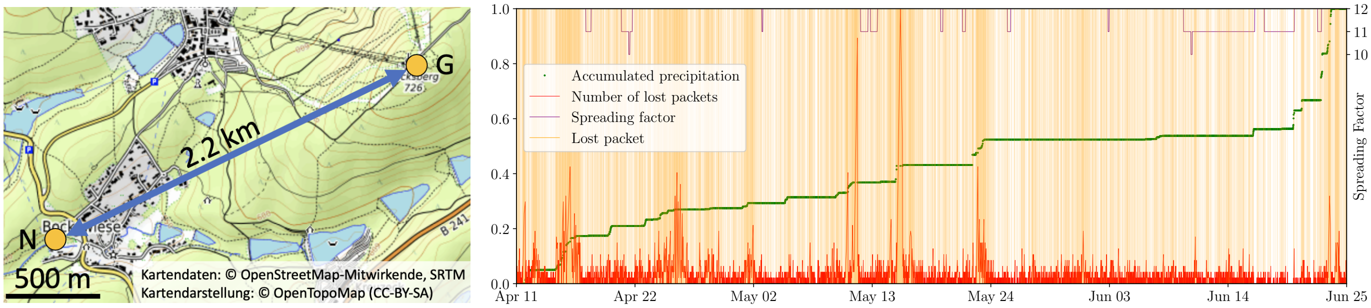
Climate change is known to be the cause of many weather extremes, like heatwaves and torrential rain [1]. One example for such an extreme precipitation event is the German *Ahrtal flood* that happened in July 2021. Within 24 hours, rainfall accumulated up to 150 liters per square meter, whereas the long-term average rainfall for the same region is less than 70 liters per square meter for the entire month of July [2]. The extreme precipitation resulted in one of Germany's most severe catastrophes of the last decades. More than 180 people died during the flood and the financial damages added up to nearly 30bn Euro [2]. Related works indicate that such extreme events may accumulate in future due to climate change [1, 3].

The research project *EXDIMUM* (Extreme Weather Management with Digital Multiscale Methods) aims to understand and analyze weather extremes by collecting and modeling data on multiple scales. One very crucial data source under consideration in the project are terrestrial data, as they can provide information about important hydrological parameters and indicators, like precipitation, river levels, and soil moisture. Due to their nature, these parameters can vary significantly over even small areas and short periods of time. For correct hydrological modeling, it is crucial to capture these local variations reliably. In order to do so, it is necessary for the measurement system to achieve a high spatial and temporal resolution. This is challenging in multiple regards. First, to achieve the desired high spatial resolution, sensors need to be deployed over a wide area, which is often also hard to reach. Secondly, the sensor nodes potentially need to transmit their measurements over long distances in the range of several kilometers, calling for wireless networking. Furthermore, the functionality of all nodes must be ensured for a long period of time with the limited energy capabilities from batteries. And lastly, data captured under extreme weather events is of particular high importance, as it contains valuable information for hydrological analysis and modeling. Therefore, the measurement system must be able to operate and collect data reliably even under extreme weather conditions.

Even though the latter requirement is especially relevant, the impact of precipitation on wireless links in sensor networks has not seen extensive consideration in previous research (cf. Section II). We thus analyze data that was captured over several months from a LoRaWAN-based sensor network, introduced in Section III, which is operated in the Harz mountains in Germany. In order to evaluate the reliability of wireless sensor nodes under harsh environmental conditions, we specifically focus on lossy links (i.e., links that can both increase and decrease their packet reception rates in response to ambient conditions), in order to assess whether they are negatively impacted by precipitation events (cf. Section IV).

II. Related work

Since Long Range (LoRa) nodes are often deployed outdoors and thus prone to changing weather conditions, several related works have investigated the effects of weather on the link quality in LoRa networks. Most of the works agree that weather conditions have an impact on the link quality. However, the impact of individual weather characteristics is controversially discussed in recent literature. On the one hand, a correlation between temperature and link has been described in multiple works, and there is consensus that higher temperatures decrease the Received Signal Strength Indication (RSSI) and Packet Reception Rate (PRR) [4–6]. On the other



(a) Topography of the LoRaWAN deployment.

(b) Precipitation data received from the node during April 11 - June 25, 2023.

Fig. 1. A topographic map of the analyzed LoRaWAN deployment is shown in subfigure (a). The node is marked with N, while the gateway is marked with G. Subfigure (b) shows the received accumulated precipitation data from Node N as well as the number of lost packets on a normalized scale. The Spreading Factor is also shown and varies between 10 and 12.

hand, no unequivocal statement has been determined for the impact of precipitation. The authors in [7] evaluated the RSSI for LoRa transmissions under tropical heavy rain of up to 180 mm/h and their results showed no impact on the RSSI or PRR. In contrast to this, [8] evaluates the RSSI for LoRa transmissions on an offshore sea farm. The results clearly show a correlation between precipitation and the RSSI. Furthermore, even a differentiation in RSSI between light, medium, and heavy rain is visible in their measurements. These results were also confirmed by [9], where Wang et al. conducted experiments on the performance of LoRa on a campus and found that even light rain reduced the PRR significantly by almost 20 %. Another interesting study was carried out by Ameloot et al. in [10]. The authors determined that the antenna placement is a crucial point in the correlation of precipitation and RSSI. Two different antenna locations, outdoor and indoor were compared and only the outdoor antenna was suffering from dips in RSSI during rain while the indoor antenna did not show any significant variations. The authors assume that the humidity on the outdoor antenna changed its behavior, resulting in an antenna mismatch and RSSI drops.

Overall, related works indicate that weather indeed has an impact on the link quality of LoRa networks and should be considered. The specific impact on any individual link is, however, highly specific to the deployment scenario. Previously weak links seem to be particularly prone to adverse weather conditions, since the RSSI may drop more easily below the receiver sensitivity threshold, resulting in packet losses. We therefore analyze and investigate the effects of weather conditions on the LoRaWAN deployment in the Harz mountains in order to assess its reliability under different weather conditions.

III. Monitoring System

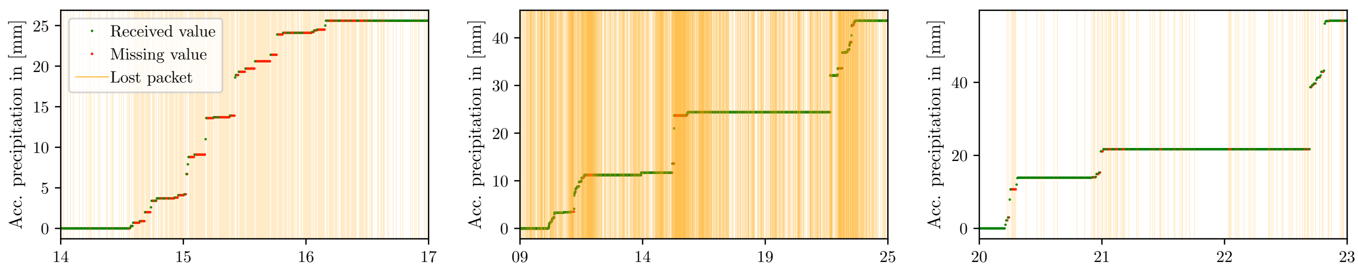
The analyzed LoRaWAN deployment is located in the Upper Harz in Germany. For an in-depth analysis we decided to focus on a node that is placed at the edge of the reception range and thus potentially particularly vulnerable to adverse weather events. The node (N) and gateway (G) locations are marked in the topographic map in Fig. 1a. The gateway is located on top of a mountain, approximately 720 m above sea level and the node is placed in the valley, approximately 540 m above sea level. The distance in between is 2.2 km and there is no line-of-sight path. A *MultiTech Conduit* [11] gateway and an *ELSYS ELT-2* [12] node were used. The node transmits data every 10 minutes using the LoRa transmission parameters as shown in Table I and uses an Adaptive Data Rate (ADR) feature, which allows for dynamic adjustments of the Spreading Factor (SF).

TABLE I
Used LoRa transmission parameters.

Frequency	Spreading Factor	Bandwidth	Coding Rate
867.1 - 868.5 Mhz	10 - 12	125 kHz	4/5

IV. Evaluation

We evaluated the data collected during the timespan of 74 days, between April 11 and June 24, 2023. During this period, 6228 samples were received and 4479 were lost, resulting in a mean PRR of 58 %. The RSSI ranged from -100 to -119 dbm, averaging at -116 dbm. The accumulated precipitation values and number of lost packets are shown in Fig. 1b. For the sake of visual clarity, all values have been normalized to a scale from 0 to 1. Additionally, vertical lines are used to mark all sample points that have been lost. Thus, their intensity gives an impression of the accumulation of consecutive packet losses. Furthermore, the SF is also shown and varies between 10 and 12. The diagram clearly shows two things. First, as mentioned earlier, the PRR is comparatively small, resulting in packet losses across the entire time period. Secondly, more packet losses occur especially during rain events (as indicated by a rise of the *precipitation* line). A similar behavior can be observed with the SF, as it stays at the maximum value of 12 during rainy periods with high packet losses and reduces during periods of no rain and minor packet loss. This is expected, since ADR is specifically designed to adapt the SF based on the link quality. In order to get a more detailed impression of the correlation between precipitation and link quality, we analyzed several rain events with different characteristics and high packet loss rates. The results are shown in Fig. 2 and confirm our previous observation: The



(a) April 14-17, 2023.

(b) May 9-25, 2023.

(c) June 20-23, 2023.

Fig. 2. A detailed view on the received precipitation data as well as missing samples for three different time periods with particular high packet loss rates.

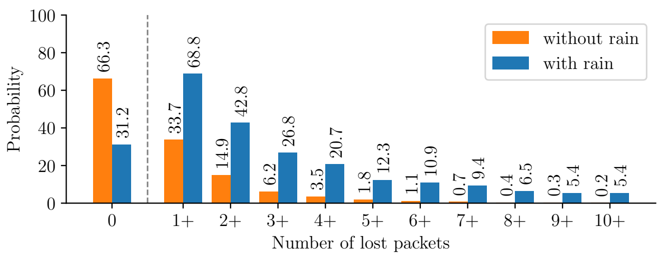


Fig. 3. Probability for the loss of different-length sequences of packets.

number of lost packets increases during rain events, as can be observed as an increase of the density of missing sample points. To quantify the results, we analyzed the probability for packet losses for times with and without rain events. Therefore, we assumed a rain event if an increase in the accumulated precipitation was measured between two received samples. The results are presented in Fig. 3 and clearly show that the probability for packet losses is increased during rain events. While there is a chance of 66 % that no packet is lost when there is no rain, it decreases to 31 % in case of rain. The probability for at least one missing sample is 34 % without rain and increases up to 69 % during rain. For larger numbers of packet losses, the probability decreases exponentially for both (rain and no rain), however, the probability stays consistently higher for samples collected during rain.

V. Conclusion and Outlook

In this paper we investigated the impact of rain on the link quality of a LoRaWAN-based sensor network. By way of an analysis of data captured during several months in the Harz mountains in Germany, we have correlated rainfall with the ensuing packet losses. In our evaluation, we have focused on a node with particular weak RSSI and PRR, given that such nodes are especially susceptible to even minor deteriorations of the link quality. Our results, contrary to some related works, indicate that precipitation indeed has a significant impact on the link quality of lossy LoRaWAN nodes. We observed a decrease in the probability for no packet losses from 66 % down to 31 % in case of rain. Furthermore, the probability for losses of subsequently transmitted packets is consistently higher during rain. For our future work, we plan to investigate the observed correlations in more detail and validate our first results on a larger dataset and with more nodes. In the future, Wireless Sensor Networks (WSNs) could benefit from considering weather conditions and dynamically adapting to them. Potential adaptions may include changes of transmissions parameters or alternative routing approaches. Also, the prediction of lossy links (due to bad weather conditions) may offer interesting research ideas, especially in regions where adverse weather conditions occur regularly.

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