Range test

Theory and practical results about Sensor and Gateway radio coverage range

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Table of Contents

Setup 1, Packet Loss

1 Introduction

Packet loss in wireless sensor networks can significantly impact the reliability and efficiency of data transmission, especially in environments with multiple devices operating in close proximity. Understanding the underlying causes of packet loss is crucial for optimizing network performance and ensuring accurate data collection. This investigation is part of an ongoing effort to diagnose and mitigate packet loss in a Proof of Concept (PoC) forest environment, where a high percentage of packet loss has previously been observed but not thoroughly investigated.

2 Aims and Objectives

The primary goal of this investigation is to determine whether packet loss observed in previous tests is due to radio propagation issues or interference from other devices. To achieve this, the following objectives have been established to facilitate a thorough comparison of packet loss in a controlled, low-interference environment vs. a noisy environment:

2. Compare Packet Loss Between a Quiet and Noisy Environment

3. Evaluate the Average RSSI of Gen2 Sensors to Gen3 Gateways in a Quiet vs. a Noisy Environment.

4. Evaluate the Average SNR of Gen2 Sensors to Gen3 Gateways in a Quiet vs. a Noisy Environment.

3 Methodology

3.1 Setup of The Range Tests

To achieve these objectives, the packet loss test was conducted in two different environments. The first test took place in a quiet location with minimal external interference, from August 16th to August 19th, 2024. The second test was conducted in a noisy environment near a substation, surrounded by a Border Gateway (BG) and sensors in proximity, from September 6th to September 9th, 2024. In both tests, the sensors were set up within a 10m radius of the Gen3 BG. The devices used include:

- 1x Gen3 Border Gateway (bg3-2401-28)

- 3x Gen2 Sensors (wf-4n9292, wf-4n9295, wf-4n9482)

3.2 Data Pipeline

Using the data pipeline engine, data was extracted from Snowflake and processed in Python. Several inputs, as shown in **Figure 1**, were provided to the data pipeline: the Snowflake API username and password, a list of sensor and BG IDs, a date range, the gateway type indicating the SN to BG relation, and the temporal frequency, which was set to daily.

```
# SN2BG
username='enter username'
password='enter password'
sn_list = ['4n9292','4n9295','4n9482']
gtw_list = ['bg3-2401-28']
date_range = ['2024-09-06','2024-09-09']
gtw_type = 0
freq = 'D'


SN2BG, SN2BG_summary, subplot= data_pipeline.run_pipeline(username, password, sn_list, gtw_list, date_range,gtw_type,freq)
```

Figure 1, *a screenshot of running the data pipeline in Python.*

The following stages outline the methodology of the automated data pipeline engine:

3.2.1 Data Extraction Engine

The data extraction process involved querying Snowflake using SQL statements constructed within the *extraction engine*. The query was dynamically generated based on the provided sensor list, gateway ID, and date range. This query retrieved relevant sensor data, including RSSI, SNR, and packet information, for the specified period. The results were then fetched into a panda DataFrame for further processing.

3.2.2 Data Cleaning Engine

Once the data was extracted, the *cleaning engine* processed the sensor and gateway IDs to ensure consistency and accuracy in the dataset. The cleaning process involved standardizing the sensor and gateway IDs by extracting specific parts of the identifiers.

3.2.3 Data Aggregation Engine

This stage, handled by the *summary engine*, involved aggregating the cleaned data to calculate key performance metrics such as average RSSI, average SNR, and packet error rate (PER). The data was grouped by sensor ID, gateway ID, and date, and resampled to a daily frequency. Missing packets were identified and counted by comparing the sequence of frame counts, and these missing packets were then factored into the total packet count. The aggregated data was merged with the calculated missing packets to produce a final summary dataframe, which included total packets, packet loss percentages, and other relevant metrics.

3.2.4 Data Visualisation Engine

The last stage, the visualization engine, generates graphical representations of the aggregated sensor data, allowing for easy comparison of key metrics like RSSI, SNR, and packet error rate (PER) across different sensors and gateways over time. The engine leverages Seaborn's plotting capabilities to create bar charts that visually capture the performance of each sensor node. The data is first grouped by sensor and gateway IDs, with timestamps providing the temporal dimension for the plots.

4 Result & Discussion

The comparison between the datasets in **Table 1** and **Table 2** highlights the impact of environmental conditions on sensor node performance, particularly regarding signal quality and packet loss. **Table 1**, which reflects data from a quiet environment, shows relatively stable RSSI and SNR values across all sensors, with sn-4n9292 consistently maintaining an RSSI between -65 dBm and -66 dBm. Even the weakest sensor, sn-4n9482, which reported RSSI values as low as -96 dBm, exhibited minimal packet loss on multiple days. Notably, sn-4n9482, despite its poor RSSI, achieved 0% packet loss on the 18th and 19th of August, suggesting that factors other than RSSI, such as SNR, played a crucial role in mitigating packet errors in a quiet setting.

Table 1*, sensor and gateway communication summary in a quite place.*

SN.id	***Timestamp***	***Avg. RSSI (dBm)***	***Avg. SNR (dB)***	***Missing Packets***	***Total Packets***	***Packet loss (%)***
sn-4n9292	16.08.2024	-66.61	13.04	3	21	14.29
sn-4n9292	17.08.2024	-65.54	13.32	7	20	35.00
sn-4n9292	18.08.2024	-65.59	13.17	2	24	8.33
sn-4n9292	19.08.2024	-65.48	13.06	0	25	0.00
sn-4n9295	16.08.2024	-35.50	10.87	4	20	20.00
sn-4n9295	17.08.2024	-35.77	12.84	6	19	31.58
sn-4n9295	18.08.2024	-35.22	11.74	1	24	4.17
sn-4n9295	19.08.2024	-35.42	11.69	0	24	0.00
sn-4n9482	16.08.2024	-93.00	9.10	5	20	25.00
sn-4n9482	17.08.2024	-96.21	8.25	5	19	26.32
sn-4n9482	18.08.2024	-94.71	8.44	0	24	0.00
sn-4n9482	19.08.2024	-94.42	8.50	0	24	0.00

Conversely, **Table 2**, which captures data from a noisy environment, reveals a degradation in performance. Across the board, packet loss surged, with sn-4n9292 experiencing packet loss rates as high as 82.35% on the 6th of September, despite maintaining similar RSSI and SNR levels to those in the quiet environment. Sensor sn-4n9295 also demonstrated poor performance in the noisy environment, with RSSI values dropping into the -80 dBm range and packet loss climbing to 66.67% on the 7th of September. This comparison suggests that noise interference has had a profound affect on signal quality and packet loss.

Table 2, *sensor and gateway communication summary in a noisy place.*

SN.id	Timestamp	Avg. RSSI (dBm)	Avg. SNR (dB)	Missing Packets	Total Packets	Packet loss (%)
sn-4n9292	06.09.2024	-65.00	13.80	14	17	82.35
sn-4n9292	07.09.2024	-65.00	12.65	16	22	72.73
sn-4n9292	08.09.2024	-65.00	12.55	12	23	52.17
sn-4n9292	09.09.2024	-60.55	13.23	6	17	35.29
sn-4n9295	06.09.2024	-82.89	10.44	13	22	59.09
sn-4n9295	07.09.2024	-84.20	9.12	10	15	66.67
sn-4n9295	08.09.2024	-85.00	10.85	3	5	60.00
sn-4n9295	09.09.2024	-79.88	11.08	15	23	65.22
sn-4n9482	06.09.2024	-66.75	11.66	6	14	42.86
sn-4n9482	07.09.2024	-67.10	11.49	10	20	50.00
sn-4n9482	08.09.2024	-67.10	11.06	10	20	50.00
sn-4n9482	09.09.2024	-65.30	11.48	8	18	44.44

4.1 Compare Packet Loss Between a Quiet and Noisy Environment

In the range test for the quite environment, as shown in **Figure 2**, packet loss fluctuates but remains relatively low. On August 17th, all three sensors experienced their highest packet loss, with wf-4n9292 peaking at 35%, wf-4n9295 at 31.58%, and wf-4n9482 at 26.32%. This indicates a possible temporary disturbance affecting all sensors simultaneously. Notably, performance improved on the subsequent days, with wf-4n9482 achieving 0% packet loss on both August 18th and 19th, despite having lower signal quality (as indicated by the low RSSI values shown in Table 1). The other sensors also showed improvement, indicating stable network conditions in this quieter environment.

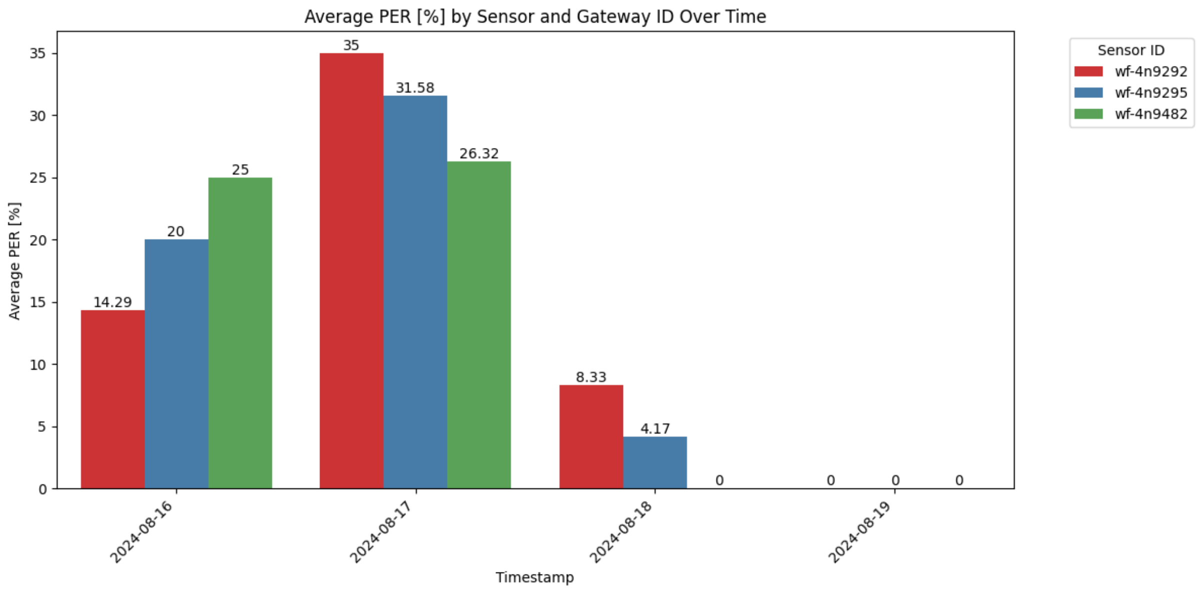

Figure 2, *Bar plot illustrating the packet error rate (%) for gen2 sensors to gen3 border gateways in the quite environment.*

In contrast, the range test shown in **Figure 3**, which took place in a noisy environment, demonstrates much higher and more consistent packet loss across the board. On September 6th, wf-4n9292 recorded a packet loss of 82.35%, while the other sensors also faced losses—wf-4n9295 at 59.09% and wf-4n9482 at 42.86%. Over the following days, although there were slight variations, the packet loss remained high for all sensors, with wf-4n9295 peaking at 66.67% on September 7th and wf-4n9482 consistently around 50%. This suggests that the noisy environment greatly impacted communication quality, resulting in substantial network performance degradation.

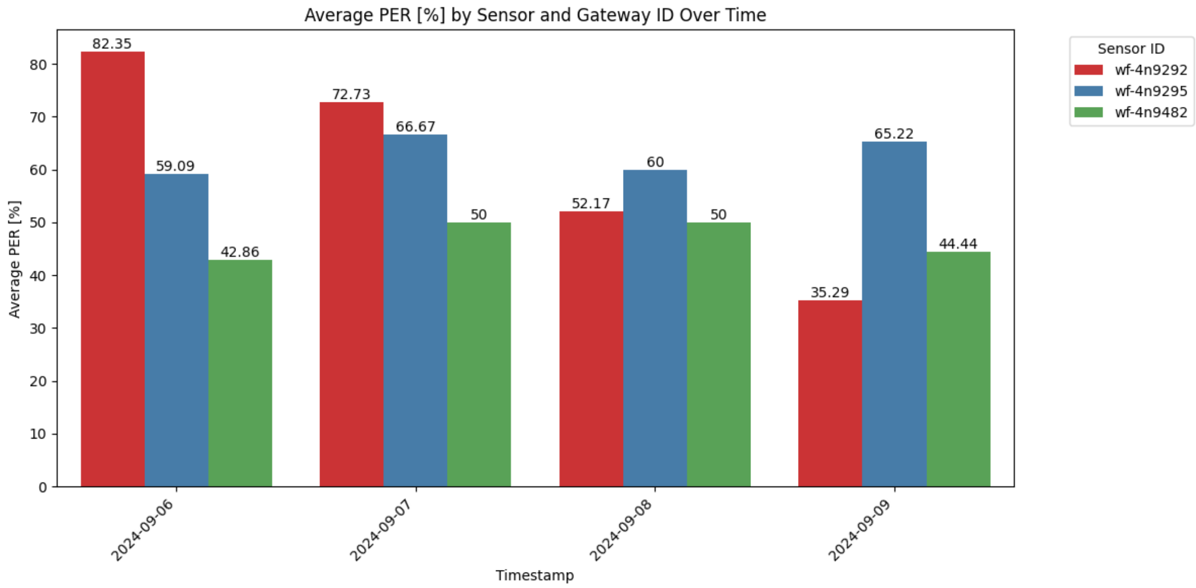

Figure 3*, Bar plot illustrating the packet error rate (%) for gen2 sensors to gen3 border gateways in the noisy environment.*

4.2 Evaluate the Average RSSI of Gen2 Sensors to Gen3 Gateways in a Quiet vs. a Noisy Environment.

In the quite range test, as shown in **Figure 4**, wf-4n9482 consistently exhibited the lowest RSSI values, ranging from -93 dBm to -96 dBm, indicating a significantly weaker signal strength compared to the other sensors. Despite these low RSSI values, wf-4n9482 maintained acceptable performance with minimal packet loss, as seen in **Figure 2**. wf-4n9295, on the other hand, consistently displayed the highest RSSI values, around -35 dBm, reflecting strong signal performance. wf-4n9292 remained relatively stable with moderate RSSI values in the range of -65 dBm across the days, providing balanced performance overall.

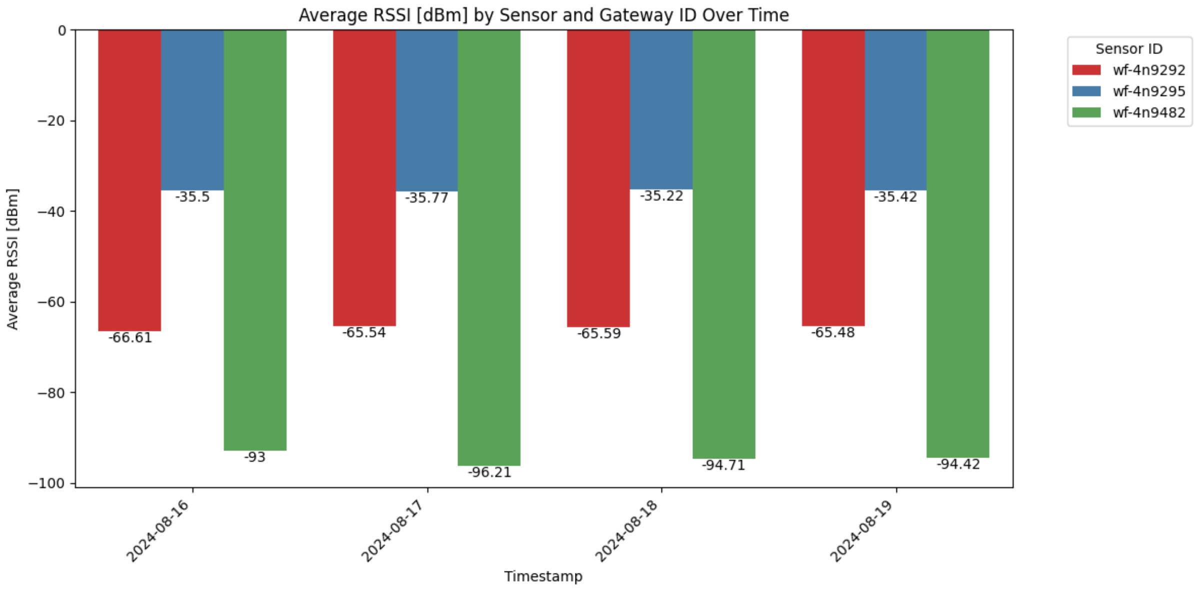

Figure 4*, Bar plot illustrating the average RSSI for gen2 sensors to gen3 border gateways in the quite environment.*

In the noisy range test, as shown in **Figure 5**, all sensors experienced significant fluctuations in RSSI values, which were generally worse than in the quiet environment. wf-4n9295, which previously exhibited the strongest signal, reported much lower RSSI values, dropping to -82.89 dBm on September 6th and -85 dBm on September 8th. Similarly, wf-4n9482 continued to show lower values, ranging between -66 dBm and -67 dBm. Interestingly, wf-4n9292 showed slight improvements in some cases, reaching -60.55 dBm on September 9th. However, the noisy environment clearly impacted all sensors, contributing to higher packet loss rates despite the fluctuations in RSSI.

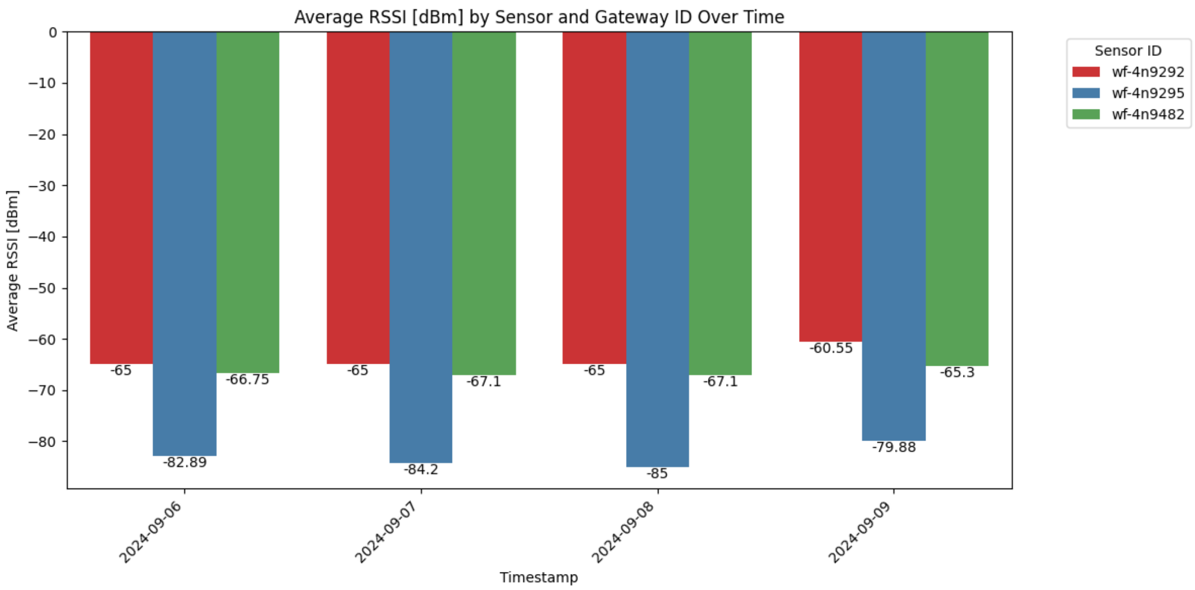

Figure 5*, Bar plot illustrating the average RSSI for gen2 sensors to gen3 border gateways in the noisy environment.*

4.3 Evaluate the Average SNR of Gen2 Sensors to Gen3 Gateways in Quiet vs. a Noisy Environment.

In the quite range test, as shown in **Figure 6**, wf-4n9482 consistently exhibited the lowest SNR values, ranging between 8.25 dB and 9.1 dB. In contrast, wf-4n9292 consistently displayed the highest SNR values, staying above 13 dB, indicating a clear signal with minimal interference. wf-4n9295 maintained relatively strong SNR values, ranging between 10.87 dB and 12.84 dB, reflecting solid communication performance overall. The relatively high SNR across all sensors points to minimal interference in this quiet environment, contributing to their stable performance.

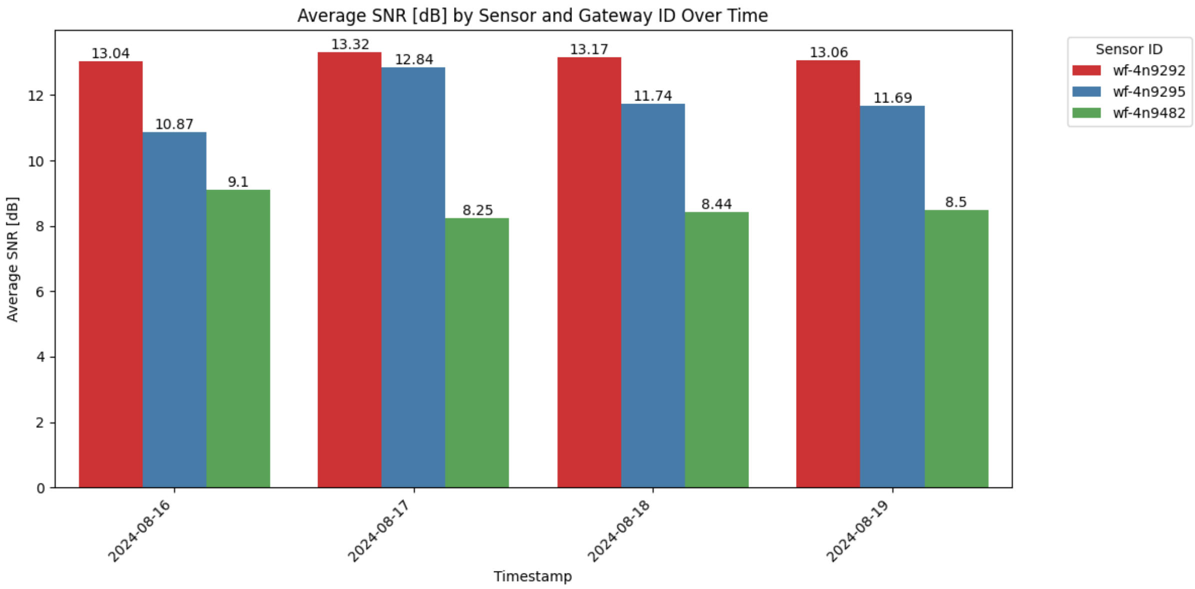

Figure 6, *Bar plot illustrating the average SNR for gen2 sensors to gen3 border gateways in the quite environment.*

In the noisy range test, as seen in **Figure 7**, SNR values remained positive but showed slightly more variability. wf-4n9292 continued to perform well, with SNR values peaking at 13.8 dB on September 6th and 13.23 dB on September 9th, suggesting that it still received a strong signal despite the expected noise in the environment. wf-4n9295 exhibited stable values around 12.5 dB, but wf-4n9482, which had the lowest SNR in the quiet environment, also reported lower values in the noisy test, reaching as low as 9.12 dB on September 7th. Nevertheless, all sensors during this test maintained positive SNR values overall. Interestingly, the noisy environment exhibited higher average SNR values, which is counterintuitive as we would of expected more noise and lower SNR compared to the quiet environment. This suggests that while interference was expected, the background noise levels were not as disruptive as anticipated, allowing the sensors to maintain relatively strong signal clarity.

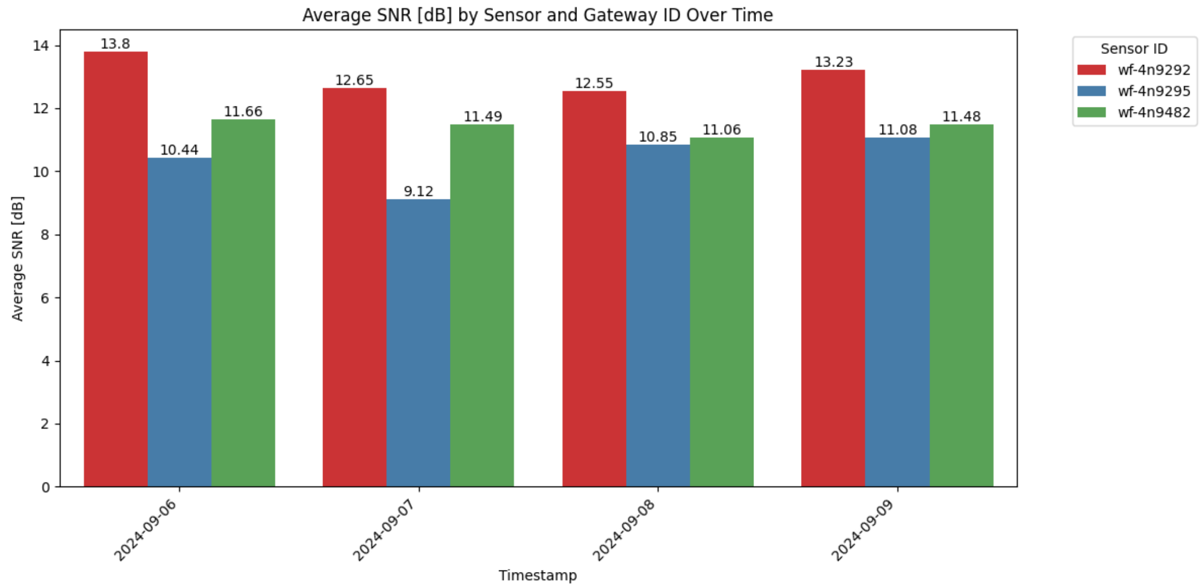

Figure 7*, Bar plot illustrating the average SNR for gen2 sensors to gen3 border gateways in the noisy environment.*

5. Conclusion

The study highlights the performance of three gen2 sensor nodes in terms of RSSI, SNR, and packet loss over several days of interaction with a gen3 border gateway. While the sensors exhibited notable differences in signal strength and clarity, especially between quiet and noisy environments, all three maintained relatively stable RSSI and SNR values overall. In the quiet environment, minimal interference likely contributed to this stability, with only occasional packet loss spikes. Interestingly, in the noisy environment, despite the higher expected interference, the average SNR values were unexpectedly higher, suggesting that background noise may not have been as disruptive as anticipated. However, the consistently high packet loss in the noisy environment indicates that other factors beyond RSSI and SNR, such as environmental noise or network congestion, may have played a significant role in degrading performance.