Poster Abstract: Understanding Long-Term Running Patterns of Citywide LoRa Networks

Shuai Tong[1], Jiliang Wang[1], Yunhao Liu[1], Jun Zhang[2]
[1]Tsinghua University [2]ENNEW Technology Co., Ltd.
tl19@mails.tsinghua.edu.cn, jiliangwang@tsinghua.edu.cn, yunhao@tsinghua.edu.cn, junzhang@enn.com

ABSTRACT

LoRa, as a representative Low-Power Wide-Area Network (LPWAN) technology, holds tremendous potential for various city and industrial applications. However, as there are few real large-scale deployments, it is unclear whether and how well LoRa can eventually meet its prospects. In this paper, we demystify the real performance of LoRa by deploying and measuring a citywide LoRa network consisting of 100 gateways and 19,821 LoRa end nodes, covering an area of 130 km^2 for 12 applications. Our measurements reveal that LoRa performance in urban settings is bottlenecked by the prevalent blind spots, and there is a gap between the gateway efficiency and network coverage for the infrastructure deployment. Besides, we find that LoRa links at the physical layer are susceptible to environmental variations. Our measurement provides insights for large-scale LoRa network deployment and also for future academic research to fully unleash the potential of LoRa.

KEYWORDS

LoRa, Network measurement, Internet of Things

ACM Reference Format:
Shuai Tong, Jiliang Wang, Yunhao Liu, Jun Zhang. 2023. Poster Abstract: Understanding Long-Term Running Patterns of Citywide LoRa Networks. In *The 21st ACM Conference on Embedded Networked Sensor Systems (SenSys '23), November 12–17, 2023, Istanbul, Turkey*. ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3625687.3625782

1 INTRODUCTION

LoRa, as a representative Low-Power Wide-Area Network (LPWAN) technology, is garnering increasing attention from both industry and academia. Despite the huge popularity, the functionality of LoRa in long-term and large-scale systems still need to be measured and validated. We study the deployment and operation of a large-scale LoRa network for real-world smart city applications. The network is designed to connect citywide municipal devices, which consists of 100 gateways and 19,821 LoRa nodes, covering an area of 130 km^2 and serving 12 kinds of smart city applications, such as gas and water metering, fire alarms, etc. End nodes in the network are deployed as shown in Figure 1. We evaluate the performance of the LoRa network from the application layer to the physical layer, revealing the performance gap between the LoRa coverage and gateway efficiency. We collect over 389M transmission records with fine-grained cross-layer network information from a five-month measurement. We estimate the energy consumption and system costs of LoRa. We aim to provide guidance for large-scale LoRa deployment and show insights for future academic research on LoRa network optimization.

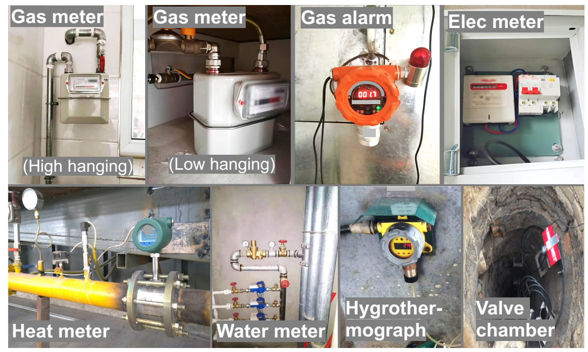


Figure 1: Deploying environments of nodes in CityWAN.

Our study differs from the previous works in the following two aspects. First, previous field studies and measurements were conducted with small-scale and dedicated LoRa deployments of only a few end nodes and gateways. End nodes in those systems are mostly deployed in simple environments such as roofs or roadsides [1, 2]. We measure the LoRa performance with a citywide large-scale network and uncover its performance challenges in real-world applications. Second, although previous works also study the link and coverage performance of LoRa, their measurements just provide a rough understanding of signal propagation. In contrast, we not only perform a detailed study to understand the LoRa characteristics at different layers but also study the facts that bottleneck LoRa performance. Our experience in deploying citywide networks provides realistic lessons for both application users and network operators in using and deploying LoRa networks.

2 STUDY METHODOLOGY

We demystify the long-term running patterns of the citywide LoRa networks from four major perspectives:

(i) Coverage Performance: One of the key advantages of LoRa lies in its ultra-long communication range, which is expected to reach upto tens of kilometers. However, previous studies show that LoRa signals in urban scenarios suffer from severe attenuation and penetration loss, leading to a coverage far smaller than expected [3, 4]. To understand the coverage issues in practice, we characterize

SenSys '23, November 12–17, 2023, Istanbul, Turkey

ACM ISBN 978-x-xxxx-xxxx-x/YY/MM…$15.00
https://doi.org/10.1145/3625687.3625782

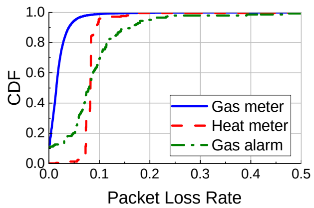


Figure 2: CDF of packet loss rates for different applications.

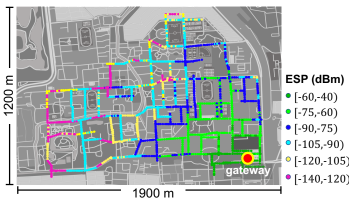


Figure 3: Coverage measurement for the ESP map in a typical urban environment.

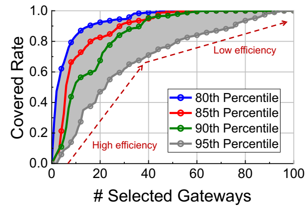


Figure 4: Node covered rate over different number of applied gateways.

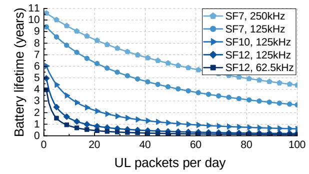
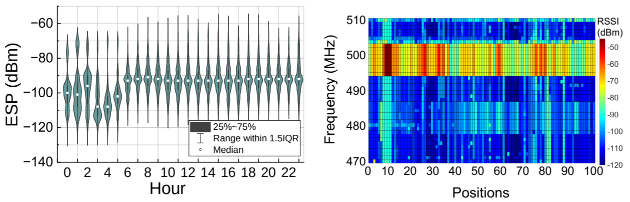


Figure 5: Node battery lifetime with different data rates and uplink transmission demands.



(a) (b)

Figure 6: Link variations (a) at different times and (b) over different frequencies and positions.

the coverage profile of the citywide LoRa deployment. We measure the LoRa coverage from the high-level system performance down to the physical layer link behaviors. Besides, we summarize the network characteristics and analyze the root cause that bottlenecks the coverage performance of large-scale LoRa networks.

(ii) Gateway Utilization: The installation and maintenance of gateways are costly and affect the coverage of LoRa networks. We investigate the impact of gateway deployment on network performance by measuring gateway utilization.

(iii) Link Reliability: LoRa links face many attrition factors, e.g., signal interference, rich multi-path, and packet collisions [5]. To understand how these factors manifest LoRa links in practice, we perform link measurements over different transmission times, channels, gateway redundancies, and surrounding environments. We analyze the root cause of link fluctuations and present innovations for improving reliability of LoRa links.

(iv) Energy Consumption: Energy consumption and costs are first-order concerns of IoT devices as they are battery-powered and should be low-cost for large-scale deployment. We measure the power profile of end nodes in our citywide LoRa network under various data transmission demands. Besides, we build economic models for estimating the system costs considering the whole lifecycle of IoT applications.

3 EVALUATION RESULTS

(i) For the coverage measurement, we reveal that packet loss and coverage blind spots are prevalent in urban LoRa applications, even though gateways are densely deployed as shown in Fig 2. Besides, the blind spots are spatially scattered as shown in Fig 3, making it expensive and inefficient to optimize coverage by adding gateways.

(ii) For the gateway utilization, we find that the importance of different gateways in the network is different, where 40 critical gateways can cover 95.3% of end nodes, but connecting the rest 4.7% of nodes needs 60 more gateways as shown in Fig 4. This indicates a gap between the gateway efficiency and network coverage.

(iii) For the link reliability, we find that LoRa links vary across transmission times, frequencies, and surrounding environments, as shown in Fig 6. We verify that both the physical environment and the radio environment can impact the link performance, implying that cognitive radios, such as carrier sensing should be studied to avoid the environment-induced link degression in LoRa networks.

(iv) Finally, for the energy consumption, we find that LoRa has different power efficiency among different transmission configurations. This inspires us to apply mixed configurations to build IoT systems with the best cost efficiency. LoRa is cost efficient due to the low protocol overhead.

4 CONCLUSION

To our knowledge, this work represents the first measurement study for the deployment and operation of a citywide LoRa network. Our main contributions can be summarized as follows: *(i)* Deploying and operating a large-scale LoRa network for connecting municipal devices in real-world applications. *(ii)* Quantitative characterization of LoRa transmission and coverage profile in urban settings, providing guidance for large-scale network deployment. *(iii)* Locating the bottleneck of LoRa performance by fine-grained connectivity measurements. *(iv)* Identifying the gap between gateway efficiency and network coverage to inspire network deployment optimization. *(v)* Profiling LoRa links under various transmission times, channel frequencies, and environments. *(vi)* A detailed measurement of LoRa energy consumption.

ACKNOWLEDGEMENTS

This work is in part supported by National Key R&D Program of China 2022YFC3801300, National Natural Science Foundation of China (U22A2031, No. 61932013, 62172250). Jiliang Wang is the corresponding author.

REFERENCES

[1] Yidong Ren, Li Liu, Chenning Li, Zhichao Cao, and Shigang Chen. Is lorawan really wide? fine-grained lora link-level measurement in an urban environment. In *Proceedings of IEEE ICNP*, 2022.
[2] Jansen C Liando, Amalinda Gamage, Agustinus W Tengourtius, and Mo Li. Known and unknown facts of lora: Experiences from a large-scale measurement study. *ACM Transactions on Sensor Networks*, 15(2):1–35, February 2019.
[3] Chenning Li, Hanqing Guo, Shuai Tong, Xiao Zeng, Zhichao Cao, Mi Zhang, Qiben Yan, Li Xiao, Jiliang Wang, and Yunhao Liu. Nelora: Towards ultra-low snr lora communication with neural-enhanced demodulation. In *Proceedings of ACM SenSys*, Nov 10-14, 2021.
[4] Shuai Tong, Zilin Shen, Yunhao Liu, and Jiliang Wang. Combating link dynamics for reliable lora connection in urban settings. In *Proceedings of ACM MobiCom*, New York, NY, USA, 2021.
[5] Shuai Tong, Yangliang He, Yunhao Liu, and Jiliang Wang. De-spreading over the air: Long-range ctc for diverse receivers with lora. In *Proceedings of ACM MobiCom*, page 42–54, 2022.