Connectivity Analysis of a Large-Scale 4G LTE-M Urban Sensor Network

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Abstract

Smart city devices are beginning to leverage IoT-specific cellular networks for real-time data communication, but little is known about how reliably these networks support large-scale, long-term stationary deployments. We present a connectivity analysis of over 8.5 million observations from a 118-node LTE-M-connected sensor network over one year in Chicago. Results show the promise of cellular networks as a reliable communication channel for citywide IoT deployments, but some sites had inadequate RSS to support sensing nodes and a small number of dates and cell towers had a significant amount of delayed readings. This work presents observations to drive reliable future cellular-connected smart city deployments with a focus on the importance of land use and tower-specific factors as considerations for the design of equitable smart city and connected sensing networks.

1 Introduction

Large-scale sensor networks can help address key challenges of urban life including traffic, noise, and air pollution [9]. Yet few cities have implemented large-scale, long-term smart sensor networks due to various barriers. The most important of them is connectivity, which is essential for real-time node monitoring, and software updates. Despite advances to low-power wide-area networks (LPWAN) [4], future urban IoT sensing will continue to use LTE networks due to widespread global availability and infrastructure, which allow for low cost and ease of setup.

Cellular network performance for mobile communication is well-researched and continuously evolving [1]. However, few prior works evaluate the connectivity of urban sensor networks in real-world settings, and those that do either focus on technologies such as Wi-Fi and Zigbee [5, 7], or are small scale, short-term studies [6, 8]. This work analyzes the connection performance of a large-scale LTE-M-connected sensing network in Chicago. We evaluated connectivity, received signal strength (RSS), and latency for 129 nodes, deployed across the city, from July 1, 2021 to June 30, 2022.

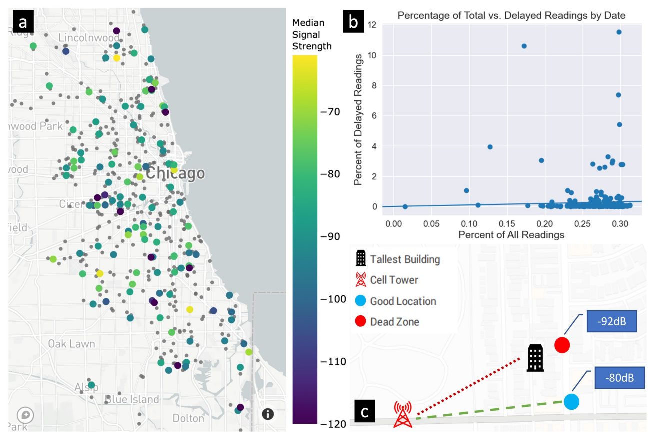

Figure 1: a) Deployed sensor nodes with their median signal strength (dark signifies no connectivity) and all cell towers (grey) connected to during the study period. b) Percentage of total readings vs. percentage of readings delayed at least 30 seconds for all 365 dates in the study period. Shows that a small number of dates accounted for a large share of the delayed readings. c) Line-of-sight issue for a sensor node blocked by built environment. Highlights connection to the same tower from two different locations.

Results were overall positive—118 locations had adequate signal strength to support a sensing node and the median latency to transmit data from a node to the cloud was about 5 seconds. However, we found two major connection-related issues: 1) Some urban locations lacked the connectivity to support reliable data transfer from a sensing node, and 2) a small number of dates in the study period accounted for a large percentage of significantly latent readings.

The findings highlight the promise of LTE connectivity as well as the challenges of relying on it for widespread urban sensing networks. Delayed readings create a hurdle for time-sensitive applications and areas with low or no connectivity show that smart city initiatives cannot be successful until network coverage is reliable across the entire city.

2 Methods and Materials

The sensing nodes were designed for urban air quality monitoring, and were placed at over 100 bus shelters in Chicago, as detailed in [2]. Each node used an *Ignion NN03-310* antenna to connect to the *AT&T IoT LTE-M One network*. The nodes sampled every five minutes from the last recorded sample time. The data transmission process includes the following steps: 1) the microprocessor wakes up and starts two separate threads, 2) One thread for sensing and the other initiates network connection, 3) Lastly, the sensor node data is packaged and transmitted to the cloud. Individual data, including node location, received signal strength, and cell tower ID are logged with each reading and stored in the cloud server. For connectivity analysis, we used *OpenCellID* and *OSM Buildings* to gather cell tower location and building information, respectively.

3 Results and Discussion

Our dataset included 8,684,756 readings for the 118 locations with connectivity. The median latency for these readings was 5 seconds, with less than 8% of readings having a latency of 10 seconds or more, and the median RSS was -86dBm.

We identified 11 locations at which the sensor nodes failed to connect. Initial mitigation strategies involved moving the nodes to the next closest bus shelter (often across the street), but we discovered that the nodes had to be moved further to establish a connection. When examining the potential causes of these "dead zones", we found that one node configuration exhibited line-of-sight interference, as shown in Fig. 1c.

8 sensor locations had a median signal strength $<= -100$ dBm. As seen in Fig. 1a, these locations, like those with no connectivity, tend to fall towards the outskirts of the city, particularly in the southeast and west. Notably, these are neighborhoods that are underserved by multiple forms of infrastructure [3]. To ensure a future where urban sensing addresses—and even helps identify inequality—there is a need to recognize the risk of disproportionately reduced connectivity in underserved communities.

We also discovered that the number of readings with a latency of 30 seconds or more were not evenly distributed by date (Fig. 1b). A small number of dates in the study period had a significant percentage of the delayed readings compared to their percentage of the total number of readings. Initial exploration shows that these delays are also tied to specific tower locations, indicating that the cause may be due to tower maintenance or other temporal network behavior. Coordination with network providers can help cities and researchers plan around such events to prevent data loss or delays. Regardless, delayed readings—even for just a small percentage of the dataset—have an implication for urban sensing applications that rely on low-latency, such as fire response.

Finally, we note the challenge of limited open data to complete a thorough analysis. Because the location of cellular towers is not publicly available, we relied on crowdsourced data. We faced a similar issue in finding updated accurate information about land use such as building heights and materials to accurately identify line-of-sight and propagation environment issues. We highlight the need for tower location and land use data as essential for future urban sensor network planning, as having this information will help researchers identify ideal sensing node placement locations.

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