Demo: Scalable and Sustainable Asset Tracking with NextG Cellular Signals

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ABSTRACT

This demonstration presents *LiTEfoot*, an ultra-low power localization system leveraging ambient cellular signals. To address the limitations of traditional GPS-based tracking systems in terms of power consumption and latency, *LiTEfoot* employs a non-linear transformation of the cellular spectrum to achieve efficient self-localization. Our design uses a simple envelope detector to realize spectrum folding, enabling the identification of multiple active base stations. The *LiTEfoot* prototype shows a median localization error of 22 meters in urban areas and 50 meters in rural areas, consuming only 40 μJoules of energy per localization update.

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1 OVERVIEW

In today's rapidly advancing pervasive computing landscape, there is a critical demand for localization systems that operate on ultra-low power and cover wide areas. Traditional GPS-based solutions, while providing high accuracy, are hampered by high power consumption making them impractical for long-term, low-power applications. *LiTEfoot* addresses these challenges by harnessing ambient cellular signals to enable efficient and accurate self-localization. Moreover, GPS-based systems, despite their accuracy in open areas, face significant challenges in urban environments with tall buildings and narrow streets.

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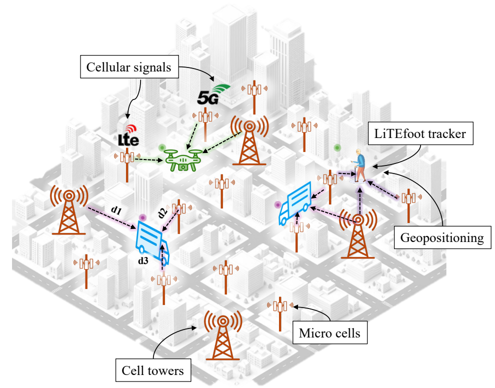
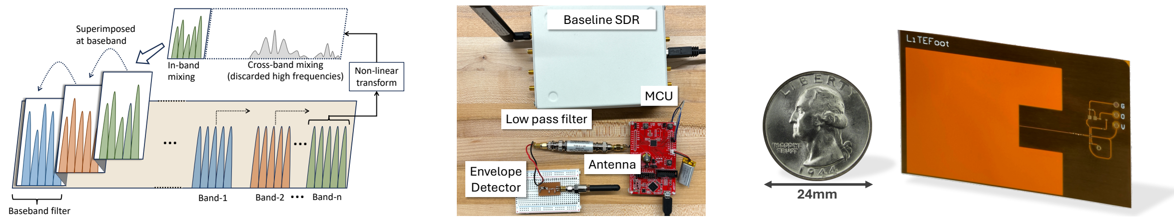


Figure 1: *LiTEfoot* is a low-power localization system that track assets using ambient cellular signals.

The extensive coverage of cellular networks presents a unique opportunity for large-scale localization without requiring new infrastructure. With the widespread adoption of 4G-LTE and 5G technologies, cellular coverage has become nearly ubiquitous. For instance, in the United States, mobile networks extend to over 98% of the population and 90% of road networks, according to FCC reports. This pervasive coverage has sparked interest in developing nationwide localization techniques, resulting in various research initiatives and commercial products for cellular-based positioning on smartphones and tracking devices. However, implementing cellular localization on low-power platforms faces two critical challenges: the latency and computational power required to scan wide bandwidths, and the need to downconvert passband signals for synchronization and cell identification.
In this demonstration we show a small, low-cost, and low-power alternative, *LiTEfoot*, which utilizes cellular infrastructure and has opened an interesting possibility of wide-area localization without investing in dedicated infrastructure, as shown in Fig. 1.

2 INTUITIONS AND SYSTEM DESIGN

LiTEfoot introduces a novel technique called 'intermodulated spectrum folding' that leverages the distinct properties of LTE synchronization signals (PSS and SSS). These signals consistently exhibit a narrow bandwidth of 1.4 MHz (1.08 MHz without guard bands) across all LTE frame bandwidths,



(a) Intermodulation and spectrum folding **(b) Demo Setup** **(c) Tracker PCB prototype**

Figure 2: (a) Illustration of intermodulation and spectrum folding technique used in LiTEfoot. (b) Overview of the demonstration setup. (c) The LiTEfoot wireless tracker prototype next to a US quarter for scale.

ranging from 1.4 MHz to 20 MHz. By implementing a non-linear operation - multiplying the signal by itself - this method isolates and folds LTE signals from various bands into the baseband (see Fig. 2a).

The core of *LiTEfoot*'s design relies on an envelope detector, which introduces non-linearity in RF circuits using a simple passive diode [3–6]. When LTE's OFDM signal is passed through an envelope detector followed by a low pass filter it produces $y(t) = \frac{N}{2} - \frac{1}{2}\sum_{n=1}^{N}\sum_{m=1}^{N}\cos(2\pi(\Delta f_n - \Delta f_m)t)$, where N is number of sub-carriers , and $\Delta f_i = f_c - f_i, \forall i \in N$, f_c being the carrier frequency and f_i is the subcarrier frequency. In other words, the signal produced contains the frequency differences of the incoming signals, effectively downconverting or 'folding' the higher frequency elements into the baseband region.

To estimate Physical Cell Identity (PCI) from intermodulated signals, we employ a time-domain correlation approach similar to a matching filter:

$$PCI = i|corr(x, PSS_i^2 \oplus SSS_i^2) > thresh, i = 1, ..., N \qquad (1)$$

Here, $\oplus$ is the concatenation operation and x is the received signal. The PSS and SSS have a constant bandwidth of 1.08 MHz, which is crucial for maintaining signal integrity across LTE's variable bandwidth scenarios. This approach allows *LiTEfoot* to achieve wideband sensing and accurate cell tower identification while maintaining ultra-low power consumption, making it suitable for long-term, battery-powered operation in various IoT applications.

3 CHALLENGES AND CONTRIBUTIONS

The intermodulated spectrum folding technique, while efficient, introduces several challenges that need to be addressed for accurate localization. Firstly, inter-subcarrier interference becomes a challenge as LTE bandwidth increases, with data subcarriers overshadowing PSS and SSS signals after non-linear transformation; this is mitigated by exploiting the periodicity of synchronization signals and stacking multiple frames to enhance Signal-to-Interference-and-Noise Ratio (SINR). Secondly, inter-band interference occurs when cell towers operate at different bands, causing frequency differences from inter-band subcarriers; this is resolved by employing a low-pass filter with a cutoff frequency of 1.4 MHz to remove all inter-band interference. Thirdly, inter-synchronization signal interference arises from the superposition of multiple synchronization signals; however, the robust correlation characteristics of PSS and SSS, preserved even after non-linear squaring operations, ensure high accuracy in PCI estimation despite this superposition. Finally, the system faces challenges in recovering base station signal strength from the composite received signal, which is addressed through a blind source separation algorithm that iteratively isolates each cell's contribution.

4 DEMONSTRATION

We demonstrate ultra-low-power localization using our SDR-based baseline system and PCB prototype (Fig. 2b, 2c). *LiTEfoot* tags sense the 3GHz wideband LTE spectrum in 10ms, consuming only 40 μJoules per location inference. Our 4cm x 6cm flexible PCB prototype integrates an antenna, low-noise amplifier, envelope detector, high-impedance amplifier, and an ultra-low-power ARM Cortex-M4 microcontroller. *LiTEfoot* achieves median localization errors of 22 meters (urban) and 50 meters (rural), with tags operating up to 11 years on a single coin cell battery. Table 1 compares the latency, accuracy, and energy consumption of *LiTEfoot* with baseline systems.

Method	Latency (s)	Error (m)	Energy (mJ)
SDR (Wideband search)	66100	38	21×10^4
SDR (Targeted search)	0.66	38	210
Crescendo [1]	0.66	24	210
GPS [7]	1	2	25
LiTEfoot [2]	0.01	19	0.039

Table 1: Comparing latency, accuracy, and energy.

The demo will display real-time tag tracking using custom base stations, with live updates of PCI estimates and triangulated locations. This showcases our system's accuracy and wideband response. Additionally, visitors will see interactive visualizations of key signal processing stages.

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REFERENCES

[1] Elbakly, R., and Youssef, M. Crescendo: An infrastructure-free ubiquitous cellular network-based localization system. In *2019 IEEE Wireless Communications and Networking Conference (WCNC)* (2019), IEEE, pp. 1–6.

[2] Garg, N., Ghosh, A., and Roy, N. Litefoot: Ultra-low-power localization using ambient cellular signals. In *Proceedings of the 22nd ACM Conference on Embedded Networked Sensor Systems (SenSys 2024)* (New York, NY, USA, 2024), ACM. University of Maryland, College Park.

[3] Garg, N., and Roy, N. poster: Ultra-low-power angle-of-arrival estimation using a single antenna. In *Proceedings of the 21st Annual International Conference on Mobile Systems, Applications and Services* (2023), pp. 569–570.

[4] Garg, N., and Roy, N. Sirius: A self-localization system for resource-constrained iot sensors. In *Proceedings of the 21st Annual International Conference on Mobile Systems, Applications and Services* (2023), pp. 289–302.

[5] Guo, X., Shangguan, L., He, Y., Jing, N., Zhang, J., Jiang, H., and Liu, Y. Saiyan: Design and implementation of a low-power demodulator for {LoRa} backscatter systems. In *19th USENIX Symposium on Networked Systems Design and Implementation (NSDI 22)* (2022), pp. 437–451.

[6] Rostami, M., Chen, X., Feng, Y., Sundaresan, K., and Ganesan, D. Mixiq: re-thinking ultra-low power receiver design for next-generation on-body applications. In *Proceedings of the 27th Annual International Conference on Mobile Computing and Networking* (2021), pp. 364–377.

[7] u blox. Ultra-low power gps with the u-blox m10, 2023. Accessed: 2024-07-01.