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.

CCS CONCEPTS

• **Hardware → Wireless devices**; *Impact on the environment*; • **Computer systems organization → Sensor networks**.

KEYWORDS

Asset tracking, Low-power sensing, NextG, Wideband, Ambient Computing, Sustainable, Scalable

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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.

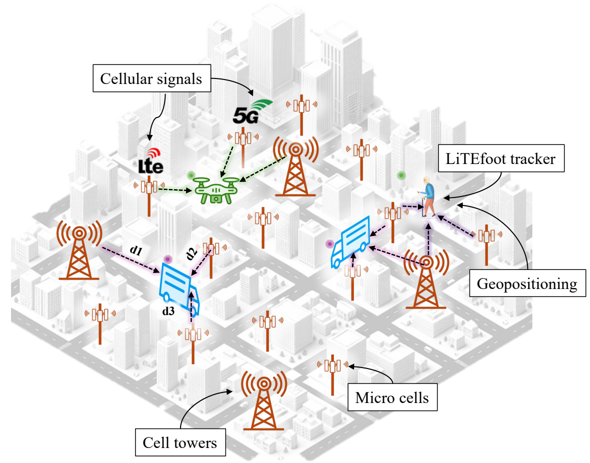

Figure 1: *LiTEfoot* is a low-power localization system that track assets using ambient cellular signals.

Cellular networks' extensive coverage offers a unique opportunity for large-scale localization without new infrastructure. With 4G-LTE and 5G reaching over 98% of the U.S. population (FCC reports), there's growing interest in nationwide cellular-based positioning techniques. However, implementing these on low-power platforms faces two key challenges: the high latency and computational power needed for wide bandwidth scanning, and the requirement 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.

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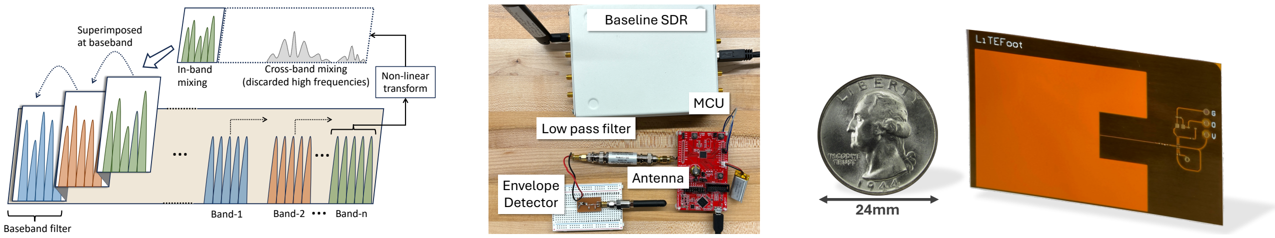

(a) Intermodulation and spectrum folding (b) Demo Setup (c) Tracker PCB prototype

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.

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, 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* relies on an envelope detector, introducing non-linearity in RF circuits [3–6]. LTE's OFDM signal through this detector and a low pass filter 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 sub-carrier count, $\Delta f_i = f_c - f_i$, f_c is carrier frequency, and f_i is 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. PCI estimation uses time-domain correlation where PSS and SSS maintain 1.08 MHz bandwidth across LTE scenarios. This enables wideband sensing and accurate tower identification with ultra-low power, suiting long-term IoT applications.

3 CHALLENGES AND CONTRIBUTIONS

The intermodulated spectrum folding technique introduces several challenges. Inter-subcarrier interference occurs as data subcarriers overshadow PSS and SSS signals in wider LTE bandwidths; this is mitigated by exploiting synchronization signals' periodicity and frame stacking to enhance SINR. Inter-band interference from cell towers at different bands is resolved using a 1.4 MHz cutoff low-pass filter. Inter-synchronization signal interference is overcome by PSS and SSS's robust correlation characteristics, preserved after non-linear squaring. Finally, signal-strength recovery from the composite signal is addressed through an iterative blind source separation algorithm. These solutions collectively enable high accuracy in PCI estimation and overall localization performance.

4 DEMONSTRATION

We demonstrate the feasibility of low-power and real-time localization with the help of real-world cell-towers. Our setup consists of a baseline system built using SDR and our PCB prototype (see Fig. 2b and 2c). We show that *LiTEfoot* tags can sense the 3GHz wideband LTE spectrum in just 10ms, consuming only 40 μJoules of energy per location inference. Our prototype used in the demonstration comprises of an antenna, a low-noise amplifier, an envelope detector, and a high-impedance amplifier, all integrated with an ultra-low-power ARM Cortex-M4 microcontroller for processing. The prototype is made on a flexible pcb substrate with a form factor of 4cm x 6cm. Our evaluations show that *LiTEfoot* acheives a median localization error of 22 meters in urban areas and 50 meters in rural areas, with low power consumption capabilities that *LiTEfoot* tags can operate continuously for up to 11 years on a single coin cell battery. Table 1 shows the overall results comparing latency, accuracy and energy consumption.

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.

5 ACKNOWLEDGEMENT

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