Poster Abstract: An RFID Localization System for Smart Logistics

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ABSTRACT

In a modern logistics network, high-performance automation of inventory tracking and package management calls for a **reliable**, **high-throughput** and **long range** RFID localization system. We present RF-Chord, the first RFID localization system that simultaneously meets all these requirements. RF-Chord features a one-shot multisine-constructed wideband design that can process the RF signal with a 200 MHz bandwidth in real-time to facilitate one-shot localization at scale. In addition, multiple SINR enhancement techniques are designed for range extension. Finally, we propose a kernel-layer-based near-field localization and a multipath-suppression algorithm that reduces the 99% long-tail errors.

CCS CONCEPTS

• **Hardware** → **Wireless devices**; • **Networks** → **Location based services**.

KEYWORDS

RFID, Multisine, Localization, Real-time, Logistics IoT

1 PROBLEM STATEMENT

Today's major e-commerce giants handle about 10^{10} packages per year, calling for high-performance automation. Considering a typical warehouse (Fig. 1) where 10s of packages pass through the checkpoint to be verified, recorded, sorted, and tracked, we envision the automated RFID system to replace labor-intensive barcode scanning, and it must meet 3 requirements:

i) Reliability. The classic ROI (range of interest) reading task requires the reader to scan all the RFID tags within the ROI (*i.e.,* near-zero miss-reading rate) while do not include any tag out of the ROI (*i.e.,* near-zero cross-reading rate). *ii) Throughput.* The packages come to the checkpoint in bursts (*i.e.,* 100~200 packages, including ~ 50 in the trailer and other nearby packages) while all the logistic operations need to be finished within 2~3 seconds before they check in/out. *iii) Range.* A single reader should cover tags within 3~5 m range, which is the typical width of the check-in/out aisle.

Existing RFID systems can be catalogued as *inventory-based* or *location-based*, both fail to meet the 3 above requirements simultaneously. Inventory-based RFID, for example, the industrial UHF reader ([2]) is fast and far but notorious for cross-reading (unreliable), while a recently proposed High-Q (i.e. very narrow band) inductive reader NFC+ [3] is reliable but of low throughput. In the location-based line, the cross-reading can be removed by extra location information, but the status-quo of high-throughput RFID locator [4] only demonstrated a sub-meter range experimentally.

2 RF-CHORD DESIGN

RF-Chord is the first RFID location system that meets the goal of high throughput, long-range, and reliability. Through a tour of the operation flow (Fig. 2), we highlight the key design elements of RF-Chord to achieve the goals.

High-throughput multisine wave packet sniffing. A reliable location depends on a wideband measurement. Specifically, we need a tag CSI measurement (phase and amplitude) of wideband and multiple antennas, but for the highest throughput of 100 tag/s, this process must consume only one EPC frame (aka one-shot localization), which means the antennas are captured *in parallel*. This one-shot requirement poses two challenges. First, we have to harness the beast of scale– in our system, a computer would need 250 million I/Q ADC samples per second (corresponding to ~ 200MHz), and it controls 8 RX antennas, then it needs $250\text{MSamp}/(\text{ant}\cdot\text{s})\times 8\text{ant}\times 32\text{bit/Samp} = 64\text{Gbps}$ IO burden. RF-Chord instead discretize this spectrum into 16 "tones" by transmitting a multisine wave ❷. Then we perform a channelization at RX (i.e. downconversion)❹ around each 250kHz region around each "tone" in a hardware of wideband RF frontend and FPGA, resulting in only ~4 Gbps IO load. Second, we need to synchronize to each tag-to-reader EPC frame before we extract

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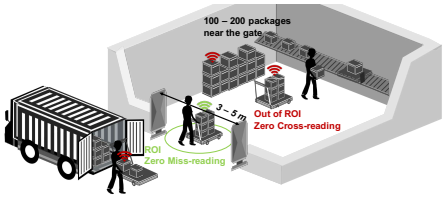

Figure 1: RFID in logistics networks.

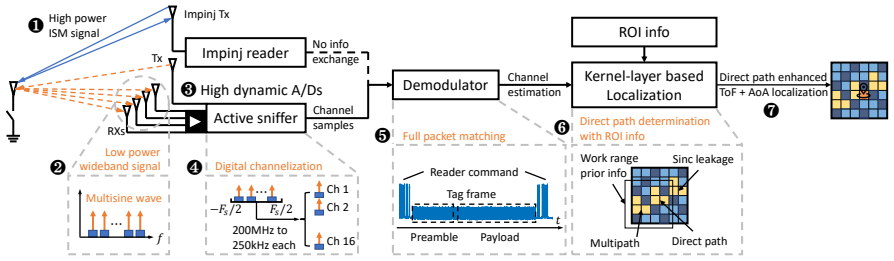

Figure 2: RF-Chord's system overview.

the CSI from them. However, as wideband ToF remains unsupported by most highly-optimized RFID readers, we would suffer from low MAC-layer efficiency of open-source EPC protocol stack (as in [4]). RF-Chord instead embraces *any* ISM-band reader as the tag activator (charging and coordinating the collision of EPC Gen II tags), while the RF-Chord overhears and decodes these tags alone without information exchange to ❶ in real-time, resulting in a high throughput solely limited by the protocol (180tag/s for Miller-4 uplink encoding).

Processing gain to for long range. The wideband must transmit low power (-13.3dBm per tone, compared to +30dBm of ISM) mandated by FCC, so there are fewer dBs in the link budget for the path loss to spend, making it very challenging to meet the long-range requirement. To boost SINR, RF-Chord first minimizes the self-interference by employing a recent high-dynamic-range RF frontend ADRV9009 (❸), and a careful low-crest-factor transmit tone phasing. Then, the noise is white, and noise power is proportional to the bandwidth, and our multisine channelization (❹) improves the SNR because it keeps only 250kHz of noise bandwidth instead of 200MHz whole band. Finally, RF-Chord further exploits the integration gain of full packet matching (❺) for channel estimation accuracy by performing accurate tag clock tracking during decoding.

Wideband and multipath-suppress for reliability. RF-Chord ensures high-reliability (*i.e.,* near zero miss-reading and cross-reading) by high-accuracy localization with the custom fine-grained distance resolution hardware and multipath-suppress algorithm. The distance resolution is inversely proportional to bandwidth, and traditional UHF RFID works on a 26MHz wide ISM band, corresponding distance resolution of 11.5 m. RF-Chord introduces an extra active sniffer-based reader (❷) to help UHF RFID reader (❶) to realize 200MHz wideband localization. The localization algorithm of RF-Chord is holographic, which profiles the location probability at every grid in the workspace with all the information across antennas and frequencies (like AoA+ToF but works better under the near-field condition ❼). However, the distance resolution of 200MHz (1.5 m) is still not enough in all situations. RF-Chord utilizes prior information (*i.e.,* fixed location of check-in aisle in the warehouse (❻)) to suppress the multipath effect and enhance direct path enhancement for super-resolution. Then the user can decide whether the tag is ROI or not, achieving zero cross-readings.

3 MAIN RESULTS

RF-Chord is implemented and deployed, and the results show that RF-Chord presents the first RFID (localization) system that meets all the requirements:

- **Reliability.** We evaluate RF-Chord's performance at 384 locations and collect over ~20k tag responses. Its 99% localization error is 0.78 m We mounted RF-Chord in the dock door of a warehouse and the scanning gate of a fresh food delivery store. We found that RF-Chord can read 100% of the tags passing the checkpoint (0% miss-reading rate). Its cross-reading rate is only 0.0025%~0.0154%.
- **Throughput.** RF-Chord can localize up to 180 tags per second, which is close to pure inventory product.
- **Range.** RF-Chord can reliably localize tags 6 m away from the reader.

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