Demo Abstract:

RF Time-of-Flight Ranging on Commodity Software Radios

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ABSTRACT

Recent advances in RF ranging techniques have shown superior performance in difficult RF environments but either lack the practicality of a real-time implementation or lack flexibility through purpose-built hardware. We present SR2, a super-resolution ranging platform developed for the software radio environment. SR2 achieves low resource utilization and hardware complexity requirements through a coherent RF design, making SR2 realizable on commodity software radios.

Categories and Subject Descriptors

B.m [**Hardware**]: Miscellaneous

Keywords

FPGA, Software Radio, Super-Resolution, Time-of-Flight

1. INTRODUCTION

A plethora of papers assume that radio frequency (RF) time-of-flight (ToF) ranging is a basic primitive on which more sophisticated services, such as localization, can be built on. Unfortunately, a paucity of systems that support RF ToF makes evaluating these services in realistic situations nearly impossible. We present SR2, a system which enables compact realization of super-resolution ranging algorithms on commodity software radios. The open implementation of our design allows for easy adaptation as a research tool by those involved in super-resolution ranging research. SR2's simple implementation will also ease the realization of RF ranging functionality on existing low-power digital radio technologies.

2. DESIGN

Realized in the software radio's FPGA fabric, SR2 incorporates coherent RF techniques to provide fast and accurate characterizations of the observed RF channel impulse response between wireless nodes while keeping system complexity low. Our demo showcases our design along with a basic IFT-based [1] super-resolution ToF ranging protocol. Other super-resolution techniques can be easily tested on top of our existing interface.

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Previous ranging systems either employ complex designs to compute super-resolution range estimates or ignore the multipath environment, leading to poor indoor performance. Table 1 shows the resource utilization of SR2 when implemented on a USRP1 software radio. Of particular note are the low memory requirements, low crystal accuracy, and no peripheral digital signal processor.

2.1 System Architecture

Figure 2 shows the system architecture of our coherent RF ranging design. The datapath is fully pipelined to process incoming RF baseband data at full speed, or one 12-bit I/Q sample per cycle. This pipelining allows range estimates to be calculated in near real-time. Stalls are forced during impulse response extraction - a short final step performed to extract Time of Arrival (ToA) estimates from the recorded data.

Baseband I/Q samples from the software radio front-end ADCs are first passed through a Costas loop, which provides the notion of coherency in our design. Coherency allows for the clock drift between wireless nodes to be accounted for, providing useful information for later portions of the datapath.

After the Costas loop, a BPSK demodulator is used to snoop the incoming data stream. All ranging information, protocol synchronization, and the ranging sequence itself are communicated using BPSK modulation over the RF channel.

Once the incoming range sequence is detected, a pipelined 256-point Radix-2^2 FFT core is used to convert the sampled range sequence into the frequency domain. Using frequency-domain techniques, the FFT data is time-shifted using the supplied timing error from the Costas loop. This process is repeated and the range sequence is averaged over time to produce a finalized representation of the refined range sequence.

After the range sequence refinement is complete, an estimate of the ToA is required in order to obtain an estimated range. ToA estimates are extracted from the calculated impulse response of the wireless environment. The impulse response is calculated through deconvolution of the refined range sequence with the expected range sequence. Using this calculated channel impulse response, the IFT-based super-resolution algorithm heuristically determines the time of arrival as the leading 6% height of the impulse response. Range is lastly determined through the calculation of the ToF of a range sequence exchange between nodes using the ToA estimates obtained.

Figure 1: Ranging demo consisting of SR2 implemented on two commodity USRP1 software radios. Range estimates are updated automatically between two autonomous nodes, then sent to a computer for display and visualization of the channel impulse response.

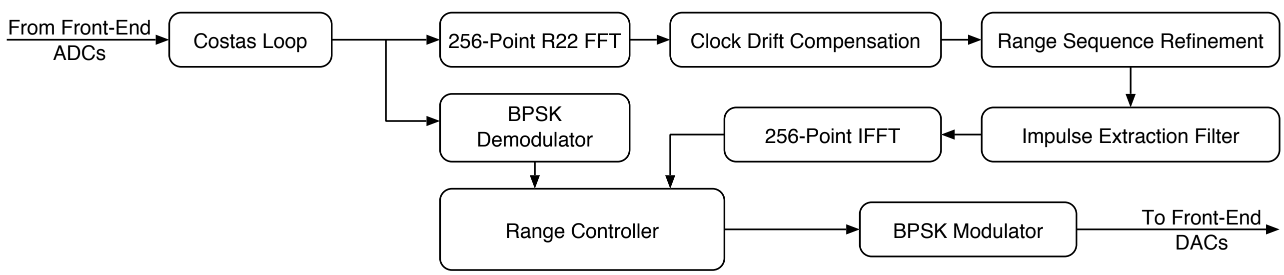

Figure 2: SR2 system architecture designed for software radio showing the data flow between system modules.

	SR2
Logic Elements	10,130
Memory	37kbit
DSP	None
Crystal Accuracy	15ppm
Range Accuracy	0.7m
Update Rate	>1000/sec possible
Bandwidth	64 MHz

Table 1: SR2 system implementation specifications on the USRP1 software radio platform.

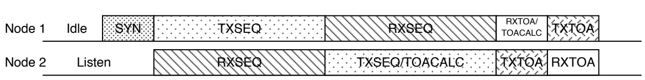

Figure 3: Ranging protocol flow. Exchange is initiated through transmission of a synchronization packet (SYN). The ranging sequence then immediately follows (TXSEQ), with the second node listening (RXSEQ). The nodes then trade roles with the first node listening. Lastly, ToA estimates are traded between nodes to come to a final ToF range estimate (RXTOA/TXTOA).

2.2 Ranging Protocol

Figure 3 shows the protocol used in performing ranging operations. Node A starts by sending a SYN packet to synchronize communications and request a ranging estimate to an addressed node. Immediately following, Node A sends a repeating ranging sequence for a pre-determined amount of time (denoted TXSEQ) while Node B listens (RXSEQ). The number of repetitions can be modified to increase SNR in demanding environments.

Node B follows by performing simultaneous transmission of the ranging sequence (TXSEQ) along with calculation of the recorded ToA (TOACALC) while Node A listens (RXSEQ). Now that the range sequence exchange is complete, Node B transmits its calculated ToA estimate to Node A (TXTOA and RXTOA) while it computes the recorded ToA from the last recorded range sequence. The ranging protocol is complete when Node A optionally transmits the calculated ToA estimate back to Node B if it is requested.

3. DEMO

This demo shows the feasibility of performing super-resolution RF ranging on commodity hardware. Operating on 5.8GHz, two USRP1 software radios will be loaded with the SR2 system. Range requests will be periodically requested between the nodes, and all ranging information will be transferred from one of the wireless nodes to a connected computer for data visualization.

The current range estimate, a histogram of recent range estimates, and a graph of the measured impulse response will be visualized on the attached computer. The range between the two software radios will be adjustable through direct movement of the free node. Dynamic changes in the environment such as body movement have a great impact on the observed shape of the impulse response. The live-update impulse response visualization provides an intuitive understanding of the difficulties faced in performing accurate range estimation in indoor environments.

4. REFERENCES

[1] T. Sathyan, D. Humphrey, and M. Hedley. Wasp: A system and algorithms for accurate radio localization using low-cost hardware. *IEEE Transactions on Systems, Man, and Cybernetics – Part C*, 41(2):211–222, Mar. 2011.