



RF Technology

By.Prateek Singh
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Motivation

Design

Hardware Implementation

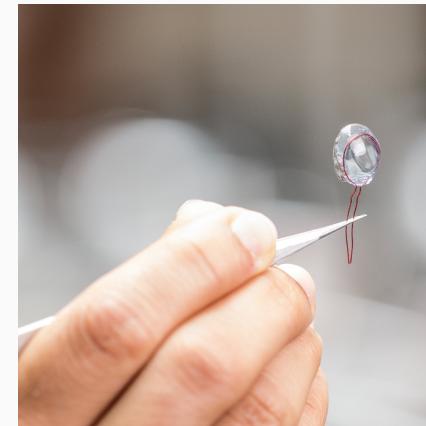
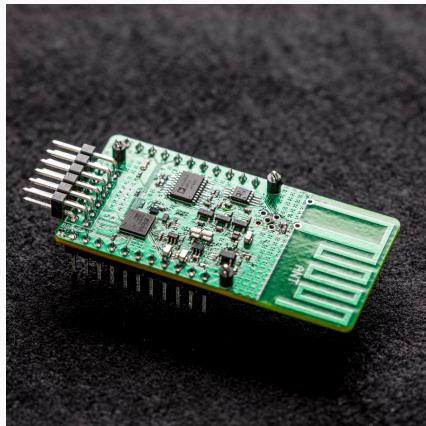
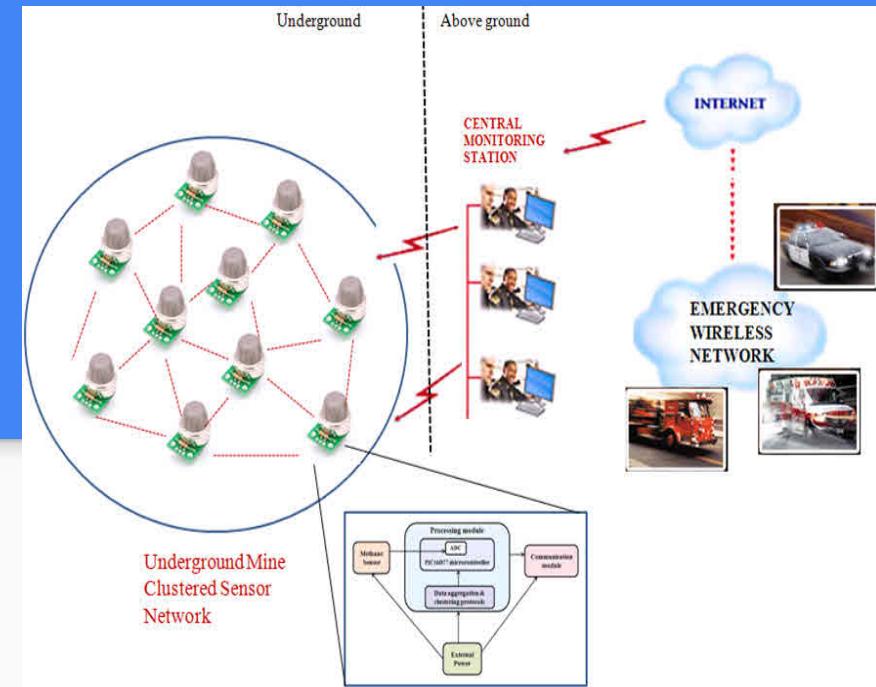
Results

Motivation: Ubiquitous Connectivity

- Implementing communication between billions of devices
- Requirements
 - Reliable and long range communication
 - Low power
 - Inexpensive to manufacture
- Issues
 - No existing technology combines all three factors
 - E.g., backscattering is low power and cheap, but short ranged
- Solution
 - LoRa

Applications

- Smart cities
- Precision agriculture
- Whole-home and office sensing
- Body-mounted medical sensing



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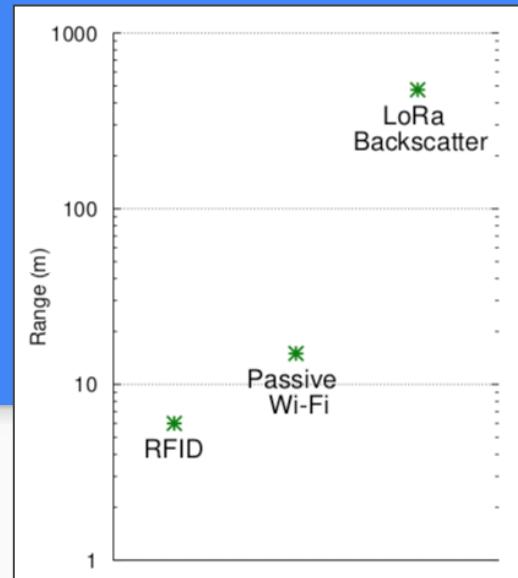
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Why LoRa ?

Advantages:

- **Low power consumption** (three orders of magnitude lower than radios; not significantly better than other backscatter modes)
- **High operating range** (100s of meters compared to tens for other backscatter modes)
- **Low cost and size** (primarily digital construction materials)



Alternatives Explored:

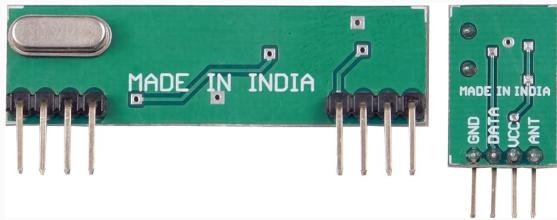
Radios

- Wi-Fi
- BLE
- ZigBee
- SigFox

Backscatter

- RFID
- Passive Wi-Fi

RF Module



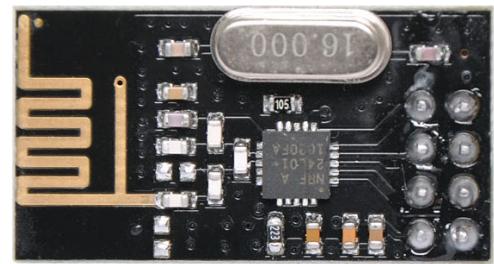
RF zigbee Module



1. Low Power Consumption.
2. Easy For RF-based Application.
3. Complete Radio Transmitter.
4. Transmit Range Up To 50m.
5. CMOS / TTL Input.

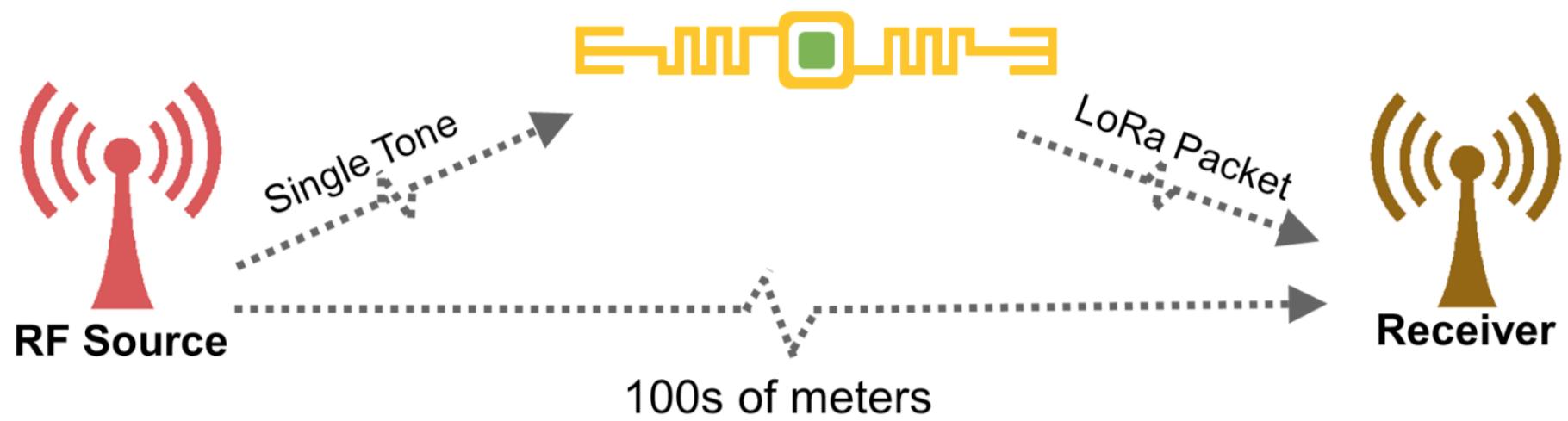
1. Integrated, Wire Antenna
2. Interoperable other ZigBee-compliant devices
3. 15 general-purpose I/O lines
4. Industry-leading sleep current of sub 1 μ A
5. Transmit Range Up To 1km.

RF NRF Module



1. Voltage: 3-3.6V (recommended 3.3V).
2. Maximum output power: +20dBm.
3. Power-down mode current: 4.2uA.
4. Operating Range: 1Km
5. Receive Mode Current(peak): 45mA
6. It uses 2.4GHz global open ISM band.

Why LoRa ?

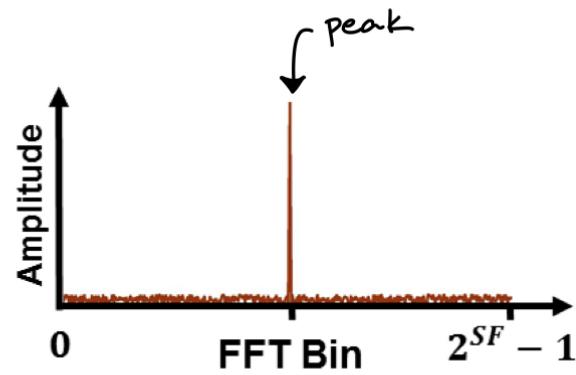
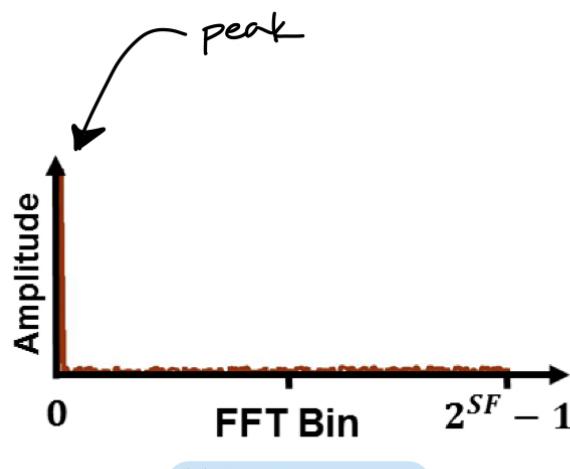
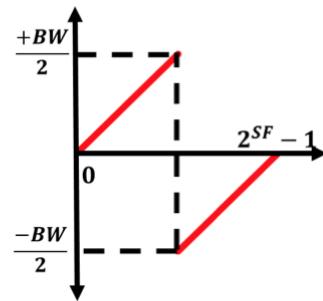
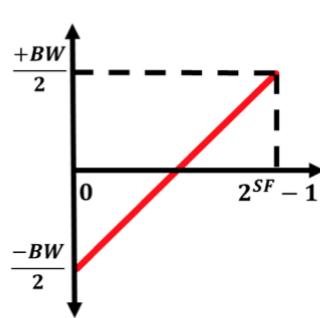


LoRa Architecture

- The LoRa wireless uses a chirp-spread spectrum (CSS) modulation with options for different Spreading Factors (SF) and bandwidth to optimize the modulation to meet the range and data requirements.
- LoRa uses ISM bands 433MHz, 868MHz or 915MHz depending on jurisdiction with the band divided up into channels.
- LoRa network consists of several elements. Most of the modern LoRa IoT LAN technologies use mesh network architecture.
 - **LoRa Nodes/ End points**
 - **LoRa Gateways**
 - **Network servers**
 - **Application server**

Synthesizing CSS with Backscatter

Recall: **Chirp spread spectrum (CSS)** encodes data as cyclic time shifts of the baseline “chirp,” which appear as frequency shifts after an FFT.



(a) Symbol 1

(b) Symbol 2

(c) FFT output 1

(d) FFT output 2

Synthesizing CSS with Backscatter

Recall: **Chirp spread spectrum** (CSS) encodes data as cyclic time shifts of the baseline “chirp,” which appear as frequency shifts after an FFT.

- Bit rate: $\text{BW}/(2^{\text{SF}}) \cdot \text{SF}$ (BW = bandwidth; SF = spreading factor)

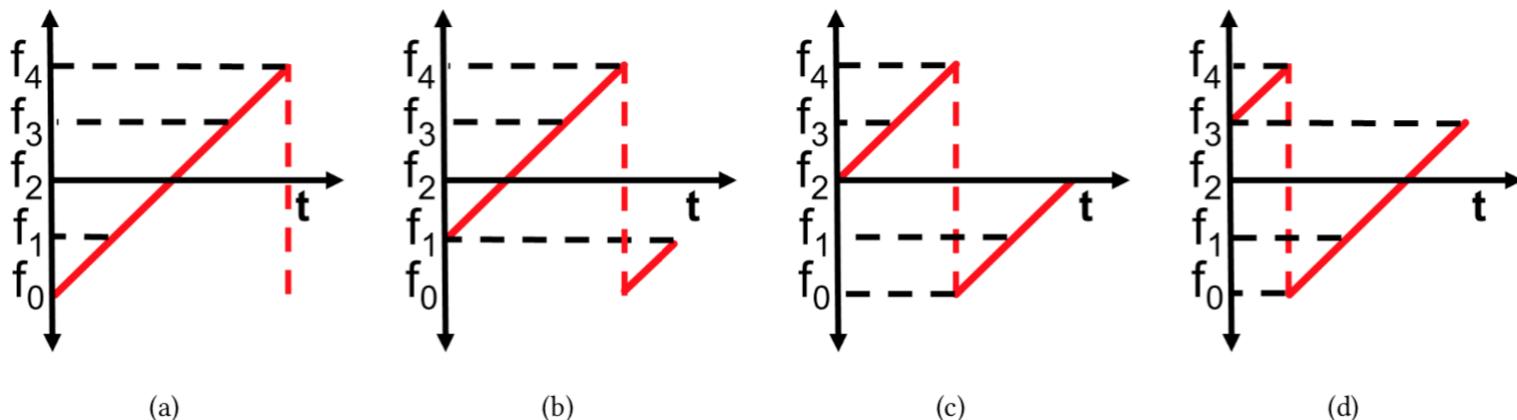


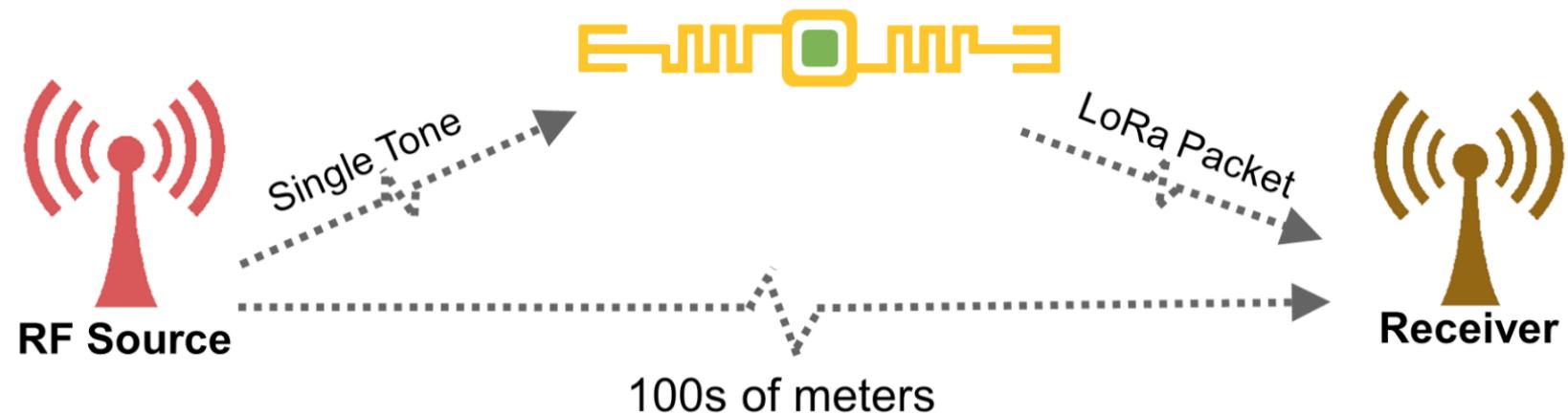
Fig. 6. Four CSS symbols when spreading factor is 2.

Backscatter Harmonic Cancellation

- Issues in signal approximation with square waves
 - Creates mirror copies at third and fifth harmonics
 - Prior systems ignored these signals (out-of-band)
 - Noisy for LoRa due to high sensitivity
- Solution
 - Use different signal than a square wave
 - Square waves have two voltage levels → high frequency components
 - Multilevel signal to better approximate sinusoid
 - Designed such that third and fifth harmonics are cancelled

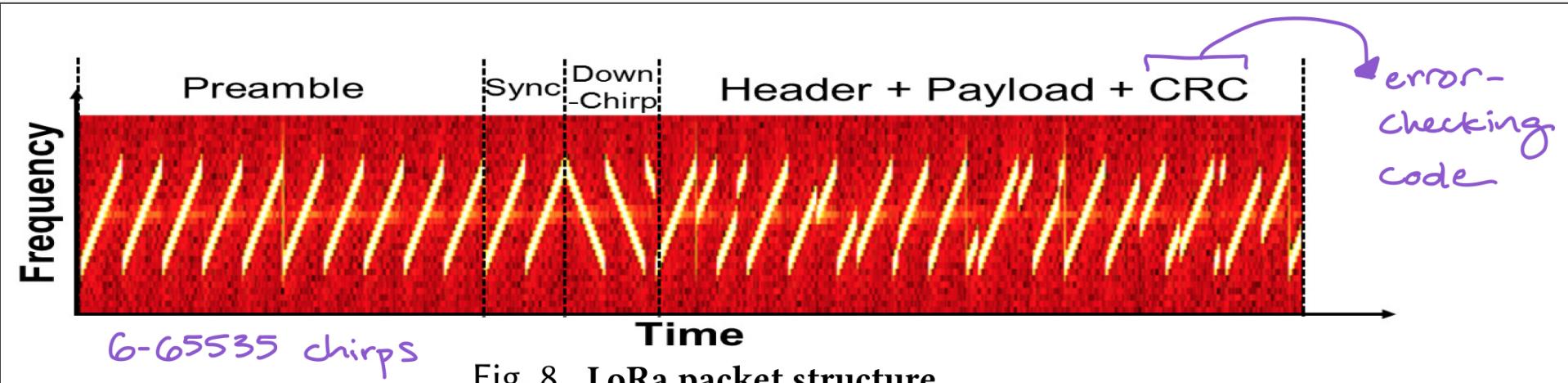
Reverse-Engineering LoRa Packet Structure

- Challenge: physical layer specification for LoRa is proprietary
- Solution:
 - Reverse-engineer LoRa physical layer using Semtech patents
 - Analyze transmissions from LoRa chipsets on a Universal Software Radio Peripheral (USRP)



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Setting LoRa Parameters

- LoRa bit rate determined by 3 factors:
 - chirp bandwidth
 - spreading factor
 - error correction coding rate
- BW and SF set in advance, known by transmitter & receiver
- High sensitivity: phase of chirps must change continuously with time and have same value at each end of chirp
 - At each frequency, increase phase by $2\pi/SF$
- To comply with FCC, frequency-hop the single-tone chirp transmitter
 - Backscatter device continues to be offset by Δf

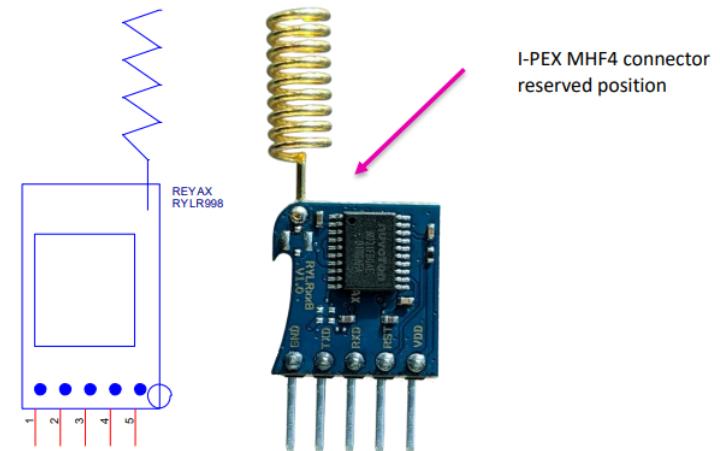
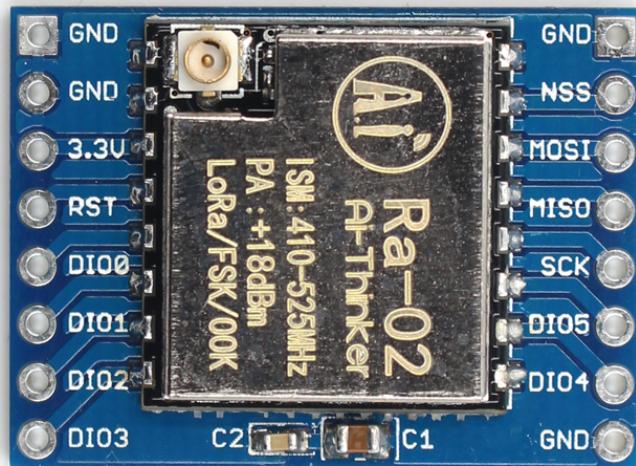
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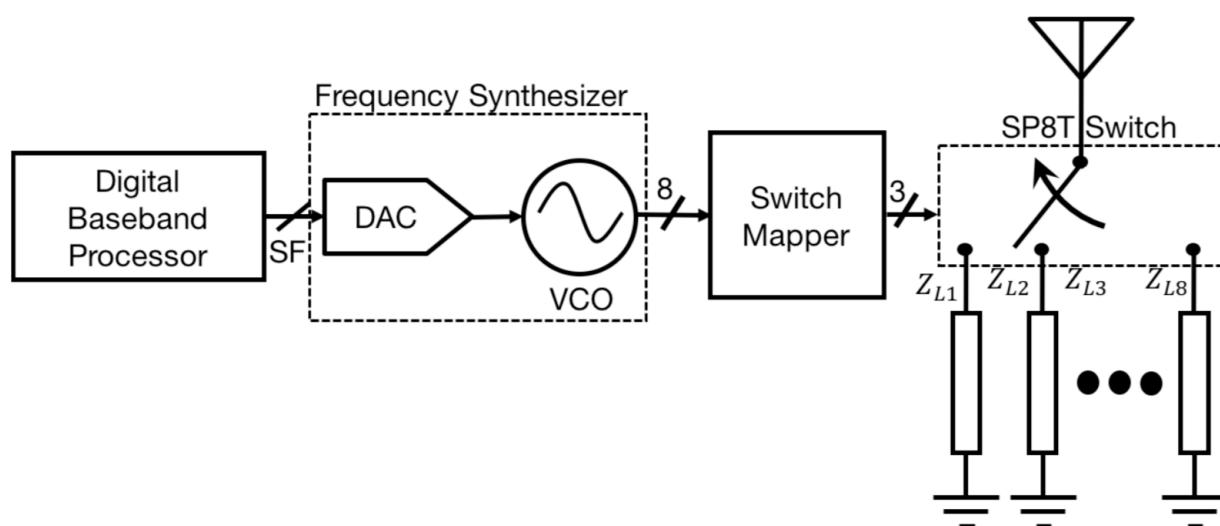
Hardware Implementation



Pin	Name	I/O	Condition
1	VDD	I	Power Supply
2	NRST	I	RESET(Active Low) 100KΩ Internal pull up, Pull down at least 100ms
3	RXD	I	UART Data Input
4	TXD	O	UART Data Output
5	GND	-	Ground

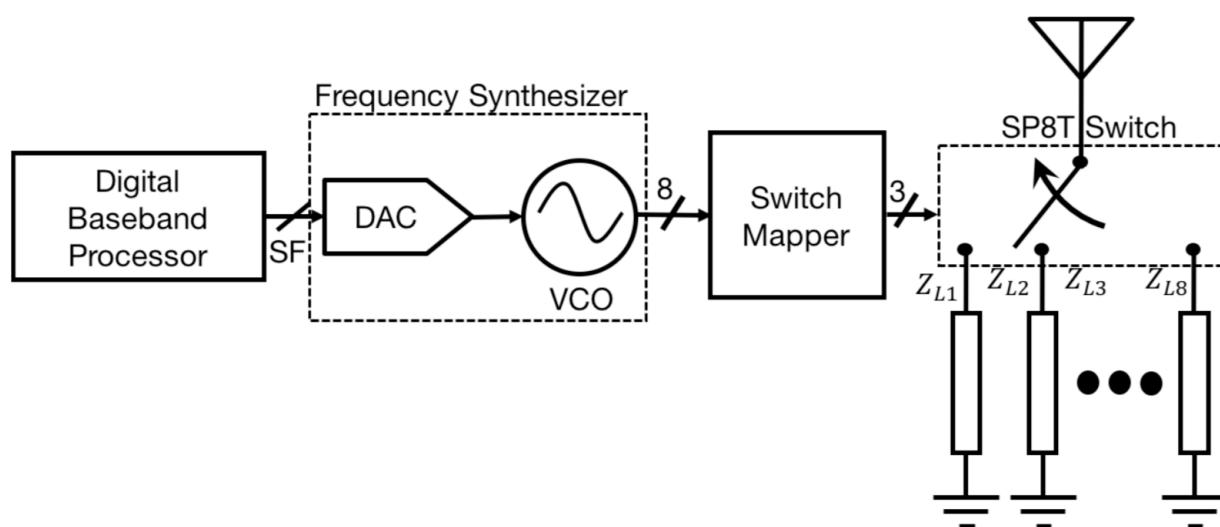
Hardware Implementation

- **Digital Baseband Processor** sends the spreading factor (SF) to the **DAC** to be converted to an analog voltage
- The **DAC**'s output controls the oscillation speed of the **VCO**
- **VCO**'s output is mapped to used to select appropriate impedance



Hardware Implementation

- VCO can only output positive frequencies, while negative frequencies are needed as well
- This can be achieved by selecting impedances to produce complex values to match the exponential signal output



Hardware Implementation

- Designed custom IC to minimize costs
- Consists of three main components
- Baseband Processor
 - Creates LoRa packet using SF, BW, and code rate
 - Sends packet data to Frequency Synthesizer to create the CSS signal
 - Uses $1.25\mu\text{W}$ to make packet with SF=12, BW=3.25kHz, and an (8, 4) Hamming code

Hardware Implementation

- Uses an **extremely** small amount of power
 - Other systems use complex analog components
 - Backscatter systems use switches to modulate reflections
- Costs **extremely** cheap
 - IC costs proportional to size of chip
 - Active radio devices like for Wi-Fi, LoRa, BLE have about 10mm^2 die area used for RF components
 - Backscatter systems like RFID use about 0.15mm^2 of die area
 - This LoRa backscatter system uses $<0.01\text{mm}^2$ of die area
 - Switches use space efficient resistors and capacitors
 - Metal in metal capacitors made on metal layers on top of MOS structures

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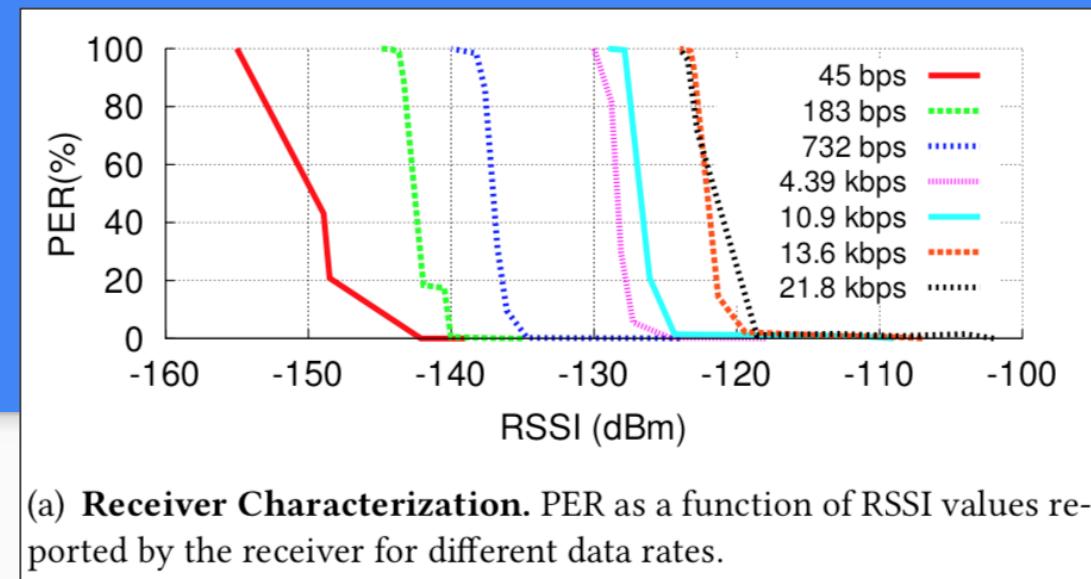
Results

Results Overview

- Receiver Characterization
- Operational Range
- Wide-Area Applications
 - Whole-Home and Office Sensing
- RF-Challenged Applications
 - Smart Contact Lens
 - Flexible Epidermal Patch Sensor

Receiver Characterization

- Wired setup (avoid multipath complications)
- Semtech SX1276 chipsets are both CSS transmitter and receiver
- **Conclusion: sensitivity is inversely proportional to the data rate of the packet**
 - Below -142 dBm, receiver cannot correctly decode packets
 - RSSI values reported by chipset do not correspond to actual power level of received packet, but proportional

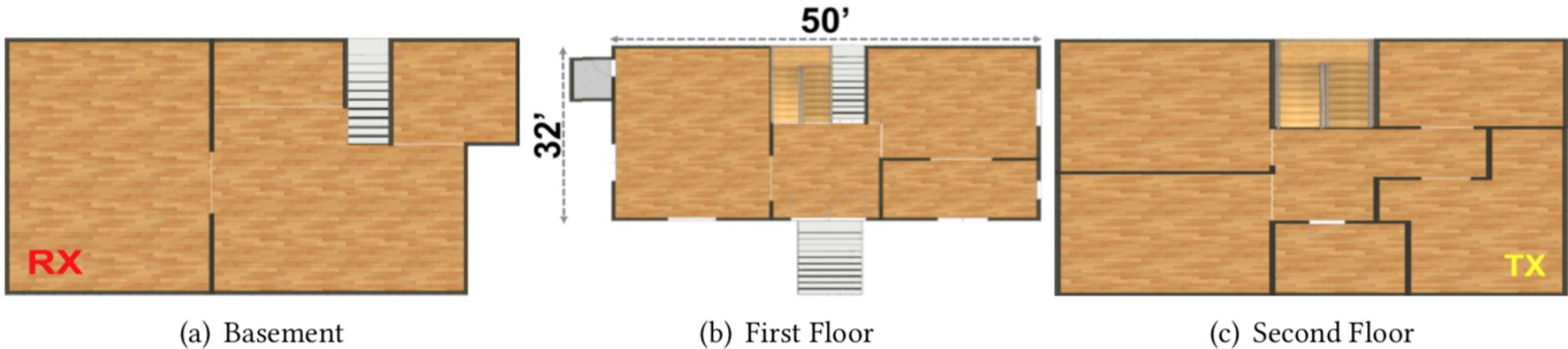
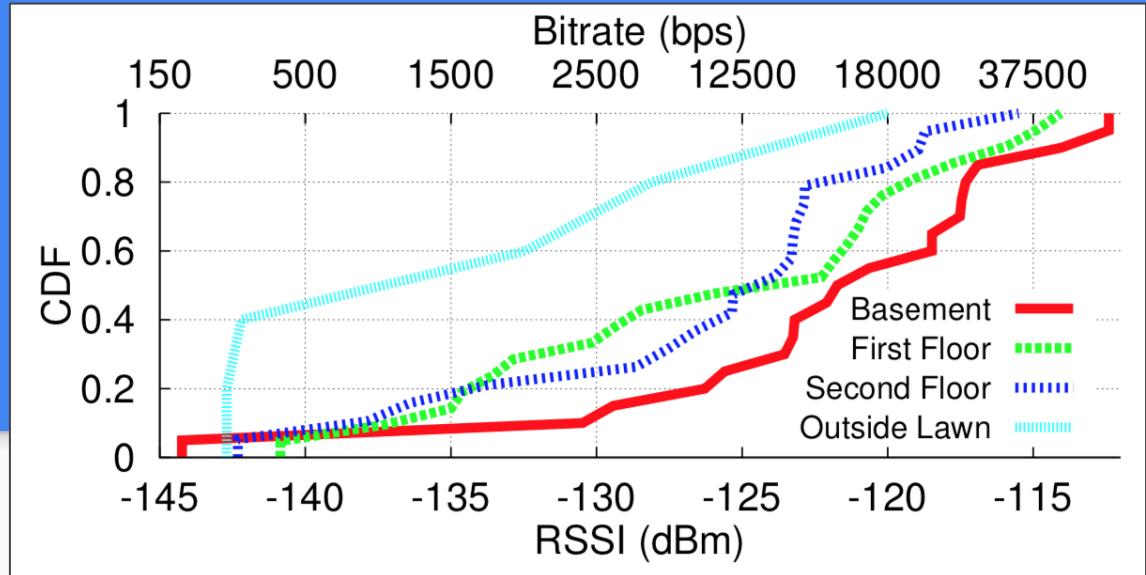


Operational Range

- Setup
 - SX1276 LoRa development kit with power amplifier as RF source
 - Transmitting 30 dBm signals in 6 dBi patch antenna at 915 MHz
 - Backscatter device to transmit LoRa packets at offset 3 MHz, SF=12, BW=31.25 kHz, (8,4) hamming code (3-byte payload, 2-byte CRC)
- Two deployment scenarios

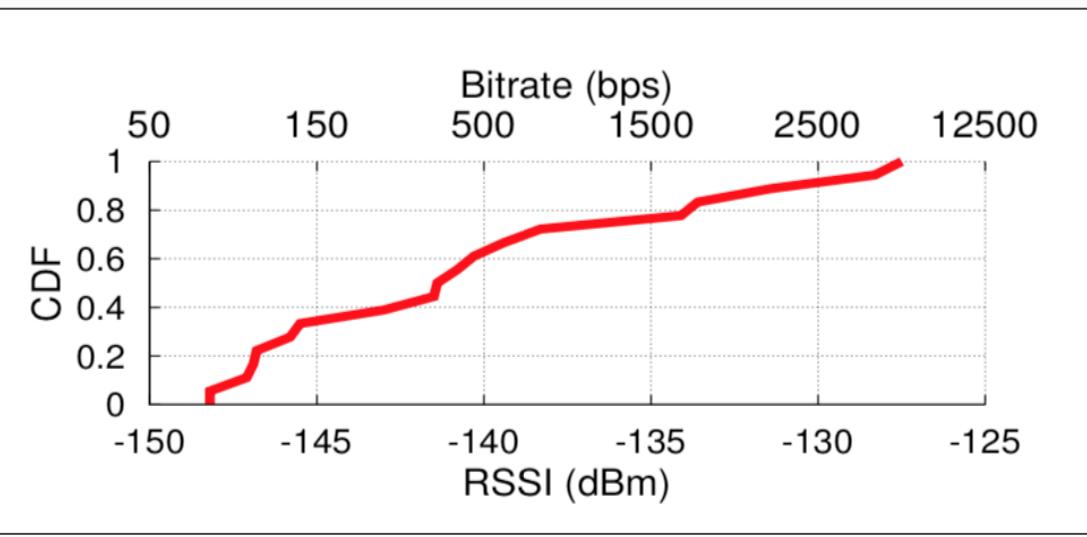
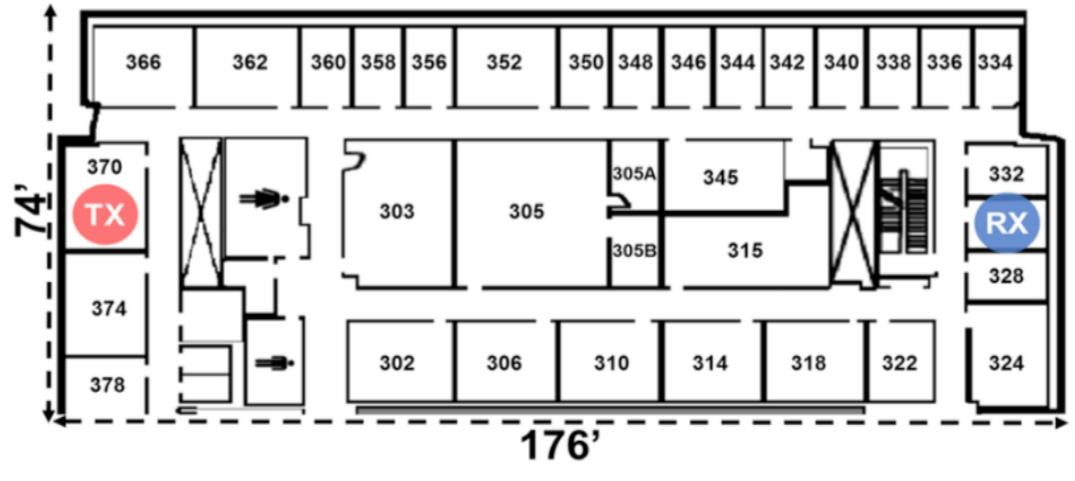
Applications: Whole-Home Sensing

- Previously: limited range and coverage preclude whole-home sensing
- LoRa backscattering deployment: 4,800 ft² three-story house ($\Delta f = 1$ MHz)
- Backscattering device moved through house in 6x6-ft. grid
- Conclusion: coverage is equivalent to typical wireless coverage; sufficient for smarthome IoT devices

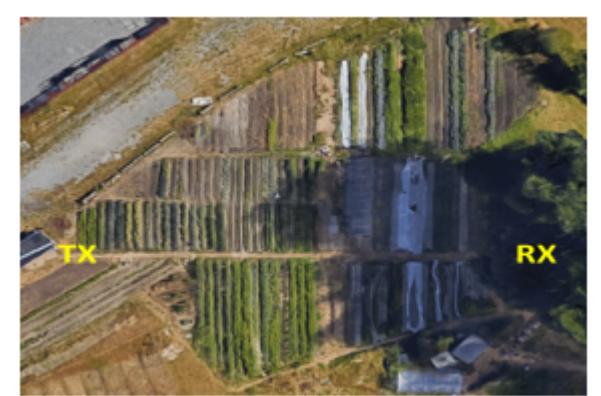


Applications: Office Sensing

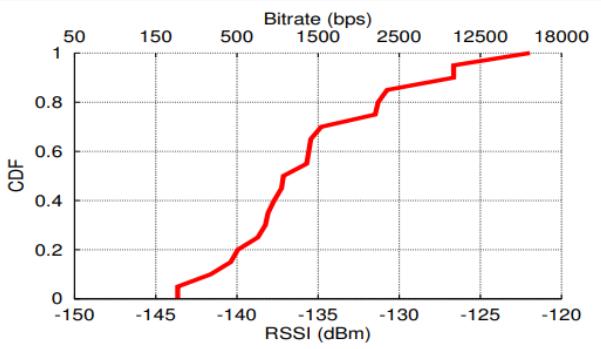
- LoRa backscattering deployment: 13,024 ft² office with 41 rooms ($\Delta f = 3$ MHz)
- Backscattering device moved through office in 26x26-ft. grid; source and receiver have sheet-rock, metal, insulation, and offices between them
- Conclusion: able to achieve wide-area backscatter coverage in significant multi-path environments



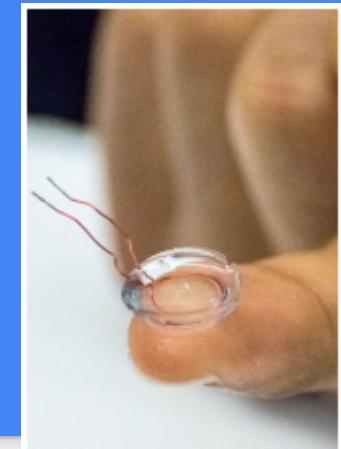
Applications: Precision Agriculture



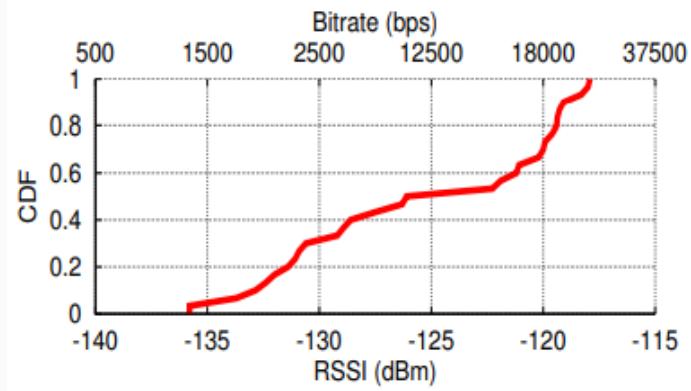
- Deployed on one-acre ($\sim 43560 \text{ ft}^2$) farm
- RF source and receiver on opposite sides
- Farm divided into 45ft x 45ft grids
- Backscatter device w/ 1MHz offset placed at ground level, between plants and bushes
- RSSI measured across 20 locations at center of the grids
- Median RSSI = -137 dBm, minimum RSSI = -143 dBm
- Conclusion: reliable backscatter communication across a one-acre farm with only one transmitter and receiver



Applications: Smart Contact Lens

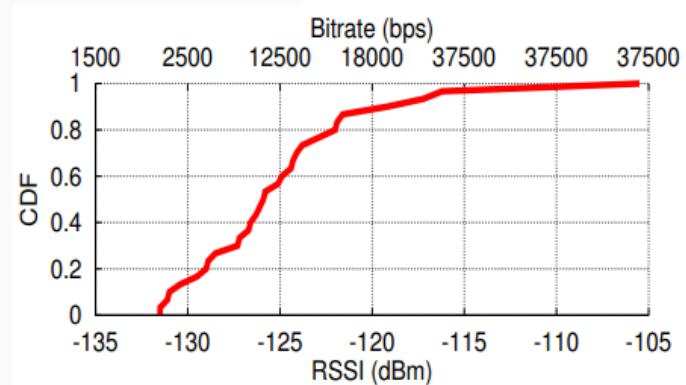


- Can measure various health indicators (glucose, sodium, cholesterol) in tears
- IC not currently possible to place in lens
- 1 cm diameter loop of 30 AWG wire between two contact lenses
- Deployed in 104ft x 32ft atrium with RF source and receiver at opposite ends of the room
- Driven by FPGA PoC and sends LoRa packets at 1MHz offset
- RSSI measured at center of 12ft x 10ft grids in the room
- Conclusion: smart contact lens **can** communicate via CSS backscatter at farther distances than prior approaches



Applications: Epidermal Patch Sensor

- Measure temperature, sweat, ECG, and other vitals in real time
- Sticker RFID antenna (Alien's Squiggle inlay) connected to FPGA PoC driver
- Utilize cheap RFID tags with LoRa backscatter system to create cheap patch sensors
- RF transmitter and receiver at opposite ends of 3,328 ft² atrium
- Measuring RSSI of 1MHz offset backscatter signals just as the lens
- Conclusion: patch sensor provides reliable connectivity with RSSI greater than -132 dBm



Conclusion

- LoRa backscatter is the first wireless system that operates at km distances while consuming less than $10 \mu\text{W}$
- Inexpensive, flexible form factor connectivity solutions which can be integrated into everyday objects
- Feasible for wide-area deployment: whole-home coverage, precision agriculture, long-range medical implants, and more

Future Work

- Achieving higher data rates
 - Currently limited by LoRa
 - Use multiple frequency bands or multiple antenna designs?
- LoRa-independent design
 - Reliance on CSS modulation suggests key innovation is independent of LoRa
- Networking high volumes of devices
 - Currently limited by TDMA's upper bound on throughput
- Other power sources
 - RF power harvesting?

Questions?

