FracBots: The Next Real Reservoir IoT

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October 22, 2020

A Short Resume

- Abdallah Alshehri is a petroleum scientist at Saudi Aramco Advanced Research Center (EXPEC ARC) participating in industry-leading research on reservoir monitoring & surveillance. He received the Ph.D. degree from Georgia Institute of Technology, USA in 2018.

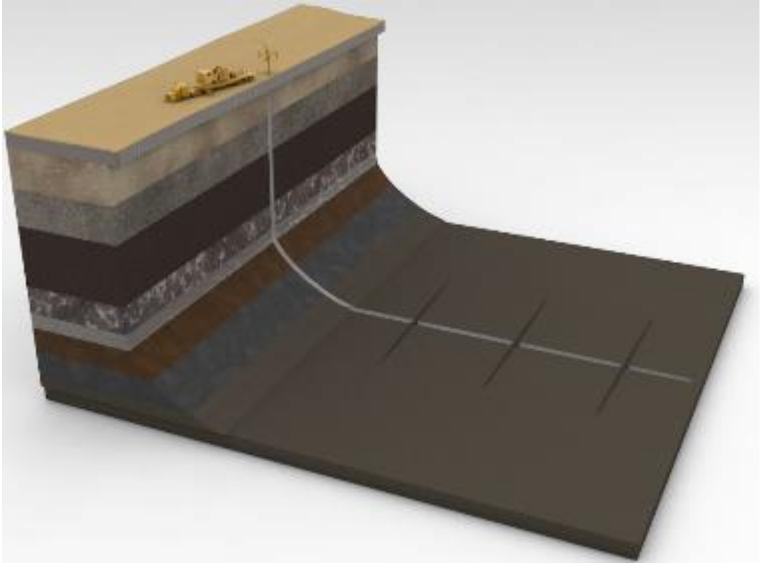
- He published more than twenty fiv papers, have been granted nine patents. He received many awards including the Outstanding Employee Award from IT/Saudi Aramco in 2009, the best Master Thesis Award from Concordia University in 2008, received the Best-in-Class Young Researcher award from EXPEC ARC/Saudi Aramco in 2017, the best paper award at the IEEE UEMCON 2017, Saudi Aramco/EXPEC ARC Annual Award on Creative project in 2019, the 2019 World Oil New Horizons Idea Award on the FracBots Technology and Saudi Aramco/EXPEC ARC Annual Award on citizenship class in 2020.

- His research interests include wireless underground sensor networks, in-suite sensing methodologies and applications for monitoring oil and gas reservoir.

Hydraulic Fractures

- Hydraulic Fractures are formed by pumping a fluid into the wellbore at a rate sufficient to increase the pressure downhole in order to crack the formation.

- Access unconventional oil and gas reservoirs
- Access tight conventional gas reservoirs
- Improve reservoir contact and production rates



Field Challenges

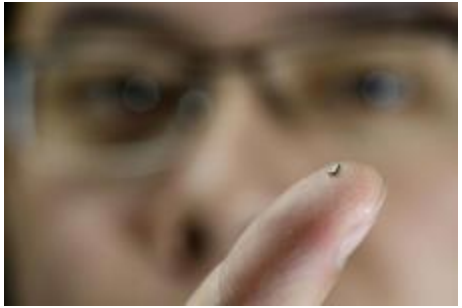
- Uncertainty in fracture mapping
- Conceptual fracture models
- Lack of dynamic stress data

Business Impact

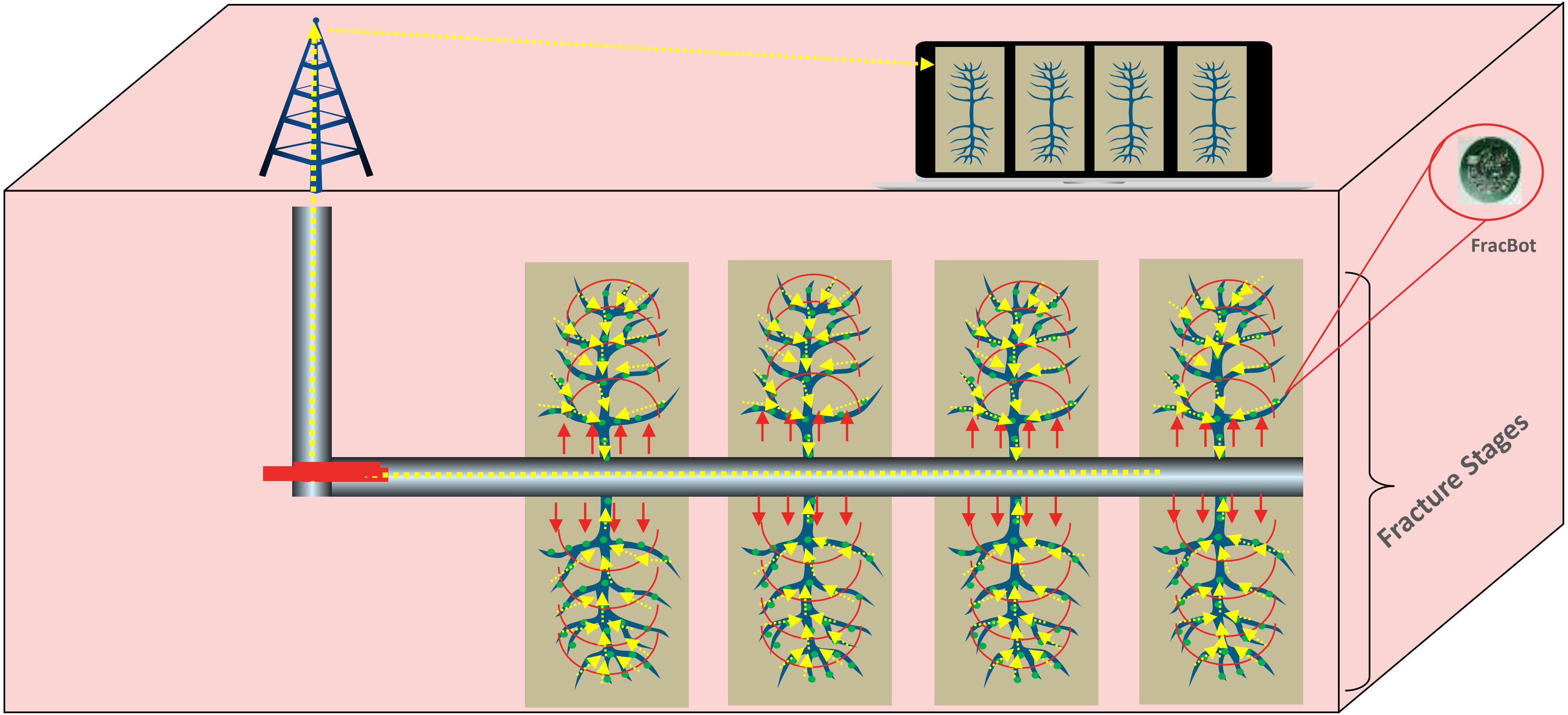
- Optimize fracturing jobs
- Maximize well productivity
- Maximize hydrocarbon recovery

What Are FracBots?

- Tiny devices with wireless communication, and sensing capabilities
- Real-time mapping of fracture networks
- Real-time reservoir information



How FracBots Technology Works



FracBots Components

Software Development

- Cross-layer Communication
- Localization Algorithms
- Energy Management

FracBot

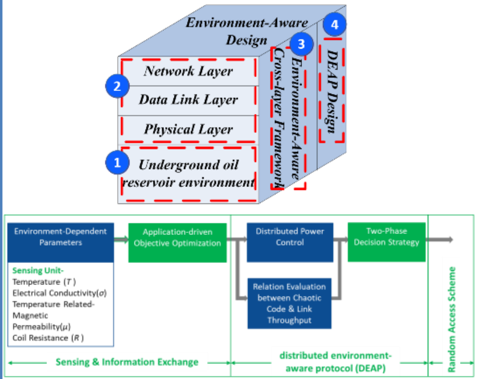
Hardware Design

- Magnetic Antenna
- Microprocessor
- Energy Harvesting Unit

Gen I R&D Milestones

FracBots Design for Hydraulic Fractures

1. Cross-layer Communication



Algorithm 1 Distributed Cross-layer Link Optimization

Input: $i, j, r_{ij}, \theta_{ij}$

$EaT_{min} = \infty$ % Initialization

for $mod = 1 : |M|$ **do** % Modulation cycle

  for $fec = 1 : |C|$ **do** % FEC cycle

    Calculate r^j_{min} via tolerable end-to-end PER Φ^{e2e}_T

    $(EaT_{ij}, P, Q, l) \leftarrow$ **Algorithm** 2$(r^j_{min}, NI_j, r_{ij}, \theta_{ij}, m_{ij}(mod), c_{ij}(fec))$

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Patented in US office

2. FractBots Localization

- RMFS measurements
- Localization Framework
- Fast initial positioning
- Fine-grained positioning

3. Optimal Energy Planning

- Power constraints
- Energy Model framework
- FracBot transmission rates
- FracBot network topology

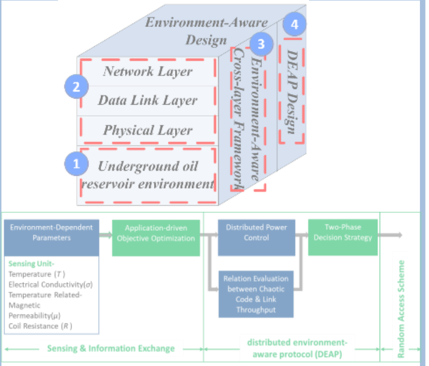
4. FracBots Design & Testbed

- MI-based FracBot node design
- MI-based FracBot network
- Experimental MI-based testbed

Gen I R&D Milestones

FracBots Design for Hydraulic Fractures

1. Cross-layer Communication



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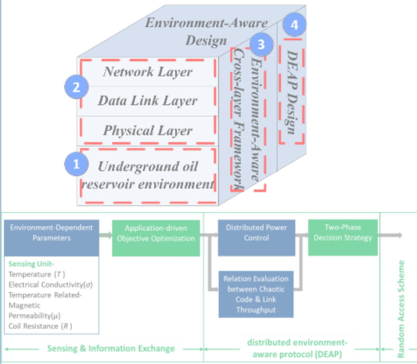

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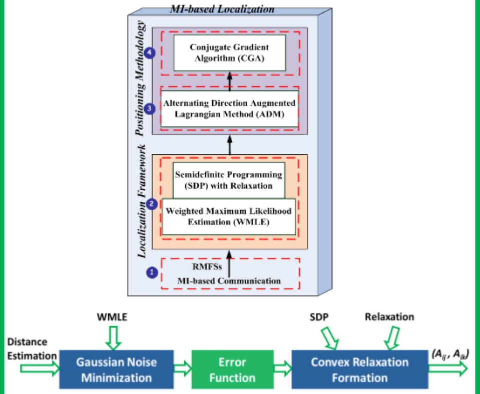

Algorithm 2 CGA (Fine-Grained Positioning)

Input: $f(\cdot)$, $X^{(0)} := [x_1^T, \ldots, x_N^T]^T$ from **Algorithm** 1
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  Compute β_m
  Compute $d^{(m+1)}$
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  end whileSet $X^* = X^{(m)}$

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3. Optimal Energy Planning

- Power constraints
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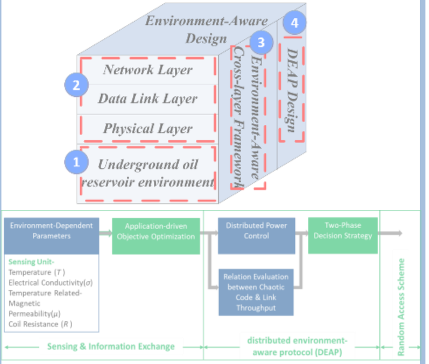

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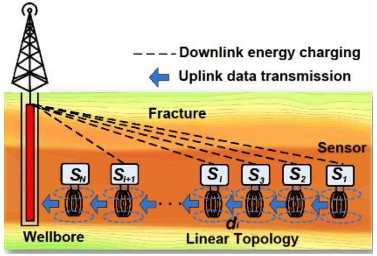

Algorithm 1 Fast Optimal Energy Planning.

set $N = 1$
repeat
calculate
$\lambda^N = \min_{i \le N} E_i^h / [iR^C(E_b^{MI}(d) + 2E_b^{elec})]$
set $N := N + 1$
until $N > \log_{(1-\Phi(d))}(1 - \Phi_T^{e2e})$
$N^* = \arg\max_i i\lambda^i$ and $\lambda^* = \lambda^{N^*}$

Published in IEEE ICC Conference

4. FracBots Design & Testbed

- MI-based FracBot node design
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FracBots Design for Hydraulic Fractures

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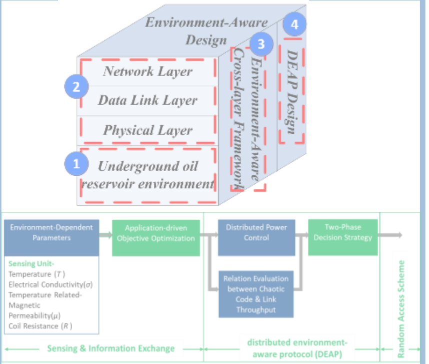

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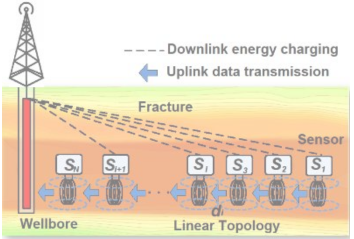

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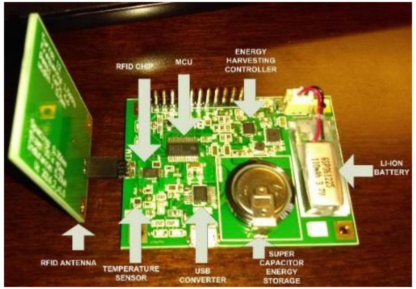

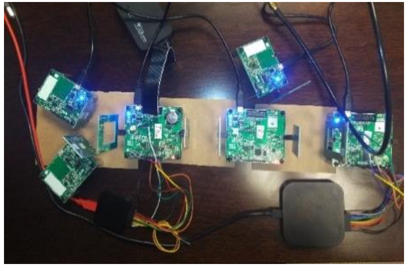

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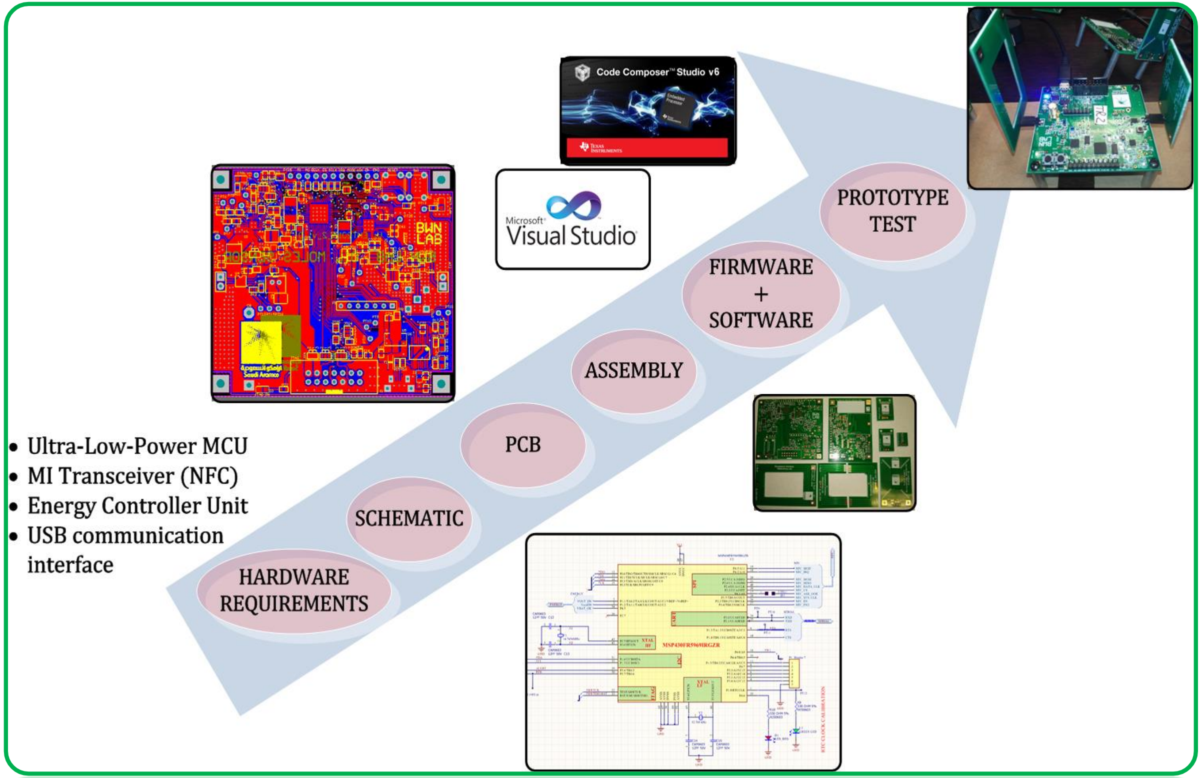
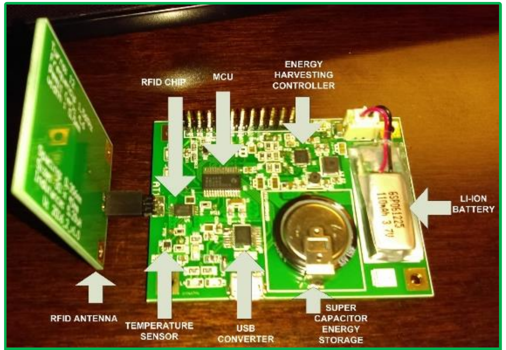
FracBot Node Design Roadmap



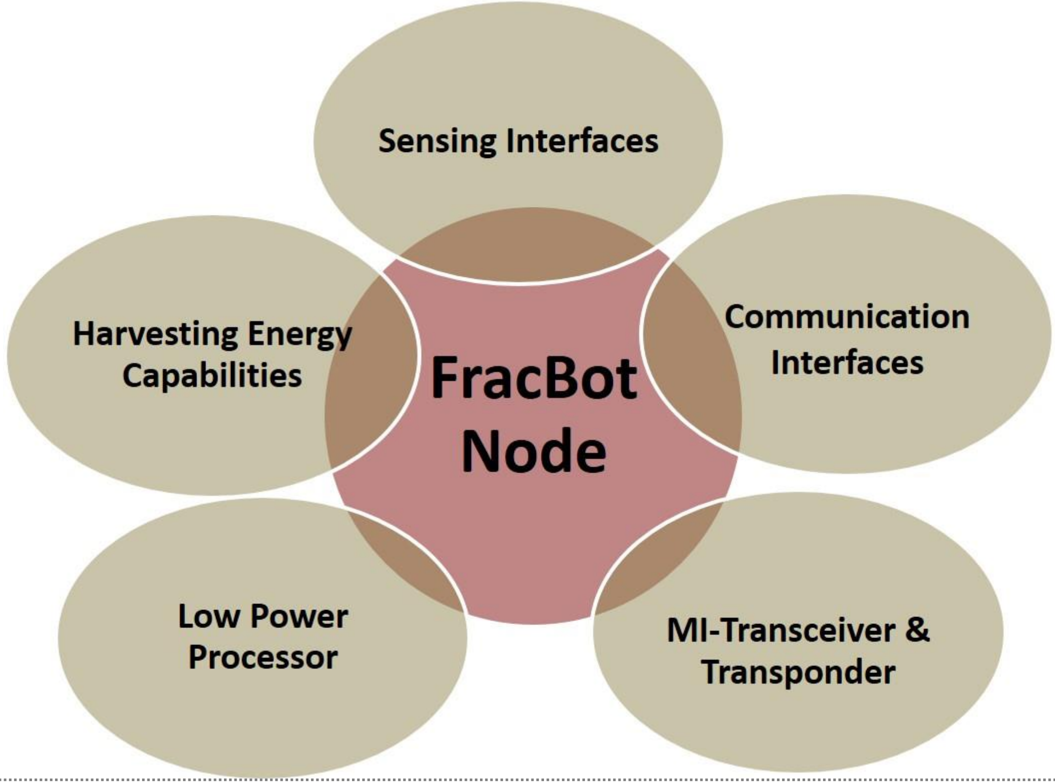
- Ultra-Low-Power MCU
- MI Transceiver (NFC)
- Energy Controller Unit
- USB communication interface



- Prototype of FracBot

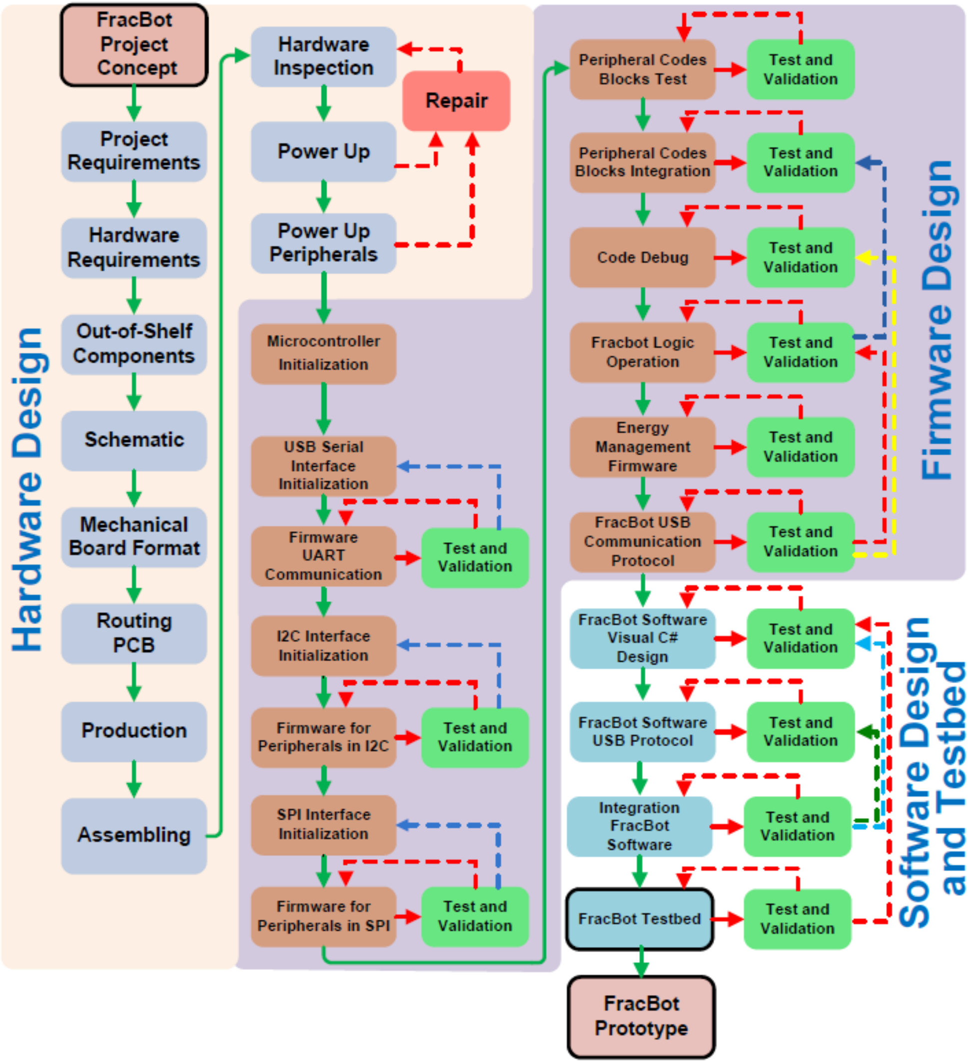
FracBot Design Requirements

- Long operation time through ultra-low-power electronics
- Advanced low-power microcontroller
- Efficient underground communication layer
- Energy-harvesting capability
- Sensing capability



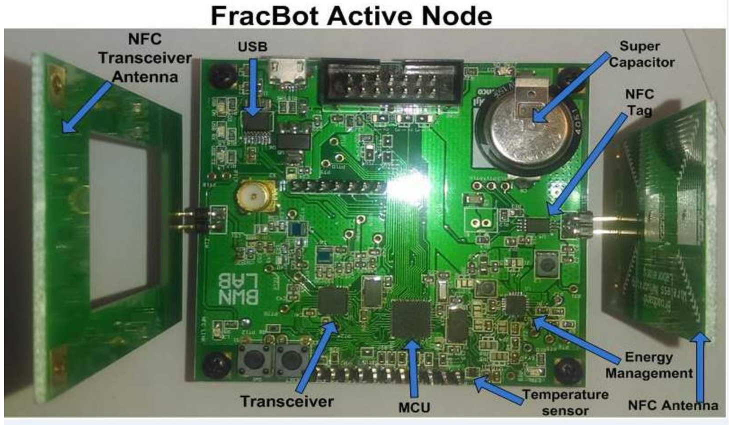
Implementation Process

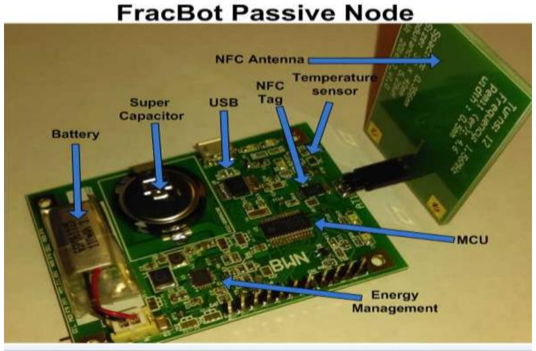
- **Components selection**
- Applications compatibility
  - Out-of-shelf components
- **Schematic drawing**
  - Shows components and the interconnections.
- **PCB design**
  - create the physical interconnections (routes) to start the board production
- **Components assembly**
  - components are soldered to the PCB in their positions.
- **Firmware and software coding**
  - A code operates the FracBots & software to manages the system.
- **Testing and verification**



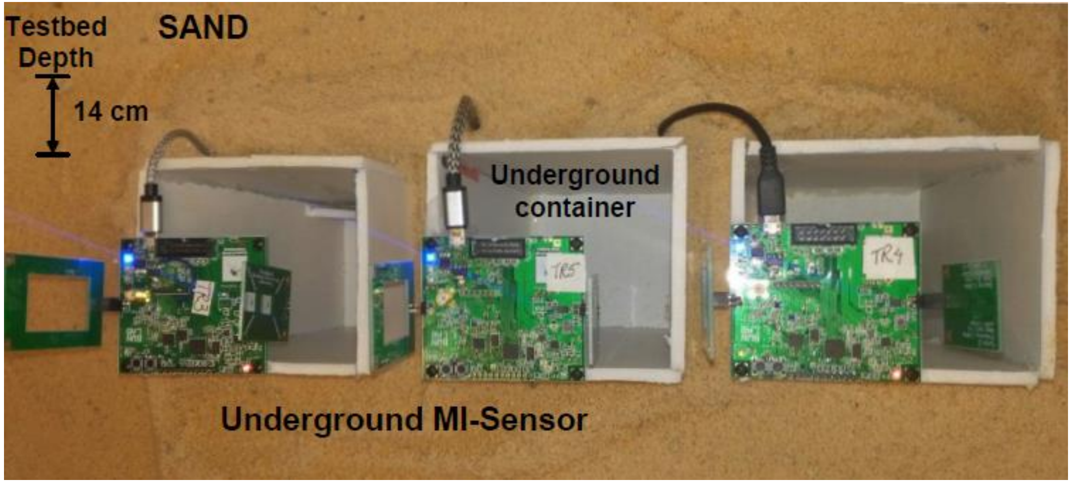
FracBot Gen I Prototype

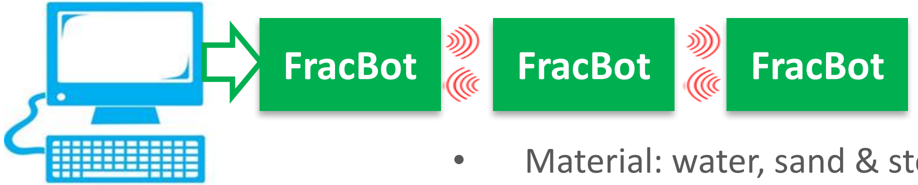
- FracBot: a proof of concept
- Characteristics
  - PCB planar coil (two layers)
  - NFC tag with EEPROM Memory and energy harvesting
  - Receiver antenna
  - Energy management unit (EMU)
  - Ultra-low power microcontroller
  - Ultra-low power temperature sensor
  - Supercapacitor or Rechargeable battery
  - USB interface (debug and Laboratorial test)
  - NFC transceiver chip
  - NFC transceiver antenna





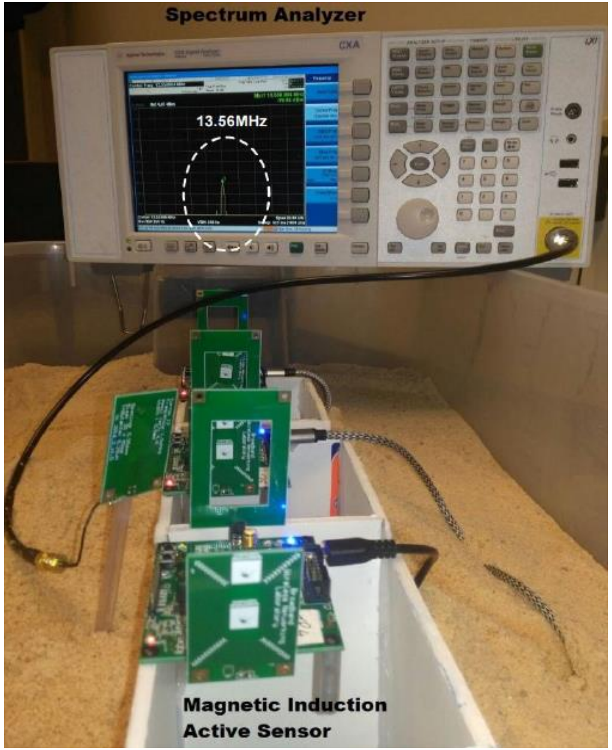
The FracBot Testbed





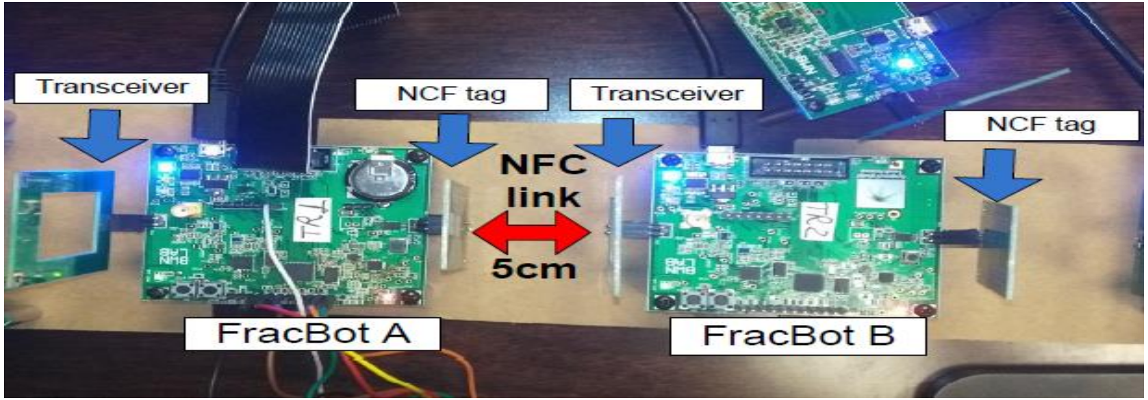
Testbed characteristics:

- Material: water, sand & stone.
- Depth: 14 cm
- Operational distance: 5 cm



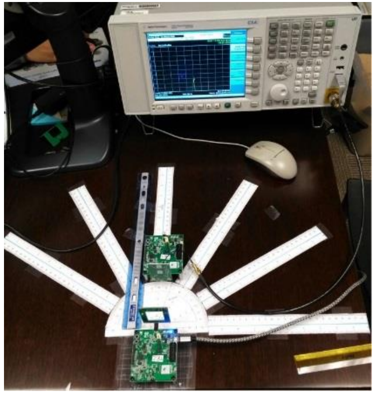
Experimental Performance of Communication Link

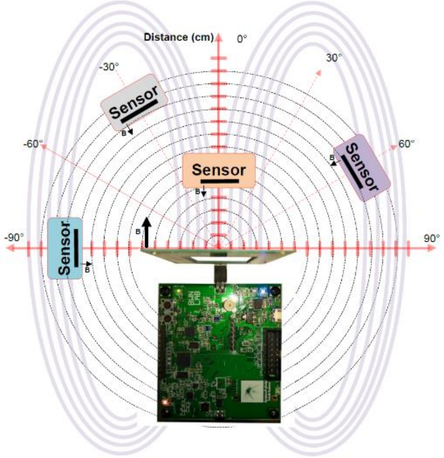
- Comparative results based on standard communication data rate provided by the NFC chips
- Environment: air, sand & stone (underground testbed)
- The low data rate is consequence of the high path loss posed by underground environment



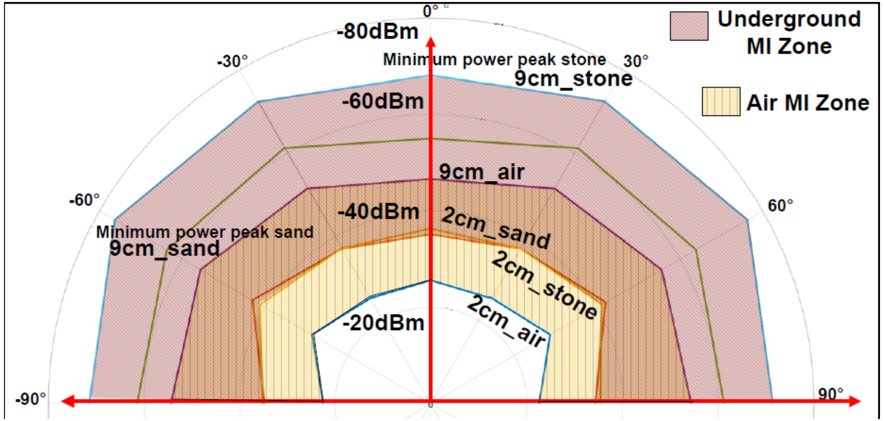
Environment	Modulation	Data rate (kbit/s)	Error (%)
Air	ASK	26	2
Air	OOK	26	1

FracBot Angular Setup & Analysis





- MCU requires **0.5s** to execute all reading tasks and transmission.
- The received power in the region of **6-25 cm** is around -50 dBm.



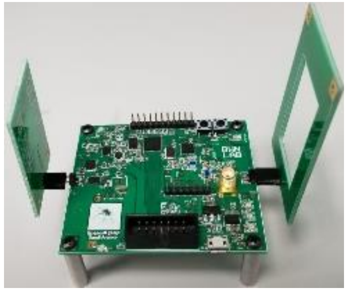
- FracBot Ulta low sensitive receiver can receive signal strength of -**70 dBm.**
- The harvesting energy unit can not harvest and store energy for MI signal strength lower than **-30 dBm (1µW).**

Key Challenges Ahead

- A Structural dimension of the fracture, the structural constrain demands ultra-scaled standalone system development.
- The harsh environment consisting of crude oil, gas, soil and rocks and other injection fluids, causes high path loss for effective communication.
- Limited power supply in the harsh environment
- Scale down the node to smaller size.
- Unavailable of electronic components that can serve the size reduction.
- Unavailable of electronic components that can sustain high temperature and pressure.

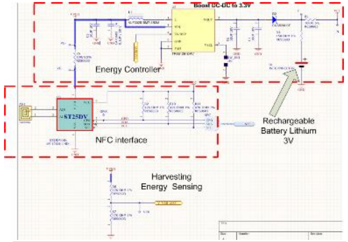
FracBot Gen II Development

FracBot Gen I → Design Optimization



- Ultra-low-power electronics
- Processing & microcontroller
- Efficient communication
- Energy-harvesting capability
- Advanced Antenna Design

Advanced Microcontroller

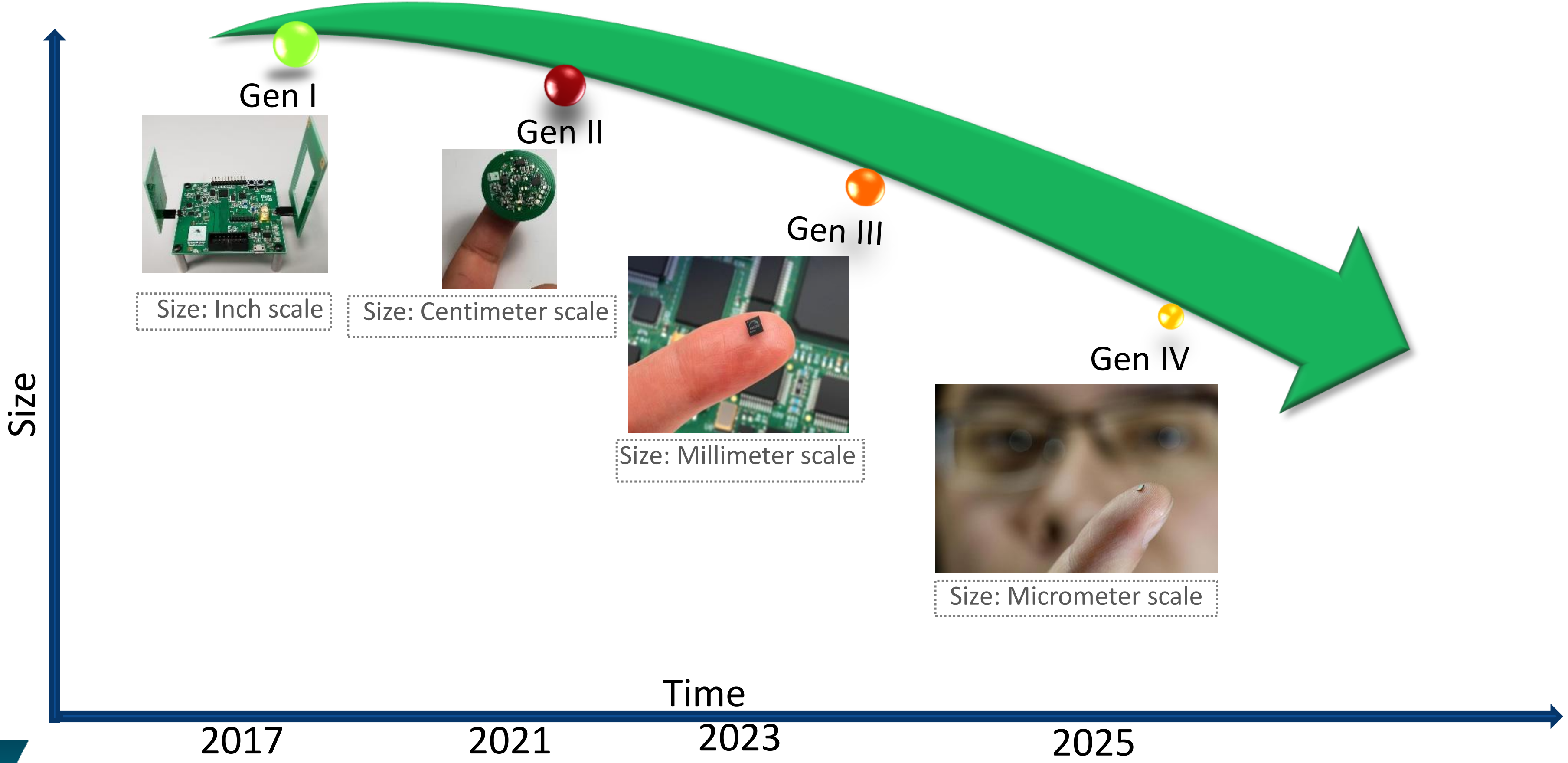


- Energy Unit Optimization
- Advanced NFC Transceiver

FracBot Gen II

Firmware Retransformation

FracBot Development



Conclusion

- Three key functions have been formulated and developed.
- A novel cross-layer communication framework for MI-based FracBot networks is developed to enable the communication in dynamically changing underground environments.
- A novel MI-based localization algorithms is developed to build up 3D constellation maps of hydraulic fracture.
- An energy model framework for a linear FracBot network topology is developed to estimates FracBot data transmission rates while respecting harvested energy constraints.
- A Novel prototypes of MI-based wireless FracBots are designed and developed.
- Designed for potential use as a platform for a new generation of WUSNs for monitoring hydraulic fractures and unconventional reservoirs, and measuring other wellbore parameters.
- Developed the hardware of the MI-based wireless FracBots for short-range communication using near-field communication (NFC) as a physical layer combined with an energy-harvesting capability and ultra-low power requirements.
- The hardware development and the testbed analyses allow us to better understand the environment challenges, improve the electronic sensitivity and optimize the minimum resources that are necessary to miniaturize the FracBot hardware.

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