IN-VIVO NETWORKING

TARA BOROUSHAKI
IVN is a multi-antenna technique to remotely power up millimeter-sized in-vivo sensors and communicate with them.
Motivation and Challenges
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Deep brain stimulation
- Parkinson's disease
- Epilepsy
- Severe depression
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Costs between $30K and $50K
10-year survival rate of 51%

Motivation and Challenges

Exponential attenuation in body

Small size of device, Small effective area for antenna

No channel feed back
Previous Works

Energy-harvesting bioelectronics:

Self-Powered

Wirelessly Powered
IVN

- Deeper in tissue (>10cm)
- Transmitter can be further from body (>1 m)
- Battery-Free
Beamforming Algorithms:

MIMO:

inverts the estimated channel
needs to power up the implant first

Antenna Arrays:

Not practical for multi layer tissue

MagMIMO:
IVN

- Works under blind channel condition
- No need for receiver cooperation
- Maximizes peak power across space
Previous Works

Backscatter Networking:

**HitchHike:**

Similar range to RFIDs

**LoRa:**

10 cm\(^2\) battery is needed

**Ambient backscatter:**

Not practical for in-door
Neither FCC compliant nor safe
IVN

- FCC compliant and safe for humans
- Battery-Free
- Works in deep tissue
IVN strategy

(a) Threshold impact at small distance in air
(b) Threshold impact at large distance in air
(c) Threshold impact in body

Power loss in tissue

Normalized Loss (dB)

Distance (m)
IVN strategy

(a) Traditional beamforming under unknown channel conditions.  

(b) IVN’s CIB technique under unknown channel conditions.
IVN strategy

Frequencies Selection?
Frequency Selection

• Solve an Optimization problem:

\[
\arg \max_{f_1, \ldots, f_N} \mathbb{E}_\beta \left[ \max_t \left| \sum_{i=1}^{N} e^{j(2\pi f_i t + \beta_i)} \right| \right]
\]

maximizes the expected peak power over all possible channel conditions

1. Ensure the sensor responses every T seconds.

2. Sensor tolerates only a small fluctuation in the amplitude of its received signal
Jamming-Free Communication

Backscatter modulation is frequency-agnostic.

The reader sense and decode the response at a different carrier frequency than powering frequency.

Reducing self-interference
Evaluation and Results

Gain Vs # Antennas:
Evaluation and Results

Gain Vs Distance, Orientation:

(a) Power Gain vs Depth.  
(b) Power Gain vs Orientation

The received power decreases with depth due to path loss.
**Gain Vs Different Media:**

80× peak power of single-antenna transmitter

independent of the medium of operation

10-antenna traditional transmitter achieves a median gain of 10× from increasing the transmitted power.
Gain Vs Traditional 10-antenna Transmitter:

the probability of the baseline having all its transmissions aligned at the receiver point is very low.

10-antenna transmitter may destructively interfere at various locations.

CIB achieves a median gain of $8 \times$ over the baseline.
FLAWS?

Is it really channel blind?

- Not successful in communicating with the standard tag in 50% of the cases in the gastric.
- failed in all the experiments with miniature tag in the pig stomach.

Orientation blind?
Possible Future works

- Addressing Security and Privacy Issues
- Accuracy of localizing RFIDs which are 30 meters away