Ultrasonically Rechargeable Platforms for Closed-Loop Distributed Sensing and Actuation in the Human Body

Raffaele Guida and Tommaso Melodia
Department of Electrical and Computer Engineering
Northeastern University, Boston, MA, USA
E-mail: {guidar, melodia}@ece.neu.edu

WiNES
Wireless Networks and Embedded Systems Lab

Background

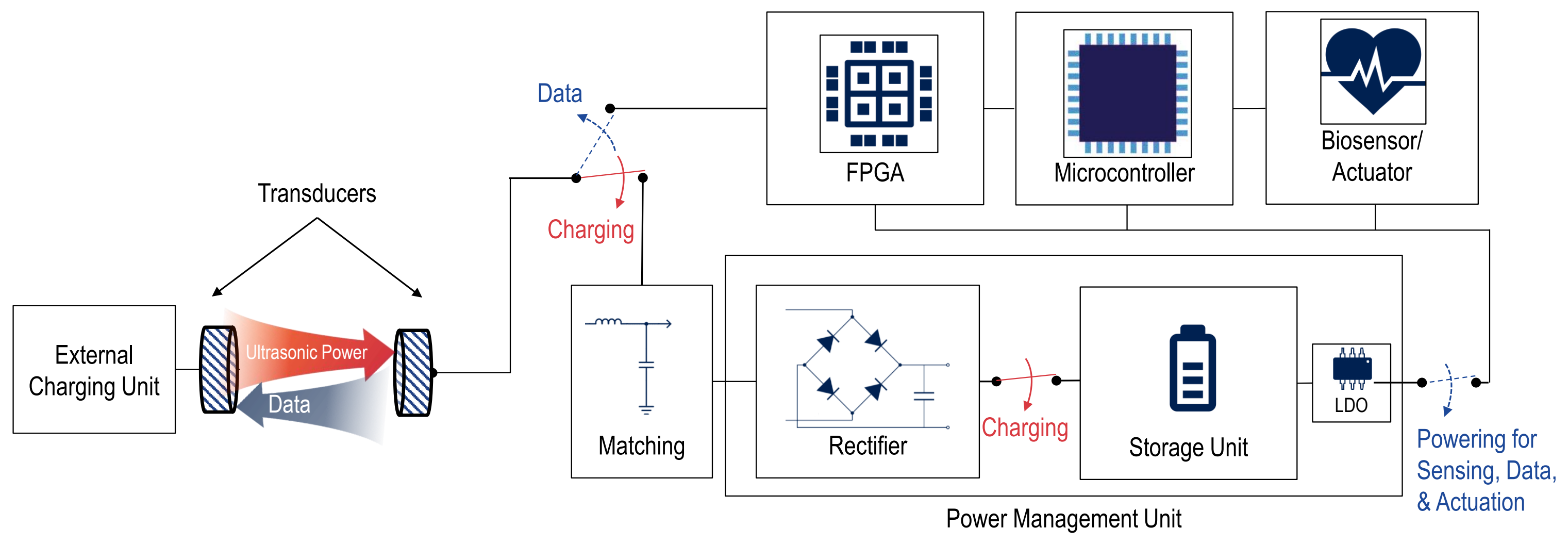
❑Traditional Implantable Medical Devices (IMDs):
- rely on wired connections that are invasive and prone to infections;
- are powered by batteries that occupy most of the device volume;
- in some cases use electromagnetic-based solutions that perform poorly in biological tissues.

A traditional pacemaker with two leads attached

❑Future IMDs will:
- implement new functionalities;
- require more energy (larger batteries).

❑Research objectives:
- leverage ultrasonic propagation to develop a batteryless and remotely rechargeable platform as a basis to build implantable devices equipped with wireless connectivity;
- implement a closed-loop distributed sensing and actuation system.

Nodes Architecture



❑ Building blocks for batteryless implantable bio-sensors and actuators that:
- can be recharged via ultrasonic transcutaneous energy transfer (UTET);
- include an ultrasonic communication system.

❑ integrates a *power unit* and an Internet of Medical Things (IoMT) mote [1].

Closed-Loop Sensing & Actuation System

❑ Phase 1

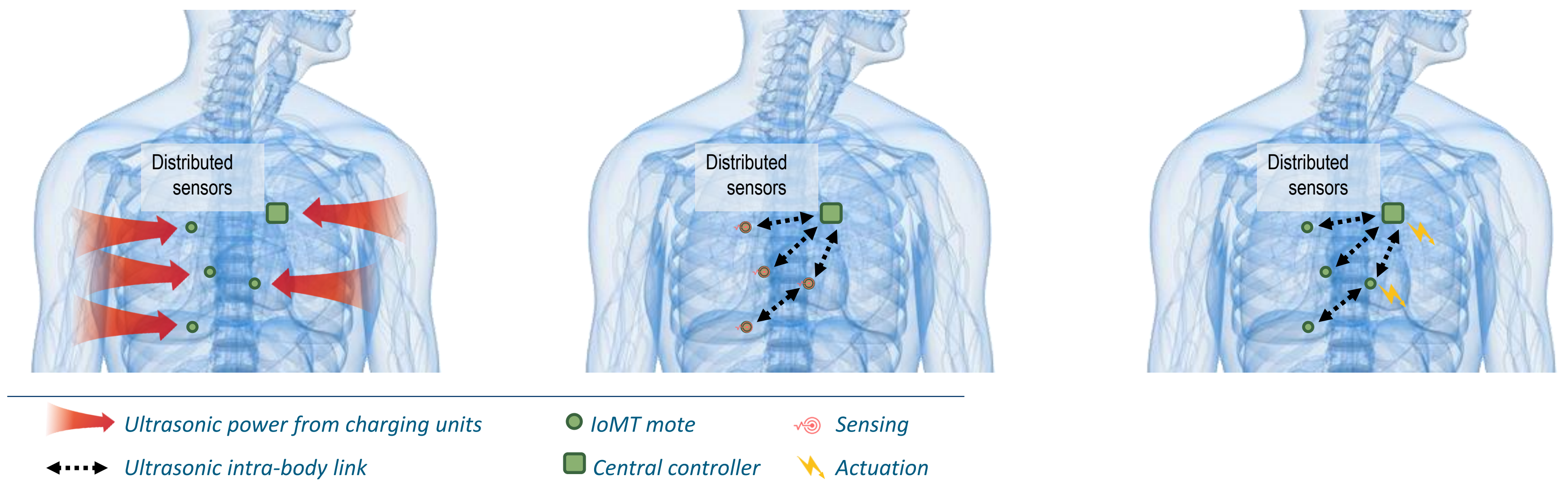
the nodes receive power from external charging units via UTET.

❑ Phase 2

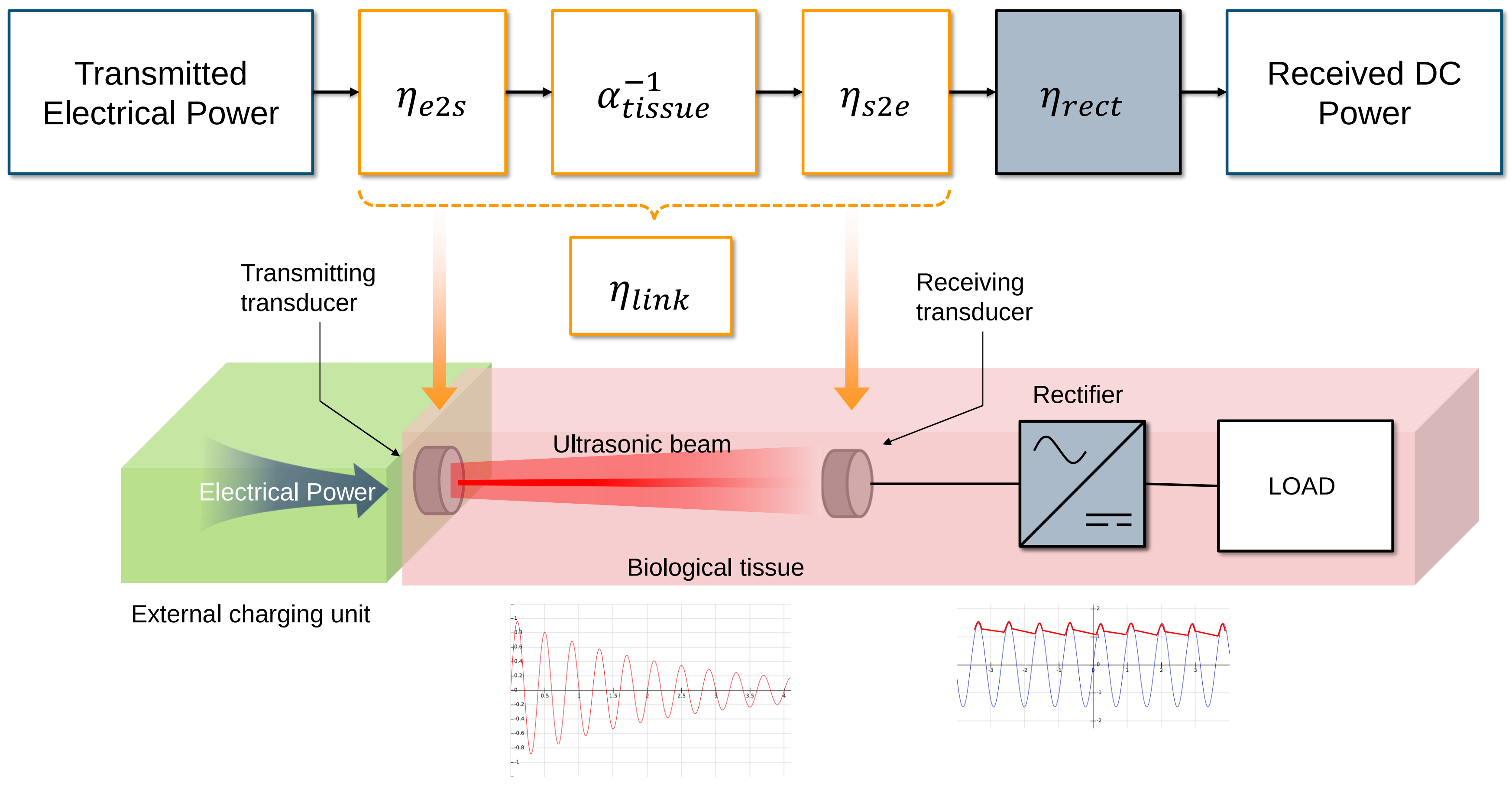
sensor nodes measure biomarkers and transmit the readings to a central node over ultrasonic links.

❑ Phase 3

central controller processes the measurements and performs an action, or demands it to an actuator.



Mathematical Model



- System efficiency $\eta_{sys} = \eta_{link} \times \eta_{rect}$
- Wireless link efficiency $\eta_{link} = \frac{\eta_{e2s} \times \eta_{s2e}}{\alpha_{tissue}}$
- Rectifier efficiency $\eta_{rect} = \frac{P_{DC}}{P_{AC}}$
- Tissue attenuation coefficient α_{tissue}
- Transduction efficiency:
  - electro-acoustic η_{e2s}
  - acoustic-electric η_{s2e}

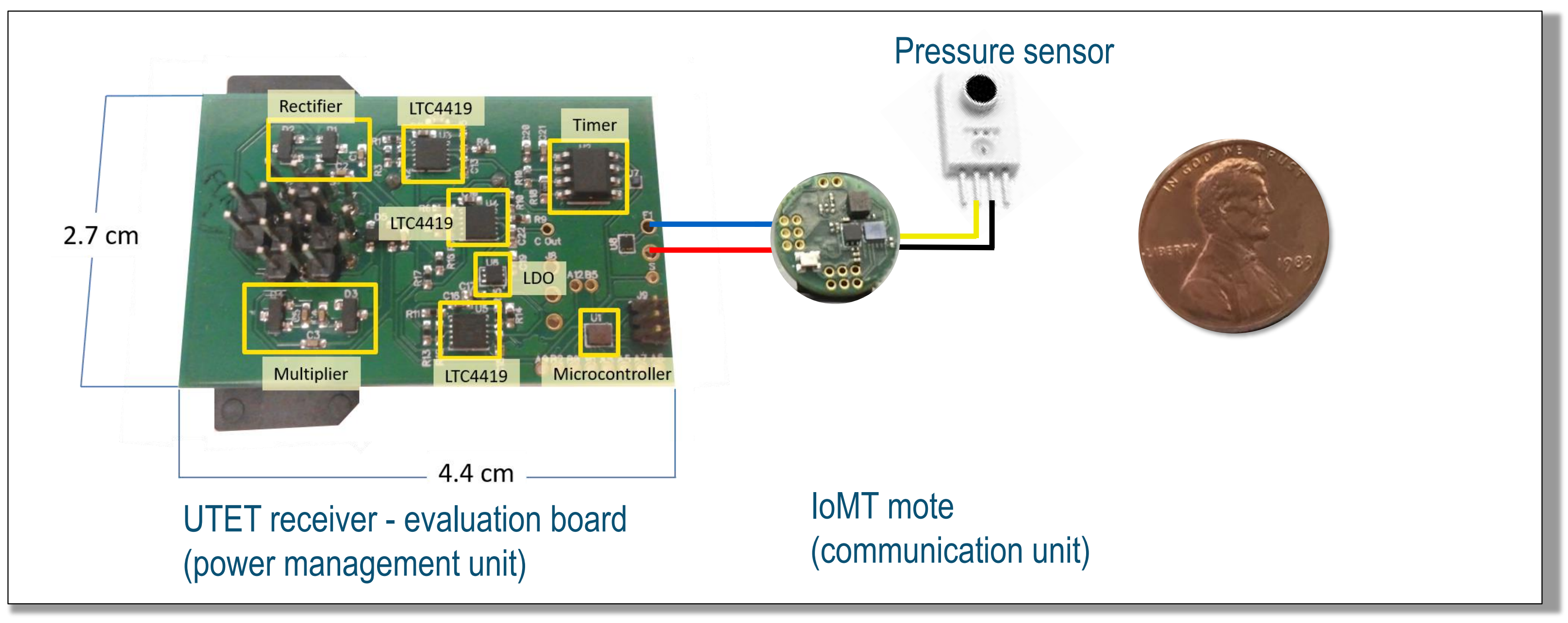
- Storage energy $E_{storage}$
- Transmitted energy for charging E_{Tx}
- Charging duration $t_{charging}$
- Node operation duration with $E_{storage}$

System efficiency performance parameters

Charging efficiency $\eta_{charging} = \frac{E_{storage}}{E_{Tx}}$

Operating efficiency $\eta_{operating} = \frac{t_{on}}{t_{charging}}$

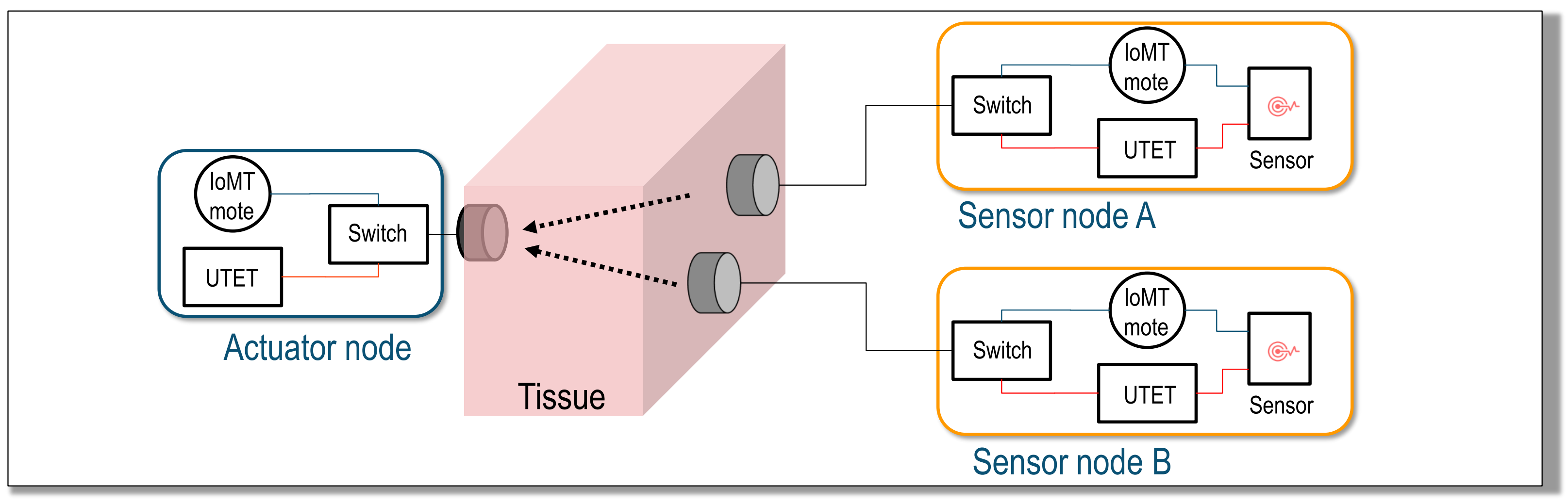
Prototype and Experimental Results



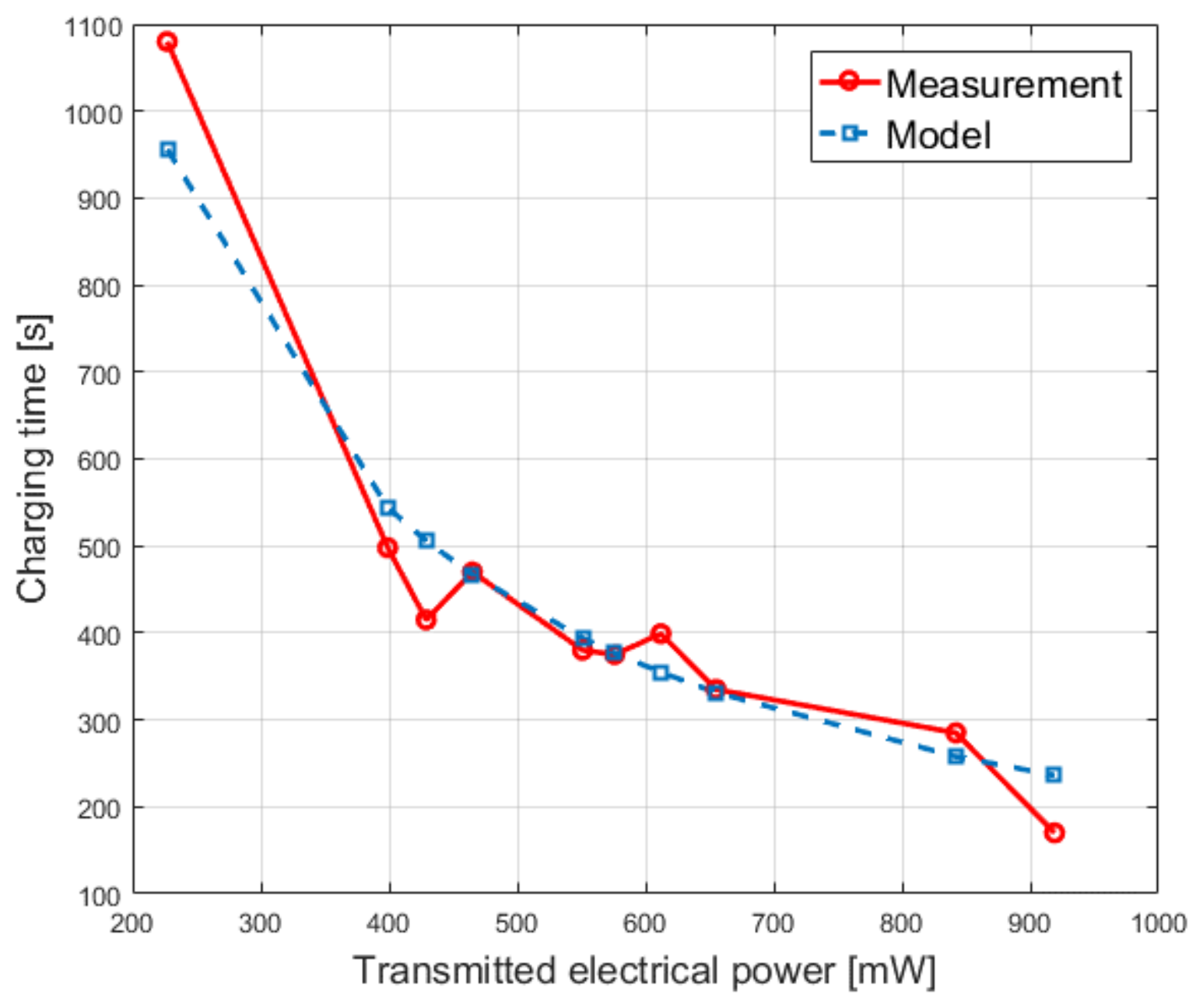
UTET receiver - evaluation board
(power management unit)

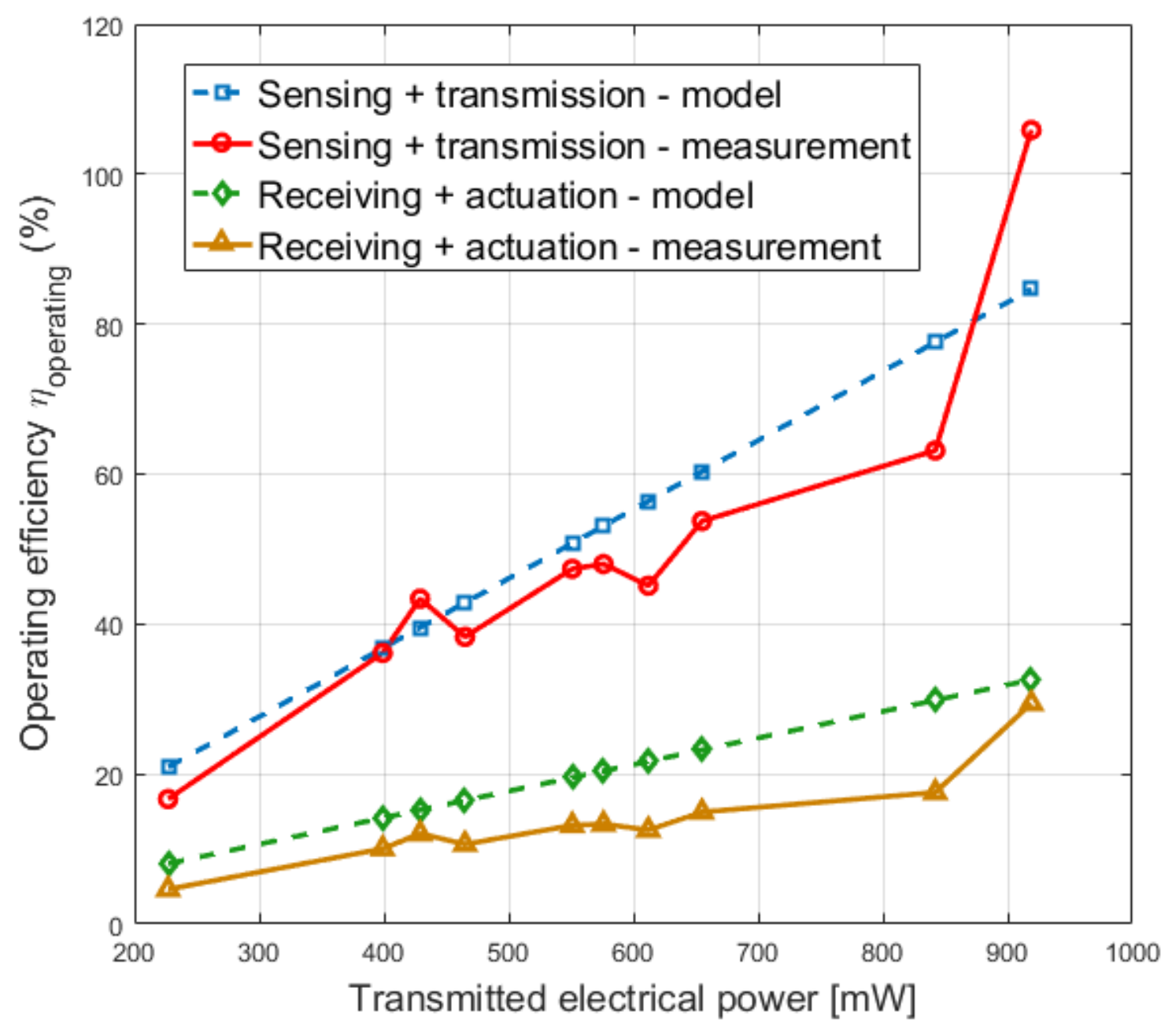
IoMT mote
(communication unit)

Closed-loop testbed diagram



System Performance





References

[1] G. E. Santagati and T. Melodia, "An Implantable Low-Power Ultrasonic Platform for the Internet of Medical Things," in *Proc. of IEEE Conference on Computer Communications (INFOCOM)*, (Atlanta, USA), May 2017.

Acknowledgement

This material is based upon work supported in part by the National Science Foundation under Grants CAREER CNS-253309 and CNS-1458019