Wireless *In Vivo* Communications and Networking

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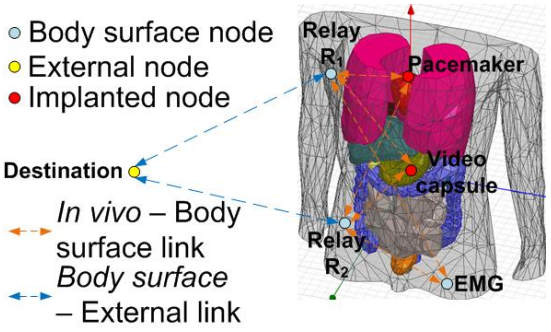
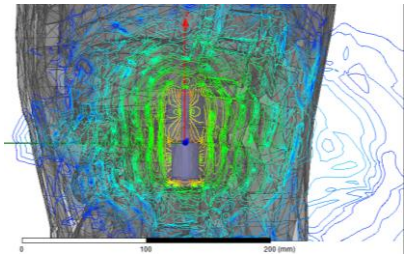
Minimally Invasive Surgery



Wirelessly networked devices



Modeling the *in vivo* communications channel

Motivation: Wireless *in vivo* communications and networking has the potential to significantly advance healthcare delivery solutions by creating wirelessly networked cyber-physical systems of embedded devices. These systems, generally referred to as Wireless Body Area Networks (WBANs) will use real-time data to enable rapid, correct, and cost-conscious responses in surgical, diagnostic, and emergency circumstances. Our initial research focus is on creating a new paradigm for Minimally Invasive Surgery (MIS).

Wireless *in vivo* communications and networking research challenges: The research opportunities and challenges are abundant and include: (1) modeling of the *in vivo* wireless channel, (2) inventing new communications and networking solutions for embedded devices of limited complexity and power, (3) meeting the high bit rate and low latency requirements of many surgical applications (e.g., HDTV), and (4) creating new approaches to privacy and security for devices of limited processing capabilities.

Research Objectives: To address the above challenges our initial focus is on (1) architecting and realizing a family of wirelessly controlled and communicating *in viv*o devices that will facilitate a new paradigm for Minimally Invasive Surgery (MIS) and (2) creating novel wireless *in vivo* communications and networking technologies to support these devices and advance the performance of wireless body area networks (WBANs) that will support MIS and other biomedical healthcare applications.

***Wireless in vivo communications* systems: invention, analysis, design, and implementation**

Wireless *In Vivo* Networked Devices

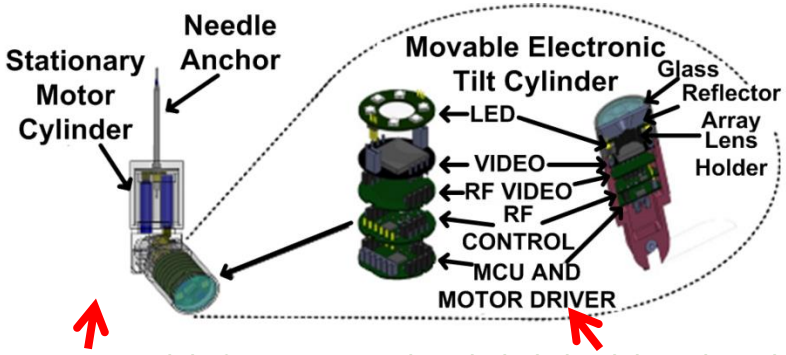
MARVEL: The first device that we have implemented is a Miniature Advanced Remote Videoscope for Expedited Laparoscopy (MARVEL), which is a wirelessly controlled and communicating high-definition video system that will provide the spatial and visual advantages of open-cavity surgeries for MIS.

Key Issue and Challenges: To provide highly reliable *in vivo* devices, there are several research challenges including (1) reliable, high- throughput and low-latency wireless communications and networking, (2) electronic and mechanical miniaturization of complex systems, (3) autofocus algorithms, and (4) localization and mapping of the intra-body camera unit and surrounding organs and tissues.

Research Directions: *In vivo* wireless devices with control of various functions including motion control, video zoom and auto focus, and LED illumination. Such wireless devices will also include HD video transmission with near zero latency and will be scalable in architecture and design.

Objectives: To address the above issues, our focus is on (1) architecting, realizing, and networking a family of wirelessly controlled and communicating *in vivo* devices that will facilitate a new paradigm for Minimally Invasive Surgery (MIS) and (2) creating novel *in vivo* wireless communications and networking technology to support these devices and advance the performance of such wireless body area networks (WBANs) that will advance MIS and other biomedical applications.

Contributions: The development and demonstration of a semi-autonomous wirelessly controllable *in vivo* device for minimally invasive surgery with scalable architecture.



CAD model of MARVEL and exploded circuit board stack

Two MARVEL CMs inside a porcine subject

Image of porcine internal organs taken by a MARVEL CM

Wireless Body Area Networks (WBANs)

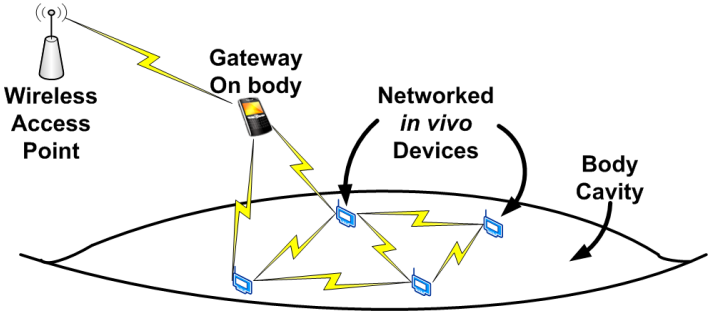
Wireless Body Area Networks (WBANs) promise significant improvement in the reliability of healthcare monitoring and treatment. WBANs comprise a number of *in vivo* intelligent biosensors and actuators that wirelessly communicate to one or more internal or external nodes.

Key Issues and Challenges: Implantable, embedded devices are typically constrained in form factor, complexity, power, and bandwidth. The design of a reliable *in vivo* network comprised of (micro or nano) sensor and actuator nodes, which are limited in transmission and processing power, and are deployed in a not well-characterized communications environment is a significant challenge.

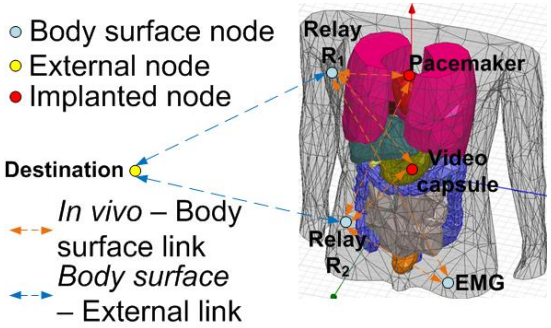
Research Directions: We are investigating high throughput, energy efficient, and robust novel networking technologies that enable reliable information transmission between devices such as MARVEL. These include channel modeling, asymmetric communications systems and network protocols, and novel networking techniques, such as "*MIMO in Vivo,*" Diversity Coding, and Network Coding.

Objectives: Our research is focused on (1) the creation of a comprehensive human-body channel model for *in vivo* wireless signal propagation, and (2) using these models to optimize high data rate WBAN communications by inventing reliable and efficient signal processing and networking protocols.

Methods: The development of the above novel channel models is achieved with the aid of high frequency electromagnetic fields simulators that include complete human body models with over 300 body objects (organ, tissues, fluids, etc.). Also, channel model validation is performed through phantoms and porcine subjects.



In vivo wireless networking



Wireless Body Area Network (WBAN)