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# ***Innovative Wireless Implantable Medical Devices***

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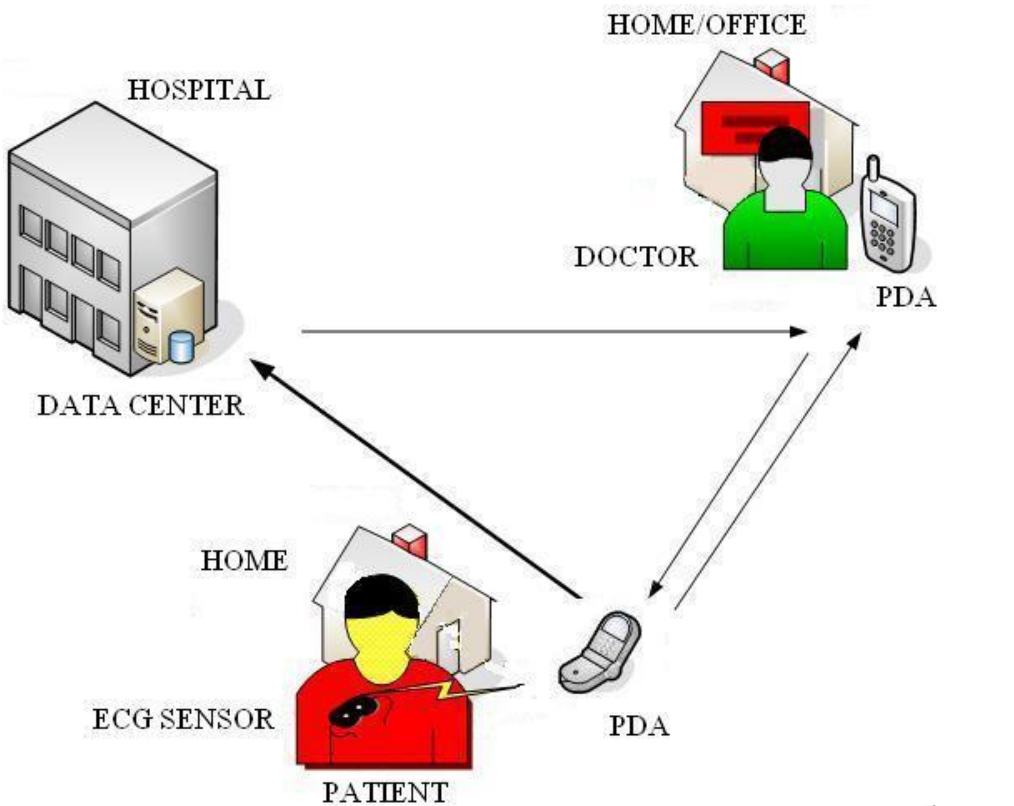
# Outline

- Introduction
- Overview of Implanted Medical Devices
- Wireless Body Area Networks (WBANs)
- WBAN standard (IEEE 802.15.6)
- The Medical Implant Communication Service (MICS)
- Research on *In Vivo* Communications and Networking
  - *In vivo* channel
  - SAR and BER for *in vivo* communications
  - MIMO *in vivo*
- ***MARVEL*** (Miniature Anchored Robotic Videoscope for Expedited Laparoscopy) for improved Minimally Invasive Surgery)
- Patent: Minimally Invasive Networked Surgical System and Method
- Summary

# Current System Architecture for Medical Applications

- Current medical sensors use dedicated systems for wireless communications, data processing, and backend databases
  - These systems rely on low data rate communications and best-effort processing of aggregate data
- As new sensors are developed and more devices are present in the body, a unified architecture becomes necessary to reduce clutter and improve the quality and reliability of communications
  - A single high data rate (possibly embedded) gateway can service multiple low data rate sensors
  - Multiple sensors operating in a mesh network topology can reroute data dynamically to avoid unreliable channels and device failures.



# Remote Patient Monitoring

| |
|---|
| Electronics /Displays /controls |
| Mechanical /cases /frames |
| Communications (WiFi, RFID, Bluetooth, Zigbee) |
| Medical Safety Standards |
| Physical Sensors /Chemical Sensors/Bio-sensors |
| Power/Battery Management /Wireless Charging |
| Workstation platforms |
| Low-Level Analog Interfacing and Signal processing |

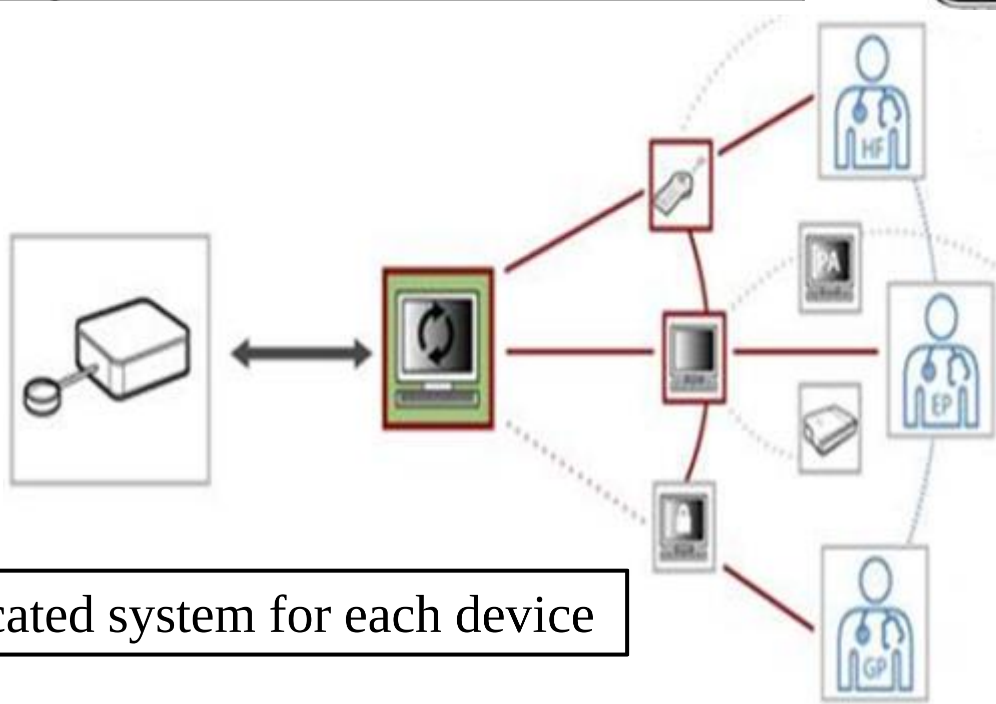

St Jude

Medtronic


Patient data can be remotely accessed by medical professionals.
Alerts or alarms can be forwarded immediately.

Biotronik


Home transmitters allow patient devices such as pacemaker, monitor, insulin pump, etc. to be monitored and accessed by physicians.

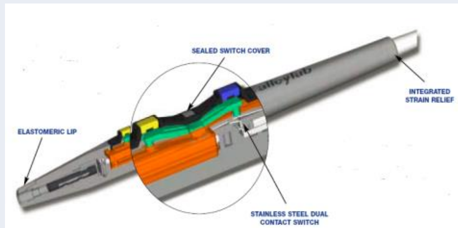



Dedicated system for each device

# Smart Phones as Medical Communicators?

- Mobile phone technology presents several disadvantages:
  - Scheduling of processing events relating to voice and internet communications can delay or conflict with critical medical sensor processing events
  - Smart phones are not designed to meet reliability needs of medical devices
  - Widespread use and quality of data make smart phones a target for hackers
  - Important wireless standards used on newer wireless medical sensors are not supported, such as Zigbee
- However, much of the technology used in smart phones remains applicable to the concept of a unified medical communicator
  - 32-bit processor architecture
  - Low power consumption, high energy density battery
  - Intuitive human interface

# Medical Products Classification

| | Device | Equipment |
|---|---|---|
| Complex |   *In vivo* camera   Electrosurgical Hand-tool |  Endoscopy  Ultrasound Imaging  MRI |
| Simple |  Syringe  Dialysis Tubing Set |  Blood Glucose Monitor  Invitro Diagnostic  Cardiac Rhythm Monitor |

# Implantable Medical Devices

Example Implantable Device Applications:

– Imaging
  - Implanted devices with camera and light source for transmission of image data; e.g. camera pill, laparoscopic cameras, etc.


– Sensors
  - Implanted devices that can test for biological conditions or symptoms and transmit data to external receivers or regulate other medical devices or actuators; e.g. implanted RFID sensors, glucose monitor, EKG sensors, etc.

– Actuators
  - Implanted devices that perform specific actions in response to internal programming or an external stimulus; e.g. neuro-stimulator, drug delivery, insulin pumps, etc.

# Sensors-Example

- The Camera Pill
- Company: Given Imaging
- Description: It lets a doctor examine a gastrointestinal tract noninvasively, taking pictures to find abnormalities.
- New digestive track diagnostic tool
- Replace endoscopy
- Better diagnostic
- Specifications
  - Size: 11 x 26 mm
  - Approximately 57,000 pictures
  - During 8 hours
  - Radio Frequency: 400-440 MHz
  - Bit Rate: 2.7 Mbps
  - Operating Power: 5.2 mW



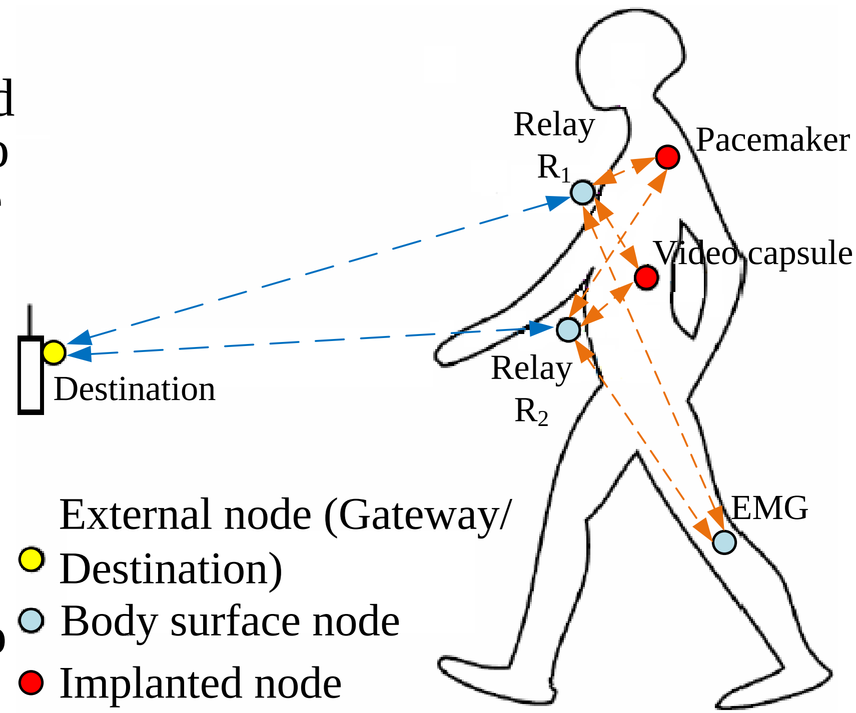
# Wireless LAN and PAN Standards

- A wireless local area network (WLAN) links two or more devices using a wireless distribution method, and usually provides a connection through an access point to the Internet.
- A wireless personal area network (WPAN) is a communication network for interconnecting devices centered around an individual person's workspace.
- Standards currently in use:

| Standard | Max Data Rate (Mbps) | Range (m) | Bandwidth (MHz) | Comm. Technology |
|---|---|---|---|---|
| IEEE 802.11 A/B/G/N WiFi | 54 - A/G<br>600 - N | 50-100 | 20<br>40 | OFDM |
| Bluetooth v4.0 (Bluetooth Low Energy) | 0.200 | 10-50 | 2 | DSSS |
| IEEE 802.15.4 (Zigbee) | 0.250 | 10-100 | 5 | DSSS |
| IEEE 802.15.6 (WBAN) | 15.6 | <5 | 499.2 | Impulse Radio (IR), CP-BFSK |

# Wireless Body Area Networks

- Wireless Body Area Networks (WBANs) are receiving considerable attention because they can provide ubiquitous real-time monitoring, often without restricting the person's regular activities.
- A WBAN is a network formed by low power and limited-energy networked nodes that monitor vital human signs and are located in, on or around the human body.
- WBANs have certain operating characteristics and requirements such as:
  - Limited transmission and processing power---size, battery and transmit power (SAR) limitations to avoid hazardous RF radiation to the human body, as well as to extend the node's battery lifetime.
  - Negligible or at least very small latency, especially for real-time applications (*in vivo* video monitoring).
  - Operating in a highly lossy, dispersive, and time varying (due to the movement of internal fluids such blood) RF channel.



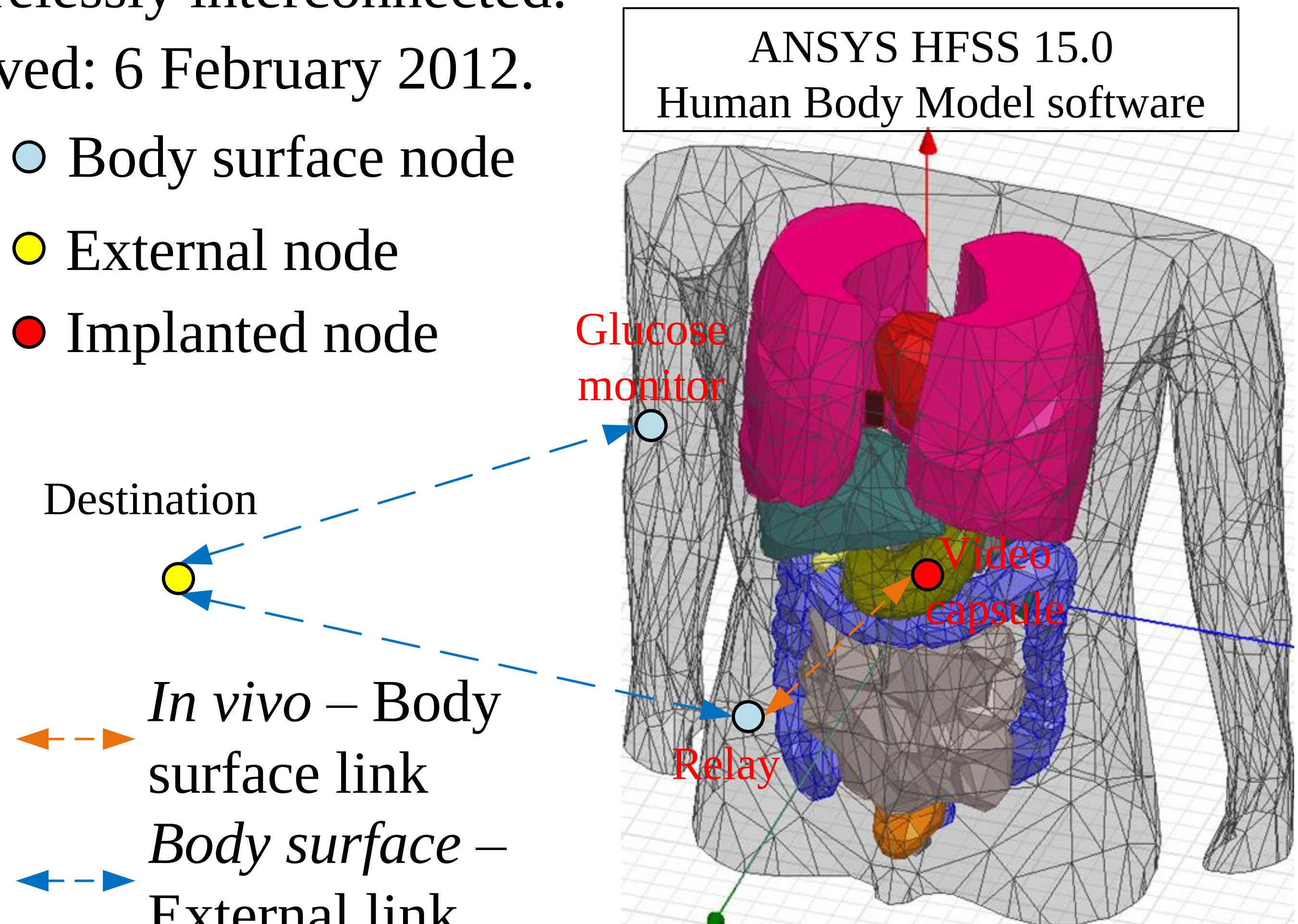

*In vivo* wireless communications and networking

# Wireless Body Area Networks: Requirements

- WBANs must satisfy stringent technical requirements, especially when the network is monitoring life-saving related signals such as indicators of a heart attack.
- Be extremely reliable by avoiding single points of failure and providing self-healing capabilities if nodes or links are not operating properly,
- Low power transmission to extend the network lifetime and preclude any harmful effects in the human body, and
- Maximize throughput over a lossy, dispersive, and dynamic channel.
- A frequent constraint is that it is often neither possible nor desirable to retransmit the sensor data.

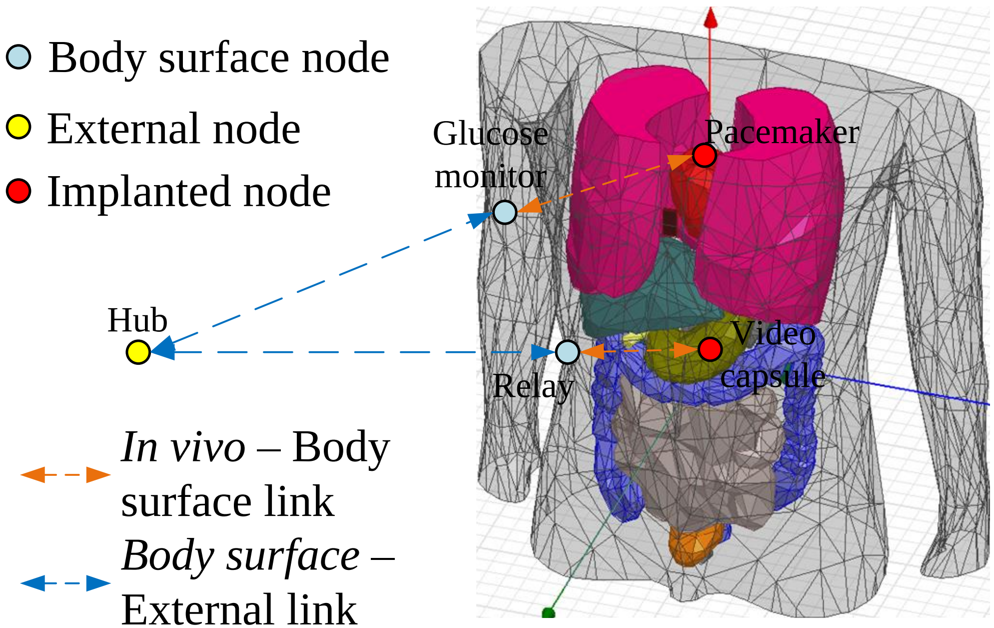
# WBAN Standard: IEEE 802.15.6

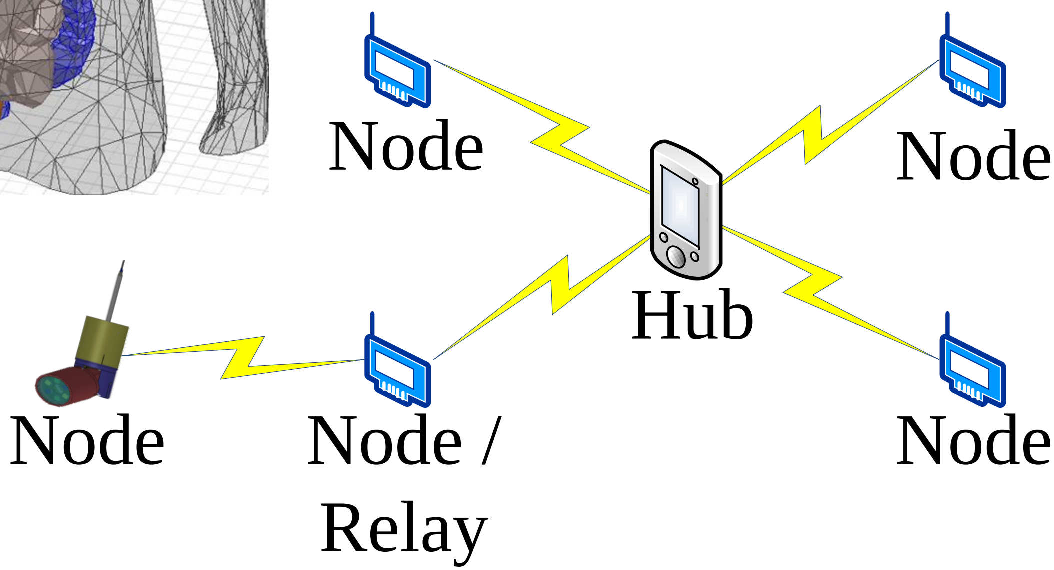
- A Wireless Body Area Network (WBAN) is a collection of low-power, intelligent devices, such as sensors or actuators, which are embedded, on-body, or in close proximity to the human body and are wirelessly interconnected.
- Approved: 6 February 2012.



# WBAN Architectures

- Hub – Node (Star topology)
- Hub – Node (Relay) – Node
- Each WBAN can have only one HUB and up to 64 nodes




Node = device

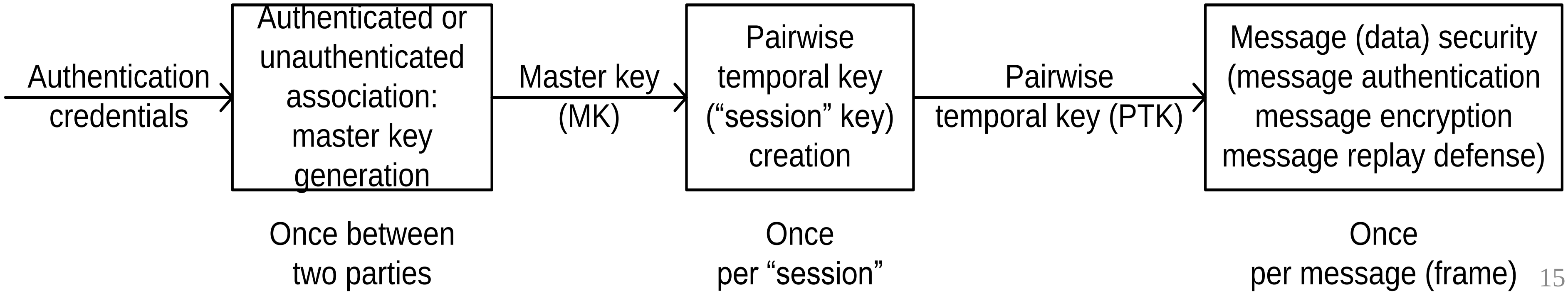
# WBAN Architecture - Protocol Summary

- One common MAC layer
  - General format: MAC header, MAC Frame Body (0 – 255 octets), and FCS (2 octets)
  - MAC Header (7 octets):
    - Frame control (Protocol version, ACK policy, security level, Frame type, sequence number, etc.) – 4 octets
    - Recipient ID – 1 octet
    - Sender ID – 1 octet
    - BAN ID – 1 octet
- 3 Physical layers
  - PHY Narrowband
  - PHY Ultra Wideband
  - PHY Human Body Communications (uses skin as a conductor)

# WBAN Security

A self-contained, low-overhead, but strong security solution between nodes and hub:

- Master key generation
  - Through master key (MK) pre-shared association, unauthenticated association, public key hidden association, password-authenticated association, and display-authenticated association
  - Simple two-way handshake for MK pre-shared association; elliptic curve cryptography (ECC) based for key agreement
- Temporal key creation/distribution
  - Pairwise temporal key (PTK) creation for unicast protection
  - Group temporal key (GTK) distribution for multicast/broadcast protection
- Data authentication/encryption
  - AES-128 CCM for data authentication/encryption
  - Replay prevention
  - Low security overhead



# WBAN MAC Layer: Priority Support

- BAN – Supported services
  - Non-medical services
  - Mixed medical and non-medical services
  - General health services
  - Highest priority medical services

- User priority mapping

| Priority | User Priority | Traffic designation | Frame type |
|---|---|---|---|
| Lowest | 0 | Background (BK) | Data |
| | 1 | Best effort (BE) | Data |
| | 2 | Excellent effort (EE) | Data |
| | 3 | Video (VI) | Data |
| | 4 | Voice (VO) | Data |
| | 5 | Medical data or network control | Data or management |
| | 6 | High priority medical data or network control | Data or management |
| Highest | 7 | Emergency or medical event report | Data |

# PHY-Dependent MAC Sublayer (Uses standard wireless MACs)

- Narrowband PHY
  - CSMA/CA
- UWB PHY
  - CSMA/CA or Slotted Aloha
  - Hybrid ARQ (type II)
- HBC PHY
  - Slotted Aloha

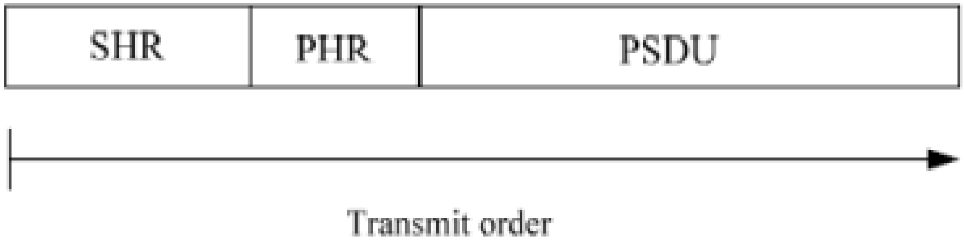
# PHY Narrowband

- Channel coding [BCH($n$=63, $k$=51)] → Add pad bits → Spreader → Bit interleaver → Scrambler → Symbol mapper

| Frequency Band (MHz) | Modulation | Information Data Rate (kbps) | Support |
|---|---|---|---|
| 402 – 405 (BW: 300 KHz) Implantable | π/2-DBPSK | 75.9 | Mandatory |
| | π/2-DBPSK | 151.8 | Mandatory |
| | π/4-DQPSK | 303.6 | Mandatory |
| | π/8-D8PSK | 455.4 | Optional |
| 420 – 450 (BW: 320 KHz) | GMSK | 75.9 | Mandatory |
| | GMSK | 151.8 | Mandatory |
| | GMSK | 187.5 | Optional |
| 863 – 870<br>902 – 928<br>950 – 958<br>(BW: 400 KHz) | π/2-DBPSK | 101.2 | Mandatory |
| | π/2-DBPSK | 202.4 | Mandatory |
| | π/4-DQPSK | 404.8 | Mandatory |
| | π/8-D8PSK | 607.1 | Optional |
| 2360 – 2400<br>2400 – 2483.5<br>(BW: 1 MHz) | π/2-DBPSK | 121.4 | Mandatory |
| | π/2-DBPSK | 242.9 | Mandatory |
| | π/2-DBPSK | 485.7 | Mandatory |
| | π/4-DQPSK | 971.4 | Mandatory |

# PHY Ultra Wideband

- The ultra wideband (UWB) PHY specification is designed to:
  - offer robust performance for BANs
  - provide a large scope for implementation opportunities for high performance, robustness, low complexity, and ultra low power operation.
- There are two PHY UWB technologies defined in the standard:
  - Impulse radio (IR-UWB) and wideband FM (FM-UWB)
  - IR-UWB is based on transmission of either a single pulse (new paradigm) or a burst of pulses (legacy) per information symbol.
  - FM-UWB combines continuous phase binary FSK (CP-BFSK) modulation with wideband FM.
- The UWB PHY provides three levels of functionality:
  - Activation and deactivation of the radio transceivers.
  - The UWB PHY may provide clear channel assessment (CCA) indication to the MAC in order to verify activity in the wireless medium.
  - The PLCP constructs the PHY layer protocol data unit (PPDU) by concatenating the synchronization header (SHR), physical layer header (PHR) and physical layer service data unit (PSDU).



# 802.15.6 Ultra Wideband (UWB)

| Band group | Channel number | Center frequency (MHz) | Bandwidth (MHz) | Channel attribute |
|---|---|---|---|---|
| Low band | 1 | 3494.4 | 499.2 | Optional |
| | 2 | 3993.6 | 499.2 | Mandatory |
| | 3 | 4492.8 | 499.2 | Optional |
| High band | 4 | 6489.6 | 499.2 | Optional |
| | 5 | 6988.8 | 499.2 | Optional |
| | 6 | 7488.0 | 499.2 | Optional |
| | 7 | 7987.2 | 499.2 | Mandatory |
| | 8 | 8486.4 | 499.2 | Optional |
| | 9 | 8985.6 | 499.2 | Optional |
| | 10 | 9484.8 | 499.2 | Optional |
| | 11 | 9984.0 | 499.2 | Optional |

# PHY Ultra Wideband (~500 MHz)

- Scrambler → Channel coding [BCH(n=63, k=51)] → Pad bits → Spreader → Bit interleaver
- Impulse Radio (IR)

On-Off signaling

| Uncoded bit rate (Mbps) | FEC rate | Coded bit rate (kbps) |
|---|---|---|
| 0.487 | 0.81 | 394.8 |
| 0.975 | 0.81 | 789.7 |
| 1.950 | 0.81 | 1,579.0 |
| 3.900 | 0.81 | 3,159.0 |
| 7.800 | 0.81 | 6,318.0 |
| 15.600 | 0.81 | 12,636.0 |

DBPSK/DQPSK modulations

| Mod | Uncoded bit rate (Mbps) | FEC rate | Coded bit rate (kbps) |
|---|---|---|---|
| DBPSK | 0.487 | 0.5 | 243.0 |
| DBPSK | 0.975 | 0.5 | 457.0 |
| DBPSK | 1.950 | 0.5 | 975.0 |
| DBPSK | 3.900 | 0.5 | 1,950.0 |
| DBPSK | 7.800 | 0.5 | 3,900.0 |
| DQPSK | 15.600 | 0.5 | 7,800.0 |
| DBPSK | 0.557 | 0.5 | 278.0 |
| DQPSK | 1.114 | 0.5 | 557.0 |

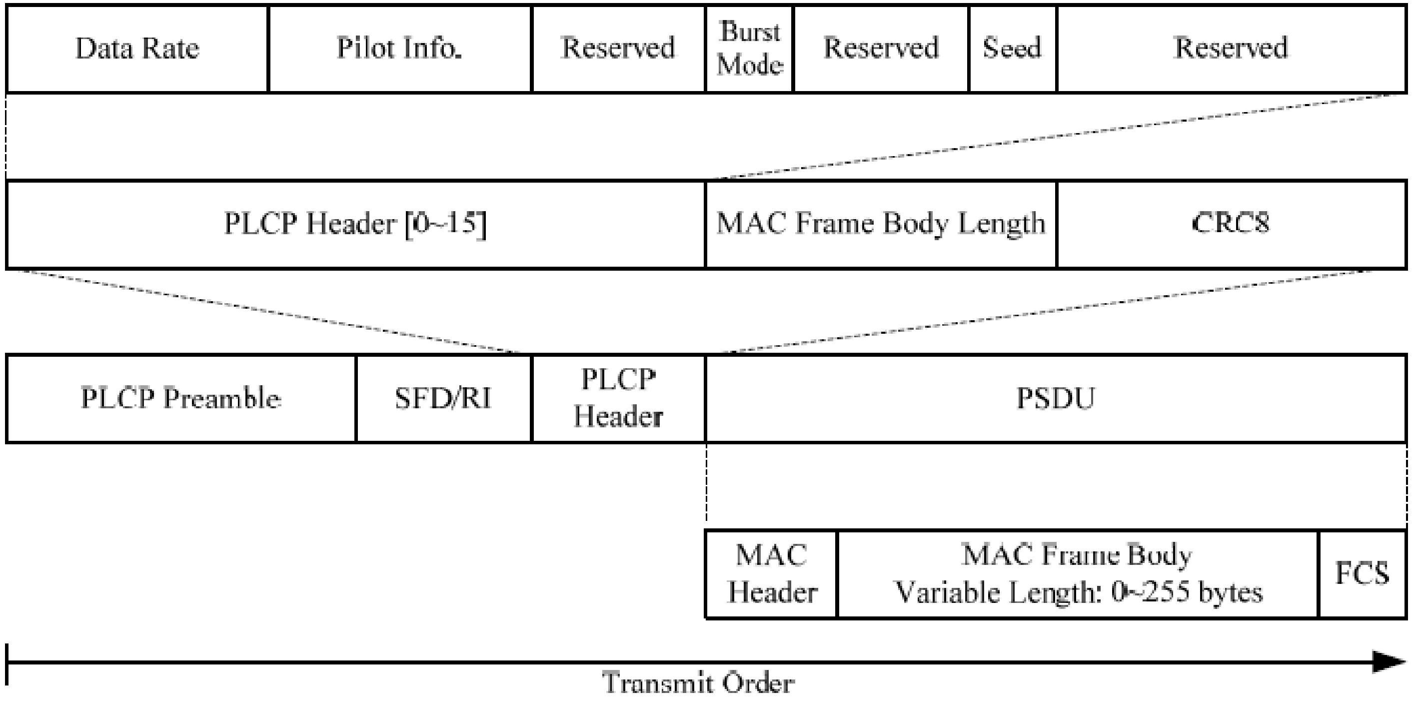
- FM (optional)

FM-UWB data rate

| Uncoded bit rate (kbps) | FEC rate | Coded bit rate (kbps) |
|---|---|---|
| 250 | 0.81 | 202.5 |

# PHY Human Body Communications

- This specification is for human body communications (HBC) physical layer (PHY) that uses the electric field communication (EFC) technology.
- The electrode in contact with the body is used for transmitting or receiving an electrical signal through the body to a device (e.g. smartphone)
- The band of operation is centered at 21 MHz.




| Data Rate |
|---|
| 164 kbps |
| 328 kbps |
| 656 kbps |
| 1.3125 Mbps |

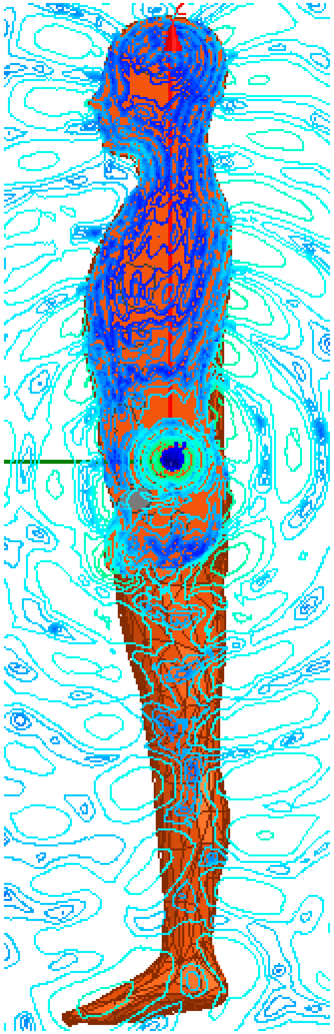
# Medical Implant Communication Service

- 402–405 MHz frequency allocation
  - FCC was petitioned in 1988, allocated in 1999
- Short-range, wireless link to connect low-power implanted medical devices with monitoring and control equipment
  - Implanted Medical Devices (IMD) such as cardiac pacemakers, implantable cardioverter/defibrillator (ICD), neuro-stimulators, etc.
  - Proprietary protocols.
- Why 402-405 MHz?
  - Reasonable signal propagation characteristics in the human body
- General world-wide acceptance
  - Approved in United States, Europe, Canada, Australia and Japan

| Frequency Band (MHz) | Number of Channels | Channel Bandwidth | Typical Data Rates |
|---|---|---|---|
| 402 – 405 | 10 | 300 kHz | 75.9 – 455.4 Kbps |

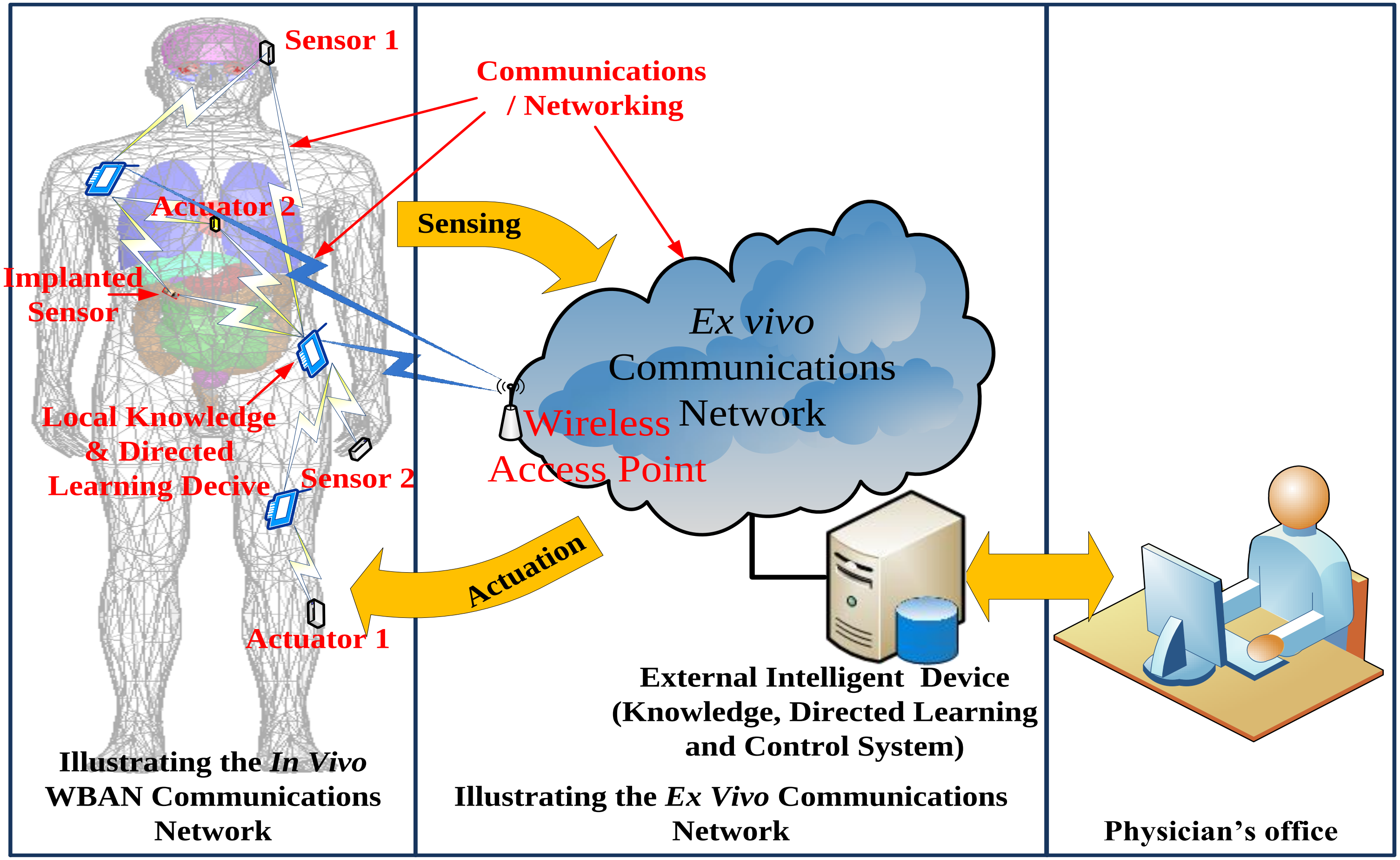
# Medical Implant Communication Service

- Traditional implants
  - Use inductive links
  - Limited range
    - In contact with patient
  - Low frequency
    - Data rates similar to a dial-up computer modem
  - Low data rate communications in the MICS band (75.9 – 455.4 Kbps)
- Our current research addresses the need for higher data rates
  - To upload patient events captured in the IMD's memory to the base station for analysis
  - Shorten doctor/patient consultancy times



# Our Research Vision: Wireless Enabled Healthcare System

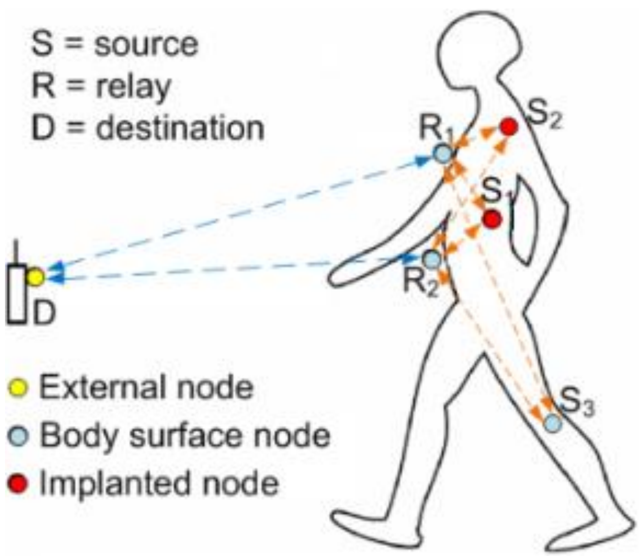
Wireless technology has the potential to advance healthcare delivery solutions by creating new science and technology for *in vivo* wirelessly networked cyber-physical systems of embedded devices that use real-time data to enable rapid, correct, and cost-conscious responses in chronic and emergency circumstances.



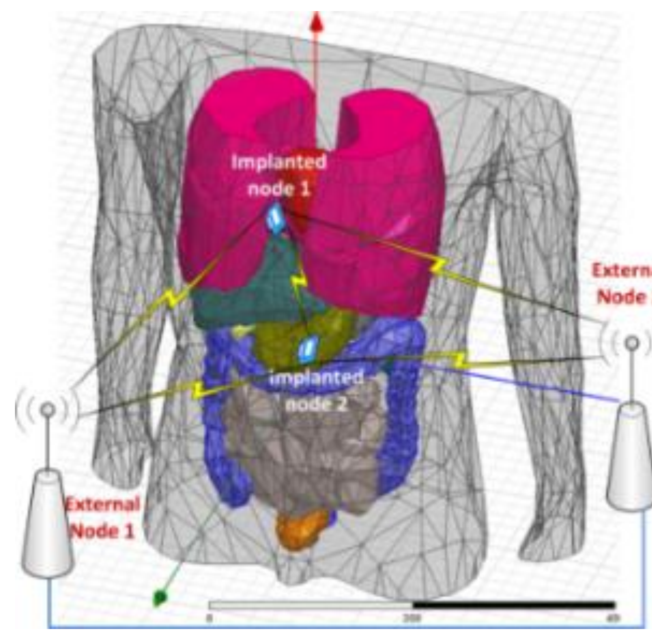

- **Research opportunities and challenges are abundant.**

# *In Vivo* Wireless Research Areas

- Sensing and actuation at the micro/nano/molecular level.
- New (asymmetric) communications and multihop networking paradigms for devices more limited, from a communication and computing standpoint, than any devices that have ever been networked by human-created means and achieving reliable, high-throughput and near zero latency intra-body wireless communications and networking.
- New approaches to privacy and security for devices of limited processing capabilities and developing a scalable architecture for data management
- New learning systems that distill complex datasets into actionable information.
- Advances in wireless communications and networking for cellular and WLANs should significantly improve the performance of wireless *in vivo* systems.



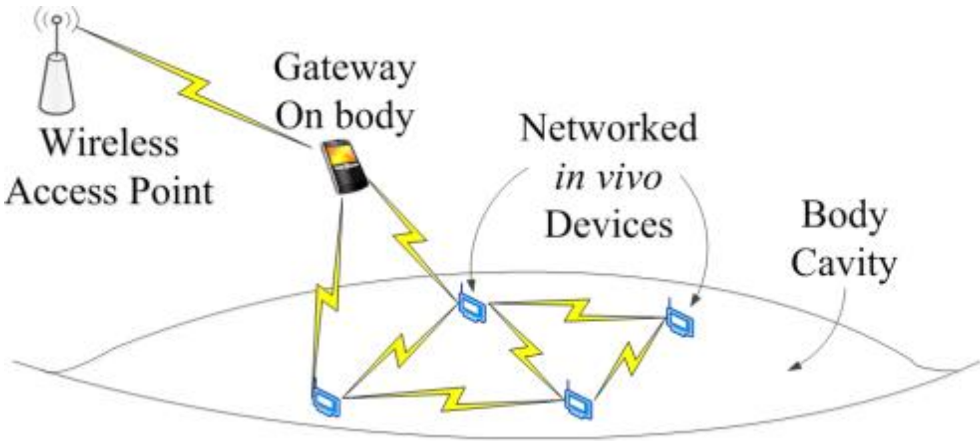

*In vivo* wireless communications and networking

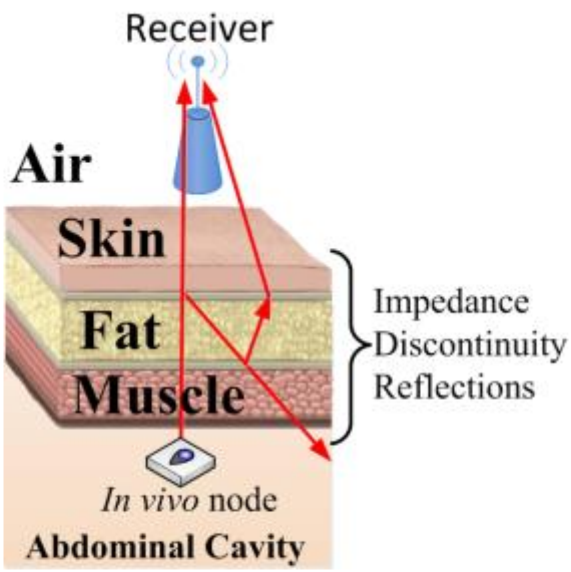



Cooperative MIMO *In Vivo*

# Some Research Challenges

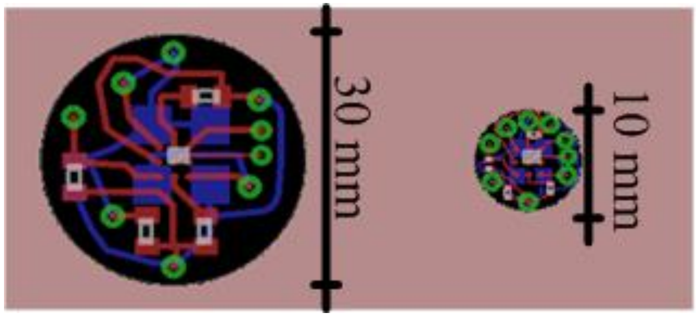
- Reliable, high-throughput and near zero latency intra-body wireless communications and networking.



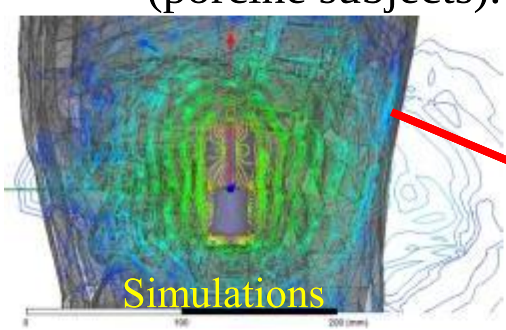

- Coping with the complexity of an *in vivo* multipath RF channel.

- Electronic, optical and mechanical miniaturization of complex systems.



# Systematic Approach To *In Vivo* Parametric Channel Modeling

- Use software to simulate the RF channel. Such simulations are key to providing "ball-park" results and intuition before experimentally sounding channels.
- The experimental channel sounding, with phantoms and live models, will then provide raw data samples of the *in vivo* channel itself and lead to useful datasets.
- More useful are parametric models will iteratively evolve based on the simulations and experimental measurements. Such models will vastly improve the ability to pursue endeavors in the biomedical device field specifically with regards to wireless communications from *in vivo* devices
- Given data from simulated, measured, and modeled channels, a thorough analysis includes benefit/cost behavior of implanted devices, performance as a location of devices in the body, power consumption, and degree of invasiveness.
- Once point-to-point communications are well understood, the possibilities of networking *in vivo* nodes is examined.
- Finally, the modality/scenario combinations are tested in phantoms and live models (porcine subjects).




Candidate Parametric Channel Model

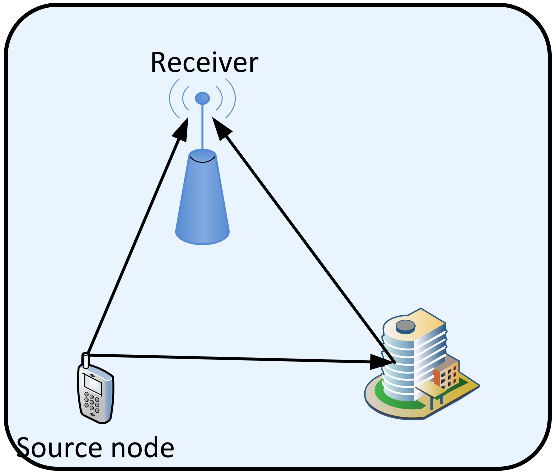

$$R(t,\tau,\varphi)=\sum_{i=1}^{L}\alpha_i(t,\varphi)e^{\theta_i(t,\varphi)}h(t-\tau_i(t,\varphi))e^{j2\pi\Delta f_i(t,\varphi)t}$$

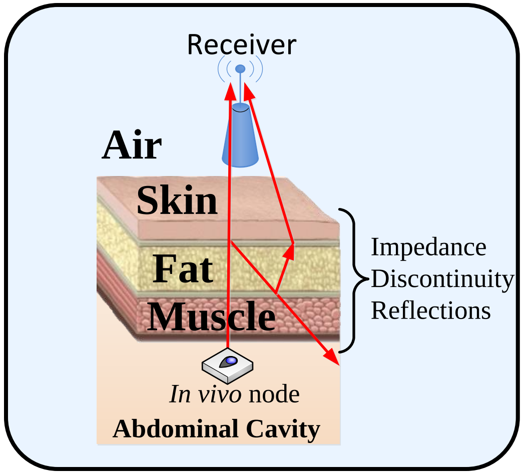
*In vivo* verification

# *In vivo* Wireless Channel Characterization and Signal Processing

- Well-studied wireless environments include: cellular, WLAN, and deep-space
- The *in vivo* channel is a "new frontier" in wireless propagation and communications
- Many new research issues:
  - Media characterization and communications optimization
  - New communications, networking, and security solutions for embedded devices of limited complexity and power
  - Near-field effects (at low operating frequencies) and multi-path scattering (at high operating frequencies) with propagation through different types of human organs and internal structures between closely spaced transmitter and receiver antennas.

Classic Multi-Path Channel



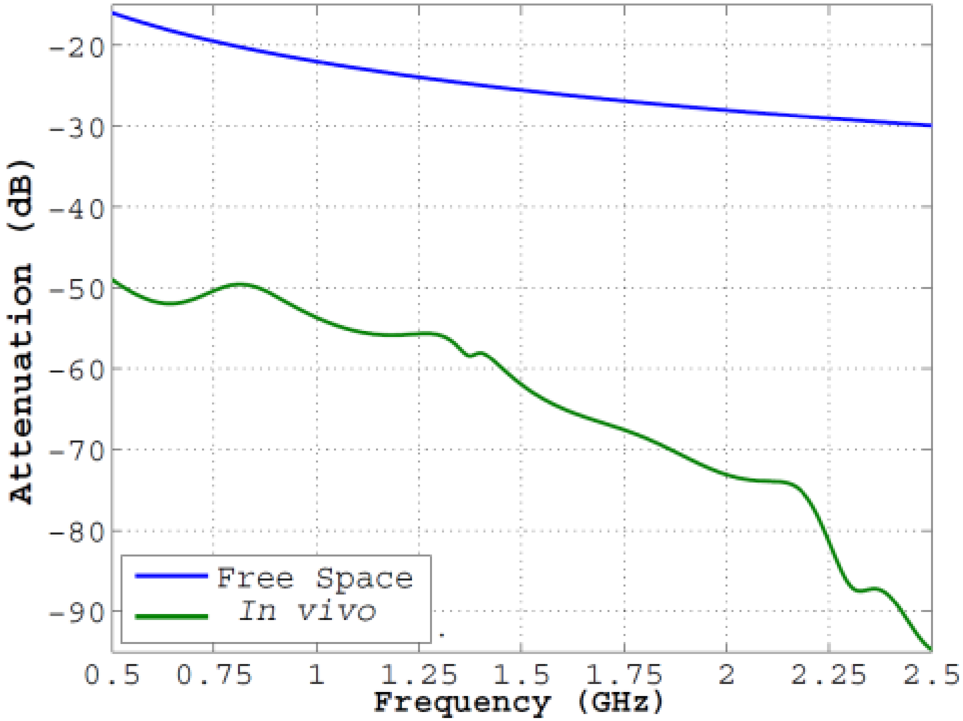




*In Vivo* Multi-Path Channel

Characterizing *in vivo* wireless propagation is critical in optimizing communications and requires familiarity with both the engineering and the biological environments.

# Free Space and *In Vivo* Attenuation

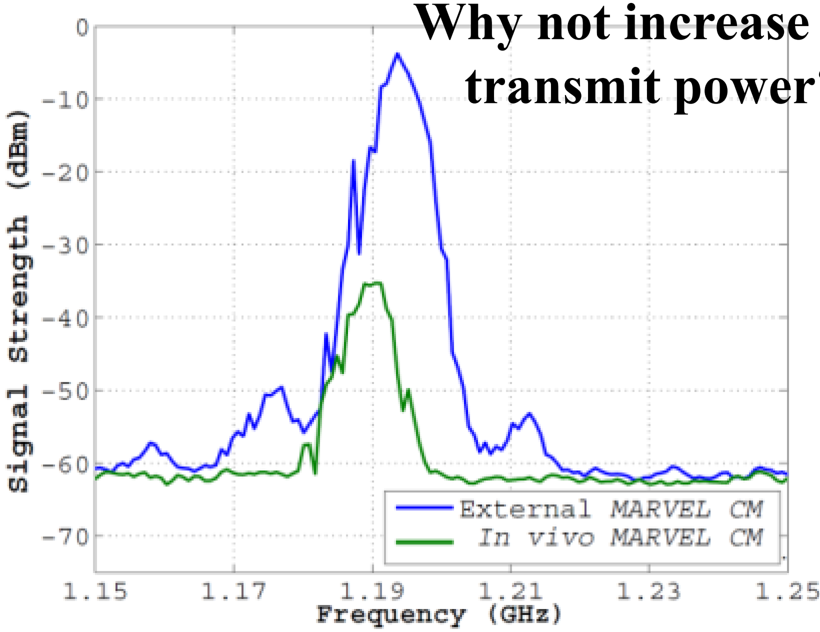
- Simulated attenuation in HFSS, where a signal travels from a monopole placed inside the abdomen to an external monopole with a 30 cm transmission path (9cm of the path are inside the body).
- Antenna effects have been removed in software by simultaneously matching each antenna port impedance in Agilent ADS.
- Signal loss shown in plot for *in vivo* attenuation and free space loss.
- Attenuation drop-off rate is not constant and is seen to increase more rapidly above 2.2 GHz.



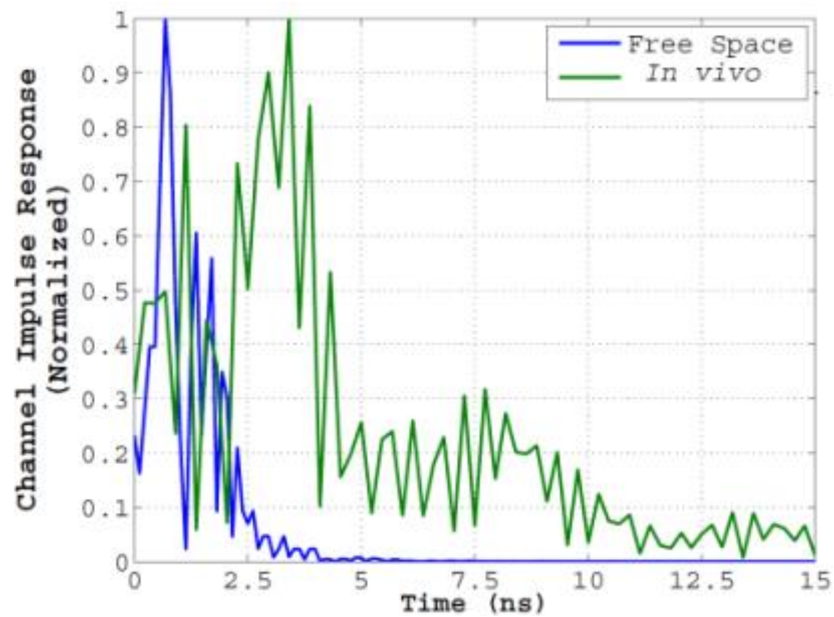
# *In Vivo* Attenuation and Dispersion

- The carrier frequency was ~1.2GHz and the video signal bandwidth is 5MHz. The FM modulation bandwidth was about 11MHz. Transmitter was located inside the abdominal cavity. The receiver was placed ~ 0.5m from the transmitter in front of the abdomen.
- It can be seen that there is about a 30 dB difference in signal strength between the *in vivo* and the external measurement, which shows that there is approximately 30 dB of attenuation through the organic tissue. This seems to be in good agreement in what is shown in the prior chart.
- *In vivo* time dispersion is much greater than expected from the physical dimensions.

**Why not increase the transmit power?**



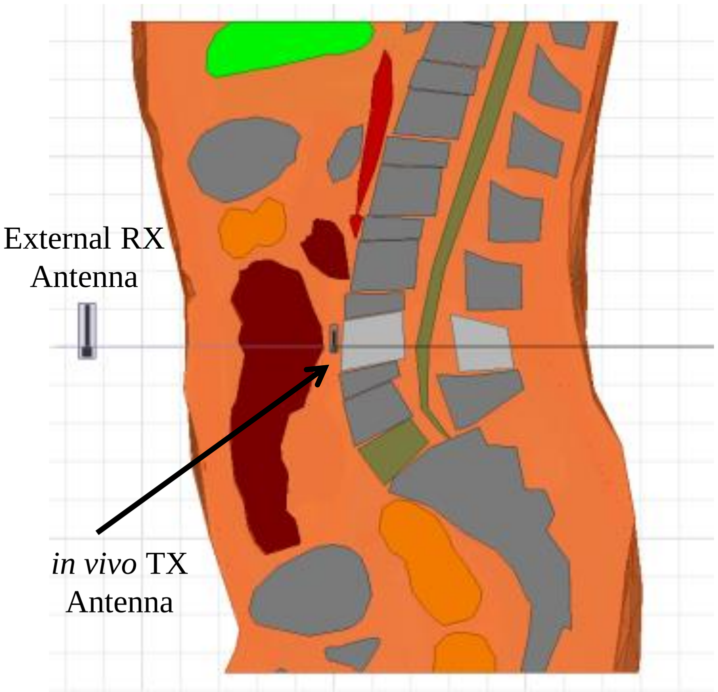

MARVEL Camera Module (CM):
**Vivarium Experiment**




Normalized channel impulse response for the human body for free space and scattered environments.

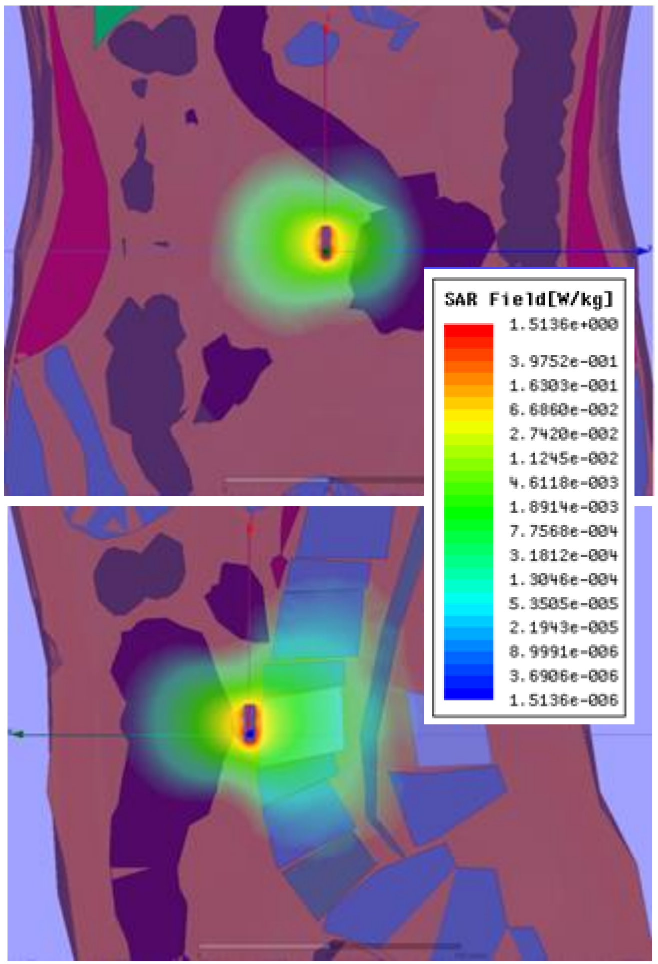
# SAR and BER for *In Vivo* Communications

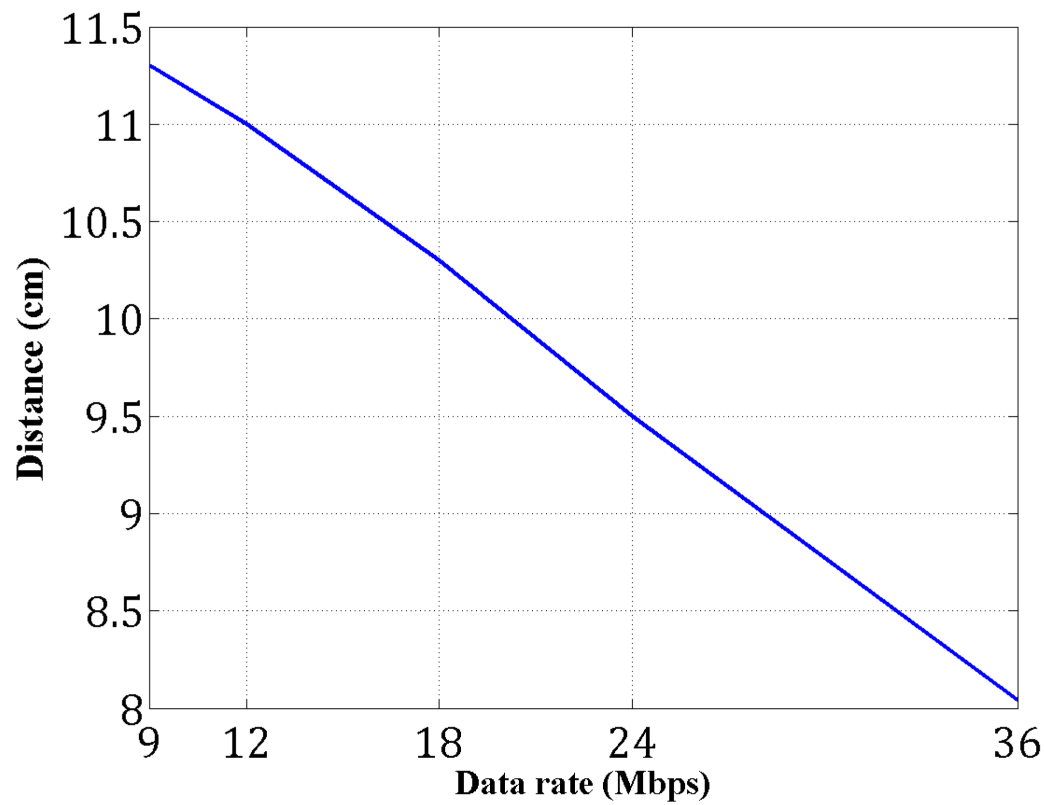
- WBANs must transmit at low power to protect the patients against harmful health effects associated with the radiofrequency (RF) emissions as well as to extend the node’s battery lifetime.
- The specific absorption rate (**SAR**) is the rate at which the RF energy is absorbed by a body volume or mass and has units of watts per kilogram (W/Kg).This sets a limit on the transmitted power.
- The SAR limit is frequency dependent, since it depends on the conductivity of the material, which changes with frequency in human organs/tissues
- Due to this limitation on the specific absorption rate, it is not possible to increase the transmission power beyond a certain level to overcome transmission errors.
- By networking the *in vivo* nodes via relay nodes, it is  possible to transmit the *in vivo* sensors’ information to external nodes while keeping the SAR within allowed limits.
- The figure shows the location of the *in vivo* and *ex vivo* antennas for our software-based experiments.



# SAR and BER for *In Vivo* Communications

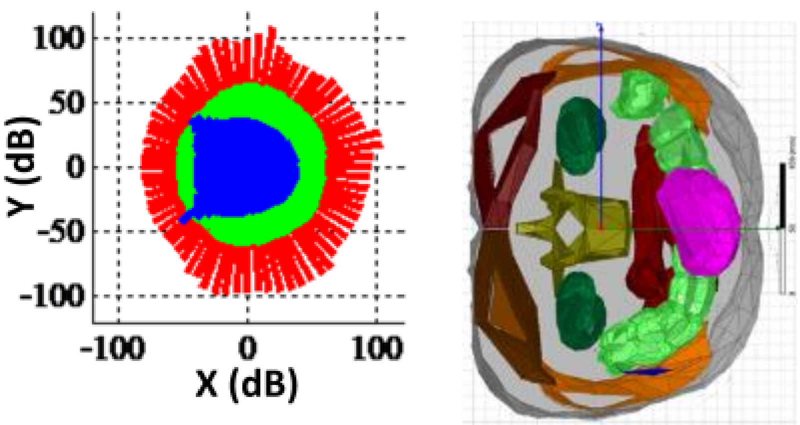
- The left figure shows the front (top) and side (top) cross-sectional views of the total SAR generated at 2.412 GHz inside the abdomen at a transmit power of 0.412 mW.
- Achievable distance, as a function of bit rate, between *in vivo* and external antennas for a BER of $10^{-6}$. is shown in the left figure.



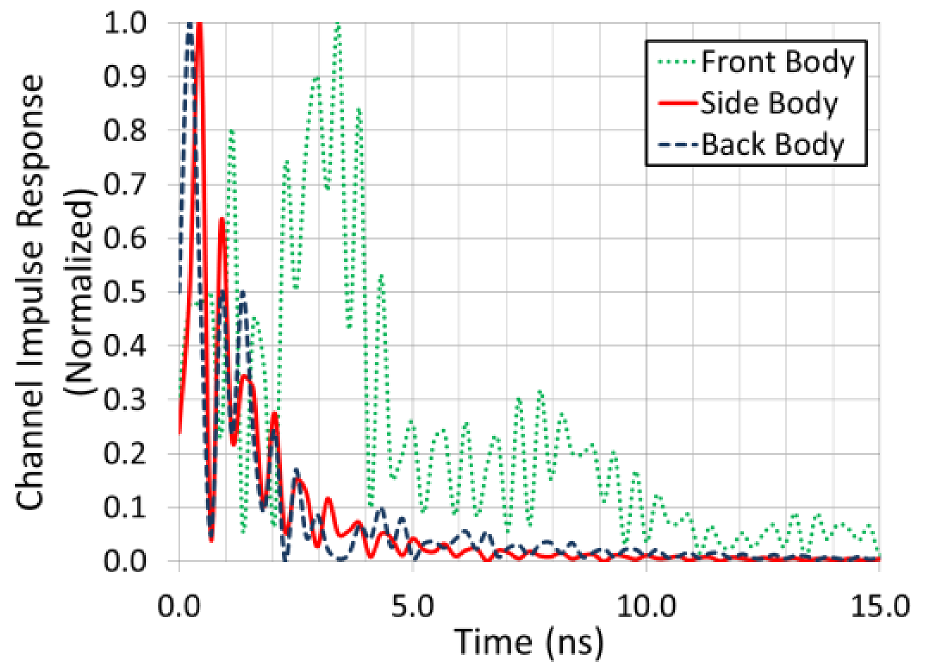



# *In Vivo* Wireless Channel Directional Properties

- One of the many differences between classic RF models and the *in vivo* channel is that the path loss and impulse response is a function of the direction (receiver location)
- Lower left figure: the path loss is a function of the frequency and not homogenous around the body. Moreover, the angular dependency is noticeable for 500 MHz as in the right figure (blue curve).
- The distance between transmitter and receiver is 30 cm with center frequencies of: Red=2 GHz, Green=1 GHz, Blue=0.5 GHz

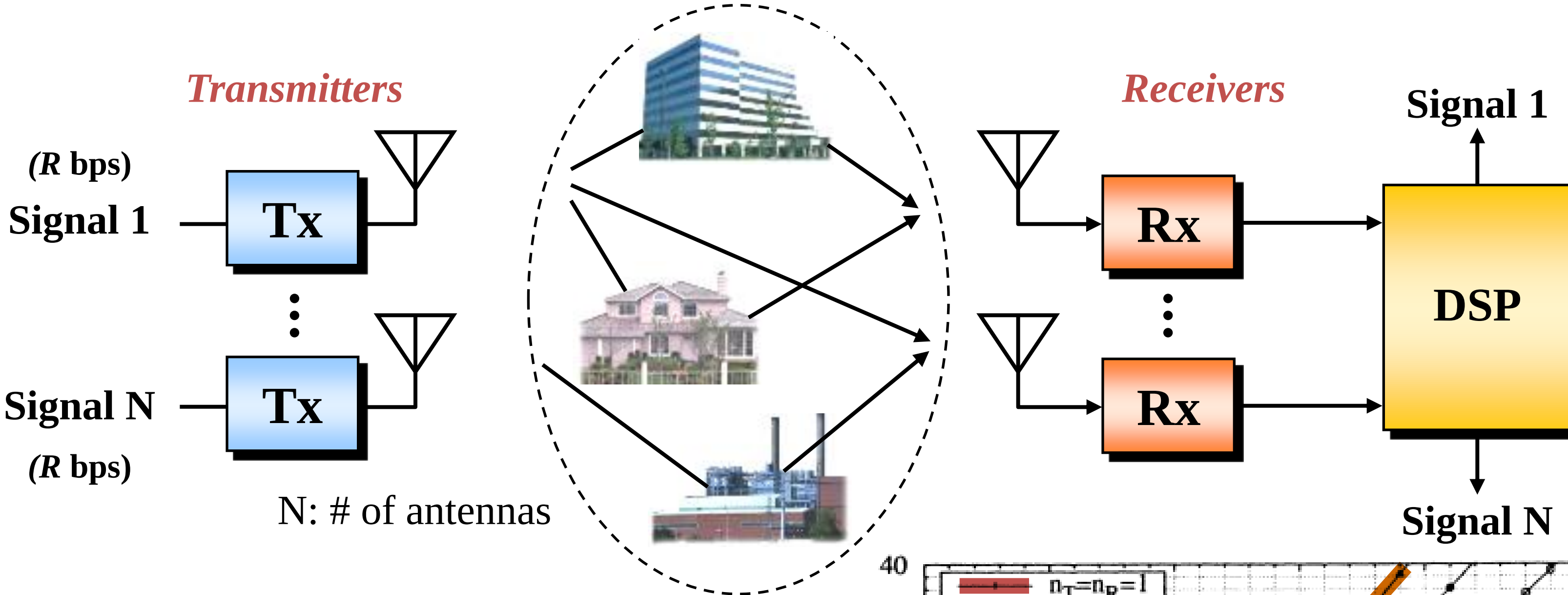



Path loss as a function of position for the human body without arms (figure on the right) with the transmitter at (0,0) and measured at a height of 1.1m. The attenuation at any point (x,y) is $[(P_x)^2 + (P_y)^2]^{1/2}$

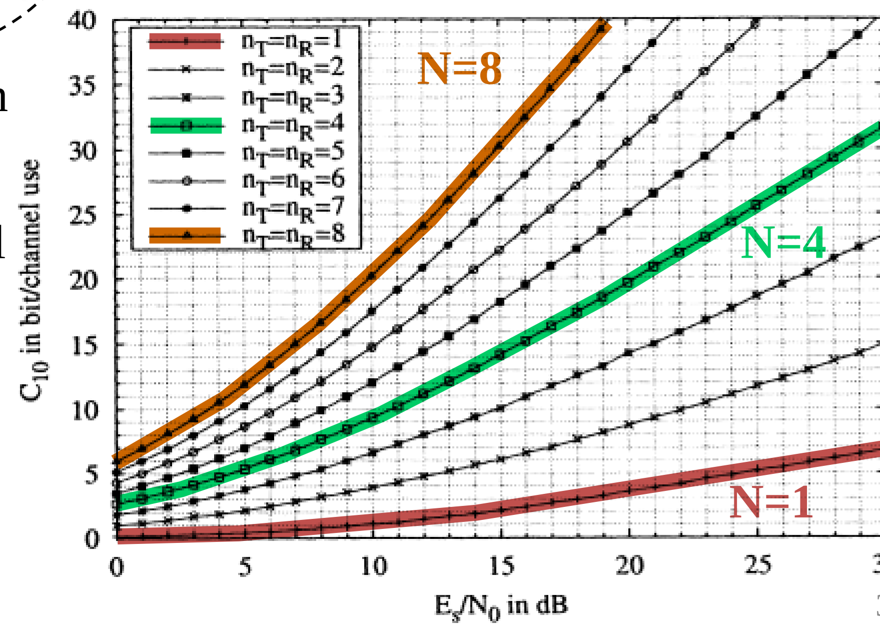



Channel impulse response for the human body for different locations of the receiver

# Advanced Technology: *MIMO* ---Multiple Transmit and Receive "Smart" Antennas Dramatically Increase Wireless Capacity

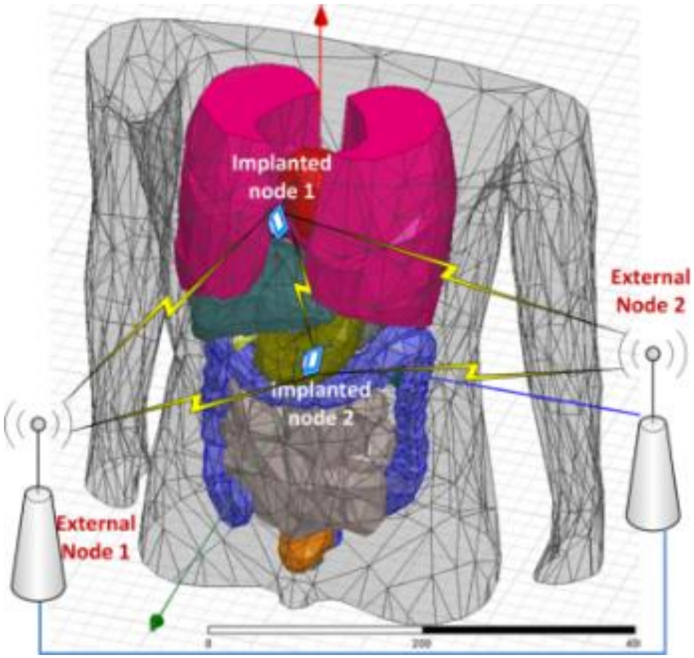



- Multipath scattering scrambles the signals -each receiver has a different combination of signals
- DSP algorithm de-scrambles the received signal to reproduce original signals and deliver the energy to the target receiver.
- Capacity increases ~ linearly with number of antennas with no increase in total power
**[MIMO** = multiple input multiple output]



# MIMO *In Vivo*

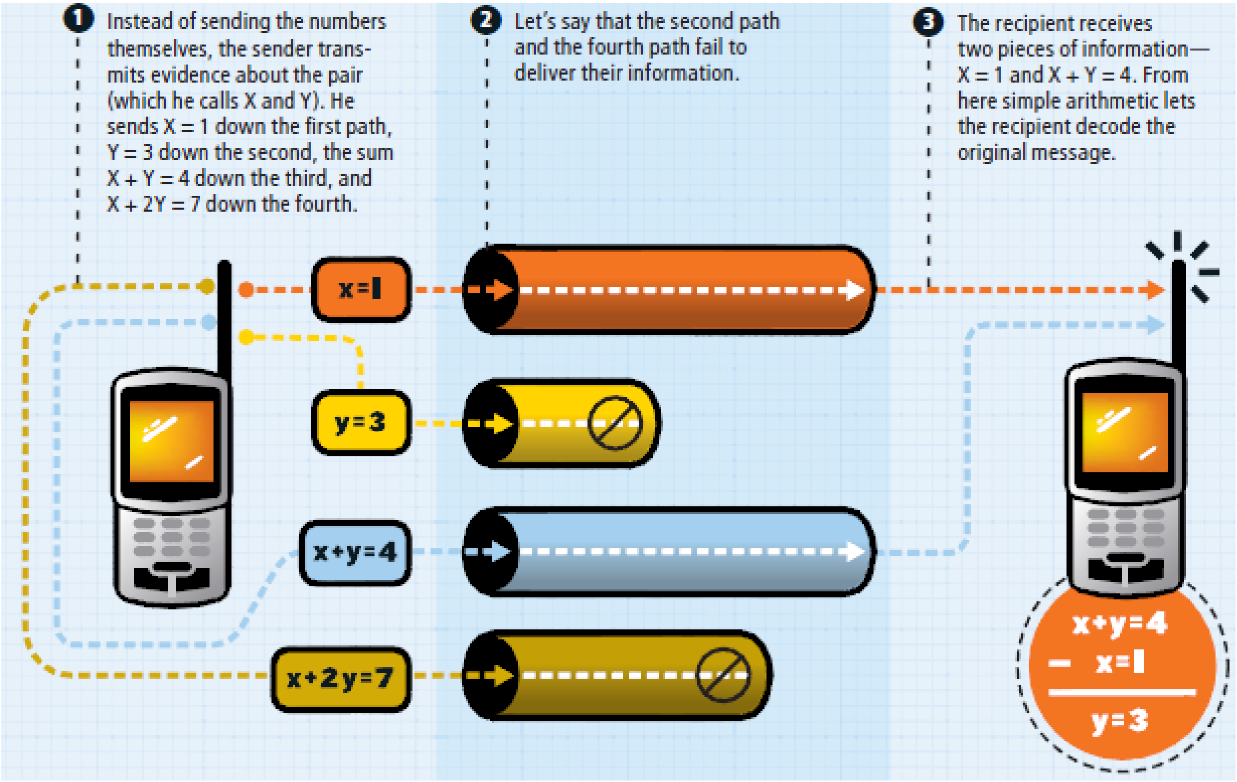
- MIMO techniques may be used to interrogate power-limited, or passive, sensors.
- If feasible, this could have the potential dual benefit of not only enhancing the data rates possible through spatial multiplexing.
- Advantages:
  - Increased read reliability using spatial diversity
  - Increased read range and throughput
  - No increase in power consumption with higher data rate
  - Full channel information at the reader through sensor backscatter
- Potential application: RFID for passive devices

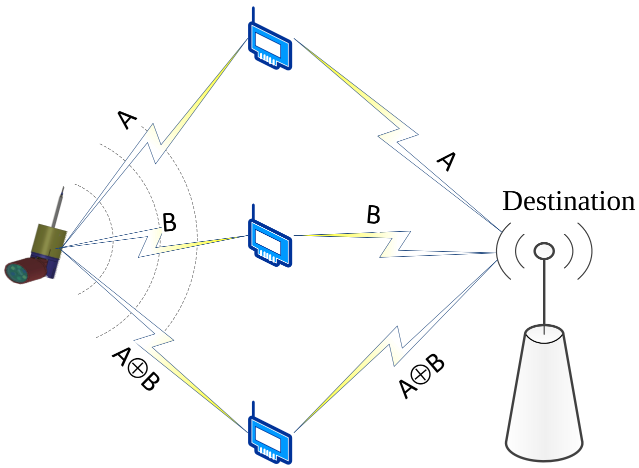



Cooperative MIMO *In Vivo*

# Advanced Technology: Network Coding – Smart Redundancy
## making reliable networks/systems out of (somewhat) unreliable subsystems

- Network Coding (NC) achieves capacity gain through coding of information.
- Improves network reliability against packet losses and link failures (and coding provides some security against casual or malicious listeners/intruders.)

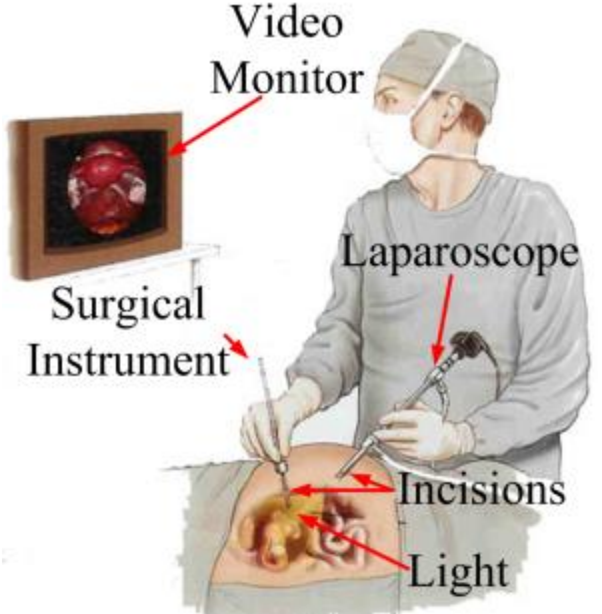


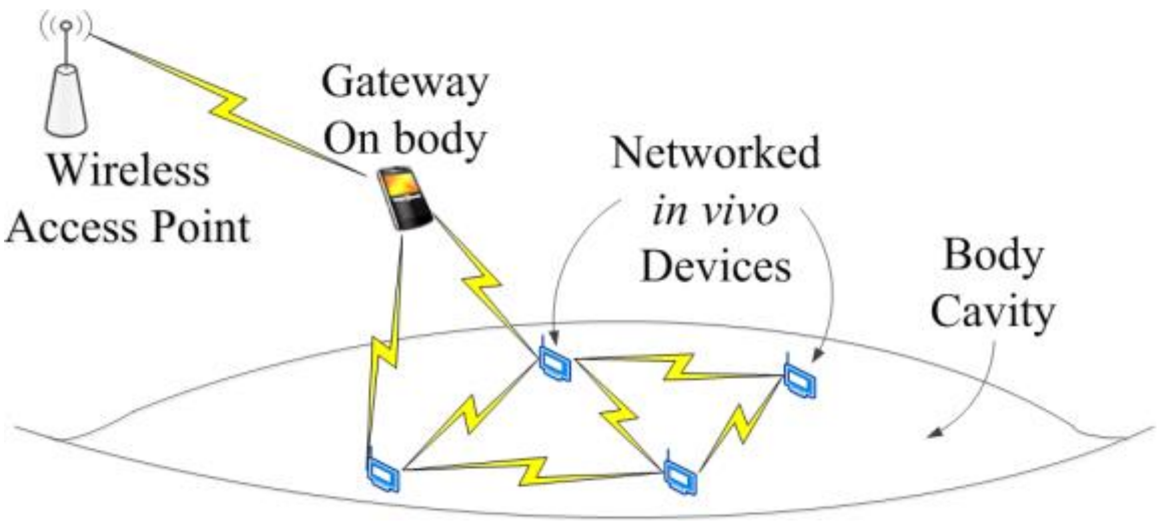

Source: http://www.scientificamerican.com (April 2010)

# Advancing Minimally Invasive Surgery (MIS) via Wirelessly Networked Devices

- Creation of a wireless network of cyber-physical *in vivo* devices that enhances and enables innovative non-invasive and MIS surgical and other procedures.
- This network is comprised of a plurality of communicating devices --- such as imaging devices, sensors and actuators, power sources, "cutting" tools (physical, optical, ultrasound, etc.) and other ancillary devices.
- The devices are electronically addressable and controllable and form a distributed wireless network whose capabilities greatly exceed that of any individual device.
- The ***MARVEL*** Camera Module (CM) is the first device in realizing “the vision.”

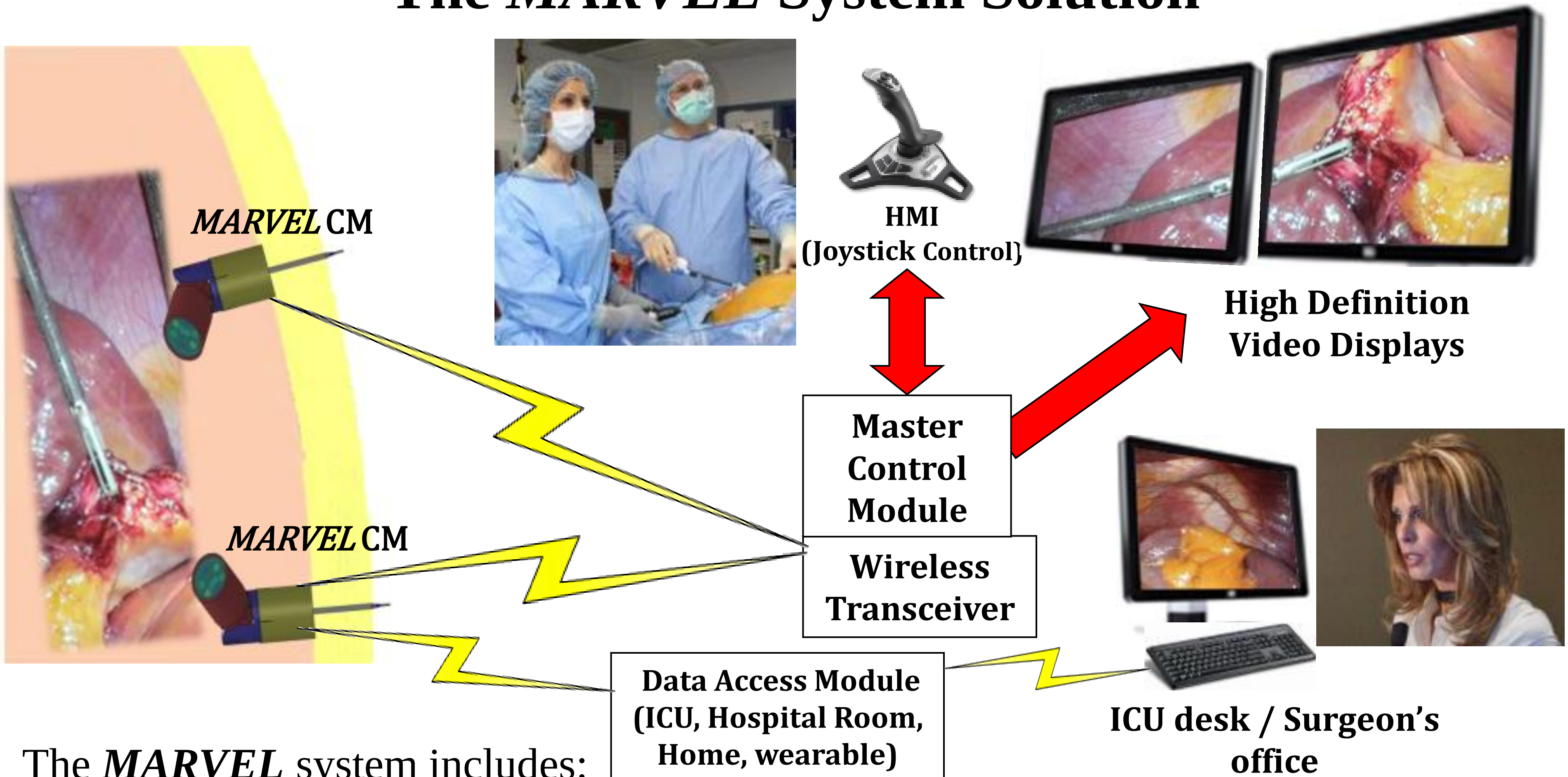


Current laparoscopic technology



*In vivo* wireless networking

# The *MARVEL* System Solution




The ***MARVEL*** system includes:

(1) multiple CMs with wirelessly controlled pan/tilt enabling a full hemisphere field of view inside the abdominal cavity, wirelessly adjustable focus, and a multi-wavelength illumination control system

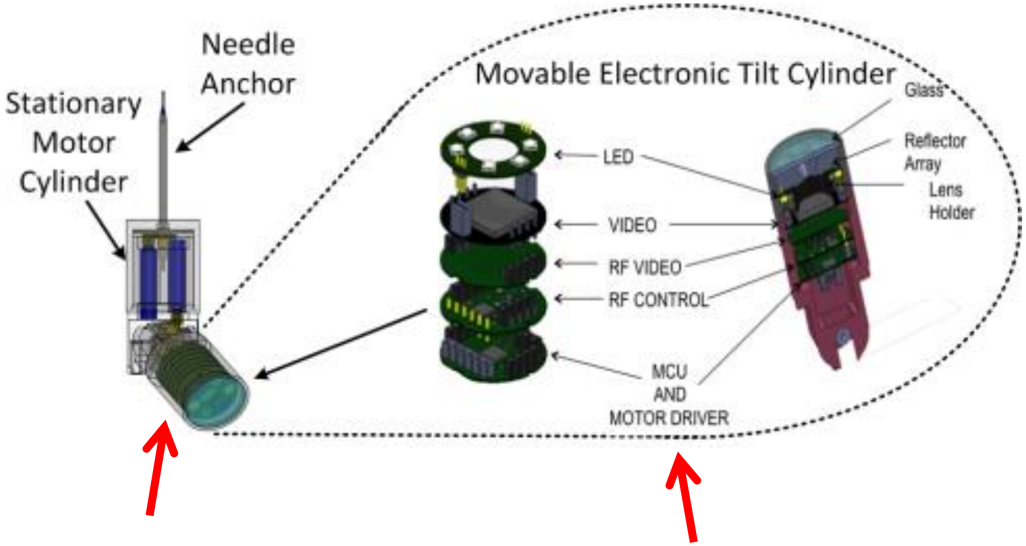
(2) a Master Control Module (MCM) that provides a near-zero latency video wireless communications, independent wireless control for multiple MARVEL CMs, digital zoom

(3) a wireless human-machine interface (HMI) that controls the CM functions.

***MARVEL* = *M*iniature *A*nchored *Robotic V*ideoscope for *E*xpedited *L*aparoscopy**

# Experimental Progress to Date

- Wirelessly Controlled and Communicating *In Vivo* Networked Devices: MARVEL
  - The first such device that we have implemented is a ***M***iniature ***A***nchored ***Robotic V***ideoscope for ***E***xpedited ***L***aparoscopy (***MARVEL***), which is a wirelessly controlled and communicating high-definition video system that will provide the spatial and visual advantages of open-cavity surgeries.
  - To achieve the above objectives several research challenges arise such as (1) reliable, high-throughput and low-latency intra-body wireless communications and networking; (2) electronic and mechanical miniaturization of complex systems; (3) autofocus algorithms for distance compensation; and (4) localization and mapping of the intra-body camera unit and surrounding organs and tissues;
  - Below are several figures that illustrate the MARVEL design and experimental results.
  - Four vivarium experiments with porcine subjects have taught us a lot.




MARVEL CAD model and exploded circuit board stack

MARVEL units in a porcine abdominal cavity

Image of internal organs captured by MARVEL unit

# Patent: Minimally Invasive Networked Surgical System and Method

(12) **United States Patent**
**Gitlin et al.**

(10) **Patent No.: US 8,358,981 B1**
(45) **Date of Patent: Jan. 22, 2013**

(54) **MINIMALLY INVASIVE NETWORKED SURGICAL SYSTEM AND METHOD**

(75) Inventors: **Richard Gitlin**, Tampa, FL (US); **Craig Lusk**, Lutz, FL (US); **Shekhar Bhansali**, Tampa, FL (US); **Alexander Rosemurgy**, Tampa, FL (US)

(73) Assignee: **University of South Florida**, Tampa, FL (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 288 days.

(21) Appl. No.: **12/608,580**

(22) Filed: **Oct. 29, 2009**

**Related U.S. Application Data**

(60) Provisional application No. 61/109,368, filed on Oct. 29, 2008.

(51) **Int. Cl.**
*H04B 7/00* (2006.01)
*H04M 1/00* (2006.01)

(52) **U.S. Cl.** .................................. **455/66.1**; 455/575.6

(58) **Field of Classification Search** ................ 455/66.1, 455/67.11, 575.6, 569.1, 100, 41.1, 41.2, 455/41.3; 607/60, 3

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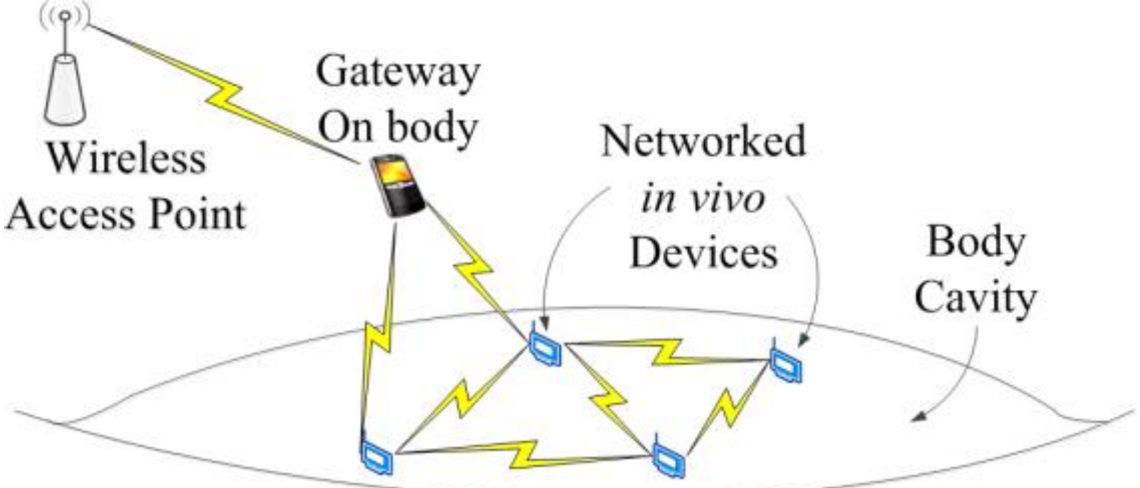
*Primary Examiner* — Eugene Yun
(74) *Attorney, Agent, or Firm* — Nilay J. Choksi; Courtney M. Dunn; Smith & Hopen, P.A.

(57) **ABSTRACT**

A system for performing non-invasive networked medical procedures including a number of in vivo medical devices, a communication path between at least two of the devices, an ex vivo control unit to control the behavior of the devices, and a wireless communication path between the control unit and at least one of the devices. An associated method for performing non-invasive networked medical procedures is also provided.

# *MARVEL* Advantages and Benefits

- Decreases the surgical-tool bottleneck experienced by surgeons in LESS procedures
- Eliminates power, video, and light source cabling issues in current laparoscopes
- Increase the dexterity and fine motion options for the surgeon
- Increases the imaging angle and the usable workspace inside the abdominal cavity.
- Next steps: Wireless high definition, reduced physical dimensions, inter-module communications, and 3D Imaging with Multiple CMs
- The ***MARVEL*** Camera Module is the first device in a family of wirelessly networked *in vivo* biosensors and actuators that are capable of wirelessly communicating to one or more external nodes that will enable the next paradigm shift in MIS surgery.




# Summary

- Wireless networking will enhance the capabilities and performance of implanted medical devices.
- Wireless Body Area Networks (WBANs) are receiving considerable attention because they can provide ubiquitous real-time monitoring, often without restricting the person's regular activities.
- WBANs must satisfy some stringent technical requirements, especially, when the network is monitoring life-saving related signals such as indicators of a heart attack.
- The IEEE 802.15.6 standard provides the guidelines to interconnect devices in a WBAN
- IEEE 802.15.6 standard mainly focused to on body applications or low data rate (narrowband) *in vivo* applications.
- New *in vivo* applications (e.g. video) require high data rates.
- The above limitations present challenges and new opportunities for *in vivo* communications and networking.

*Innovative Wireless Implantable Medical Devices*

# Thank you!

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