 Challenges in Channel Measurement and Modeling for RF Localization Inside the Human Body

Kaveh Pahlavan, Worcester Polytechnic Institute, USA  
Yunxing Ye, Worcester Polytechnic Institute, USA  
Ruijun Fu, Worcester Polytechnic Institute, USA  
Umair Khan, Worcester Polytechnic Institute, USA

ABSTRACT

In this invited paper, the authors introduce an overview of the fundamentals of radio frequency (RF) channel measurement and modeling techniques needed for localization inside the human body. To address these fundamentals, the authors use capsule endoscopy as an example application. The authors first provide the results of the Cramer Rao Lower Bound (CRLB) for received signal strength (RSS) based endoscopy capsule localization, inside the human body, using existing path-loss models for radio propagation. Then challenges demanding further research are highlighted for attaining more precise localization using the time-of-arrival (TOA) based ranging techniques.

Keywords: Body Area Networks, Capsule Endoscopy, Cooperative Localization, Implant Localization, Radio Propagation, RSS-Based Localization, TOA-Based Localization, Wireless Health

INTRODUCTION

In the past decade miniaturization and cost reduction of semiconductor devices has allowed the design of small low cost computing and wireless communication devices used as sensors in a variety of popular wireless networking applications and this trend is expected to continue in the next few decades. It is expected that a myriad of new applications designed around sensor technologies will emerge to stimulate a huge industrial growth. One of the most promising areas of industrial growth associated with this industry is the body sensor networks that are also referred to as the body area networks (BAN) (Yang & Yacoub, 2006). These networks are expected to connect wearable and implantable sensory nodes together and with the Internet to support numerous applications ranging from traditional externally...
mounted temperature meters or implanted pace
makers up to emerging blood pressure sensors,
eye pressure sensors for glaucoma and smart
pills for health monitoring and precision drug
delivery.

To support the growth of this industry,
recently the Federal Communication Com-
mision (FCC) has allocated specific bands
for Medical Radio Communication Services
(MedRadio) (FCC, 2008) and the IEEE 802.15.6
is formed to address the standardization aspects
of these emerging technologies. The IEEE
802.15.6 models the characteristics of the radio
propagation inside and around the human body
and defines wireless networking technologies
for wearable and implanted sensor networks
(Aoyagi, 2006). The standards recommend
that the transmission power should be around
25 μW to keep the EM emissions at a healthy
level (FCC, 2008).

Certainly for all BAN applications power
efficient modulation and medium access control
methods are needed in principle and a number
of researchers are working on that topic (Kim,
2008). The important and the fundamental is-
issue presented in this paper is the localization
of objects inside the human body to assist the
discovery of methods for navigating emerging
micro-robots in wireless medical applications
such as capsule endoscopy. This is a new field
of research that is gaining some momentum in
the recent years (Aoyagi, 2009; NIST, 2011).

Understanding the nature of signal propa-
gation is the key to the design of precise local-
ization for any wireless network (Pahlavan,
2005). Therefore, the first step in research is
to start a measurement and modeling program
to understand the nature of signal transmission
inside the human body. Today, the existing
literature in measurement and modeling for
understanding the propagation in and around
the human body is fragmented and it does not pay
attention to localization inside the human body
(Aoyagi, 2009). The IEEE 802.5.6 is working
on creating a comprehensive channel model for
different scenarios and frequency bands used for
communication applications (Hagedorn, 2008).
There is a need for research in understanding
the behavior of RF signal propagation inside
the human body for localization applications.

Localization techniques fundamentally
work either based on the received signal strength
(RSS) or the time of flight of the signal from the
target device to the reference points (Pahlavan,
2005; Alavi, 2006; Ghaboosi, 2011). The channel
model for localization and communication for
the RSS-based systems are the same; how-
ever, for more precise TOA-based systems we
need channel models that may be different from
those traditionally designed for communication
applications (Alavi, 2006; Pahlavan, 1998).

From an innovative research point of
view, measurement and modeling of radio
propagation inside and around the human body
for RF localization applications offers unique
challenges making this area very appealing for
fundamental research. These challenges are
raised by several specifics of the human body
medium that are in principals different from the
traditional indoor radio propagation challenges.
Inside the human body is a non-homogenous
liquid like environment for radio propagation
and this poses a challenge for precise localiza-
tion techniques using the time of flight of the
signal between a transmitter and a receiver to
estimate the distance. To localize a device inside
the human body the infrastructure of the refer-
ence points are naturally mounted as sensors
on the human body that constantly moves even
when we are standing still.

To measure the characteristics of multipath
arrivals and their effects on localization using
time of arrival of the paths, we usually refer
to statistical empirical modeling based on
ultra-wideband measurements of the channel
characteristics by placing antennas in different
location of the application environment (Alavi,
2006). Placing antennas inside the human body
for massive measurements is not practical and
we need to resort to computational techniques
or using Phantoms (Sayrafian-Pour, 2009) or
dead body of animals for empirical measure-
ments (Alomainy, 2009). The most popular
computational methods for simulation of the
radio propagations inside the human body are
the Finite Element Method (FEM) (Askarzadeh,
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