UNIVERSITAT DE BARCELONA

Wireless Biodevices and Systems

On-body

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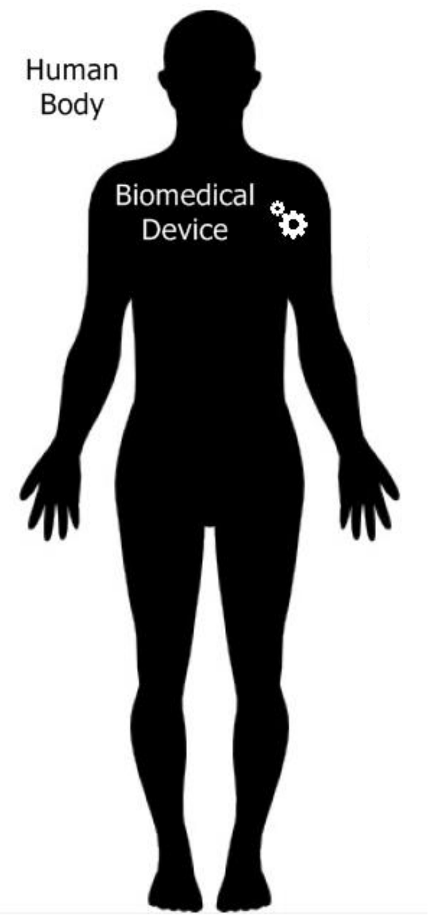
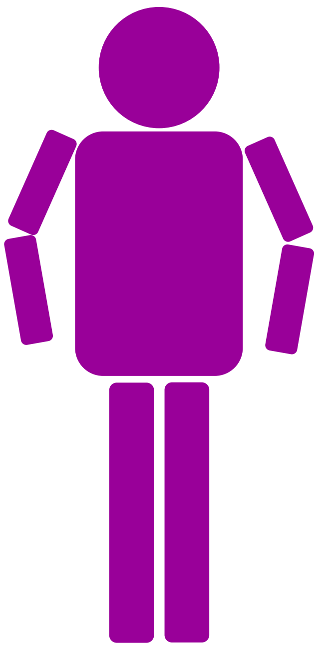


Scenarios

Channel



On-body

Most of the channel is on the surface of the body and both antennas will be on the body. This is called the on-body domain.

Introduction

Wireless radio connectivity is an obvious option for connecting body-worn devices.

Several standards for wireless connections between small, closely spaced devices have been developed, including Bluetooth, Zigbee. These types of connection can provide high levels of flexibility and comfort to the user, and therefore have received a lot of attention.

There are three primary criteria for wireless modules for on-body communications:

- They must support the high data rates expected in the future.
- They must be small and lightweight.

Both of these suggest the use of high frequencies.

- They must consume minimum power, which implies highly efficient links. In terms of antennas and propagation, efficient design requires a good understanding of the properties of the propagation channel involved and the development of optimized antennas.

Introduction

Body area networks can be used to interconnect the various components in a wearable computer system. This system maybe supporting a body sensor network for health monitoring or drug release, etc.

While these systems may use wire for their interconnection, there is a trend towards wireless interconnection- Example: Bluetooth headsets.

	Channel variations
Conventional communications (Ex. Mobile)	Interference between multiple rays scattered from the local environment: walls, buildings, furniture, etc.
On-body communications	Changes in the geometry of the body

Introduction

	Channel variations
On-body communications	Changes in the geometry of the body

Situation	Type of movement
Standing/sitting	Small
Normal activities	Significant
Playing sport	Extreme

Characterization of radio wave propagation needs to account

Variable positioning of terminals

Changes in the geometry of local environment

IEEE P802.15 Wireless Personal Area Networks
Project IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Channel Model for Body Area Network (BAN)

This document summarizes the activities and recommendations of the channel modeling subgroup of IEEE802.15.6 (Body Area Network). The Task Group TG6 is intended to develop Body Area Network for medical and non-medical devices that could be placed inside or on the surface of human body.

The channel model is needed to evaluate the performance of different physical layer proposals. They are not intended to provide information of absolute performance in different environments or body postures.

Since the subgroup was formed, a large number of documents has been submitted to the channel modeling subgroup or presented and discussed at IEEE802.15.6 meetings and teleconference calls. They can be found on the:
https://mentor.ieee.org/802.15/documents

Channel Characterization

The choice of frequency is not straightforward.

There is a significant increase in the use of the Bluetooth or WLAN modules.

Description	Frequency Band
Implant	402-405
On-Body	13.5 MHz
On-Body	5-50 MHz (HBC)
On-Body	400 MHz
On-Body	600 MHz
On-Body	900 MHz
On-Body	2.4 GHz
On-Body	3.1-10.6 GHz

Table 1: List of frequency band

An important step in the development of a wireless body area network is the characterization of the electromagnetic wave propagation from devices that are close to the human body.
The complexity of the human tissues structure and body shape make it difficult to drive a simple path loss model for BAN. As the antennas for BAN applications are placed on the body, the BAN channel model needs to take into account the influence of the body on the radio propagation.

Channel Characterization

IEEE defines 3 types of nodes as follows:

1) Implant node: A node that is placed inside the human body. This could be immediately below the skin to further deeper inside the body tissue.

2) Body Surface node: A node that is placed on the surface of the human skin or at most 2 centimeters away.

3) External node: A node that is not in contact with human skin (between a few centimeters and up to 5 meters away from the body).

For body surface communication, the distance between the transmitting and receiving nodes shall consider the distance around the body if transmitter and receiver are not placed in the same side rather than straight line through the body.

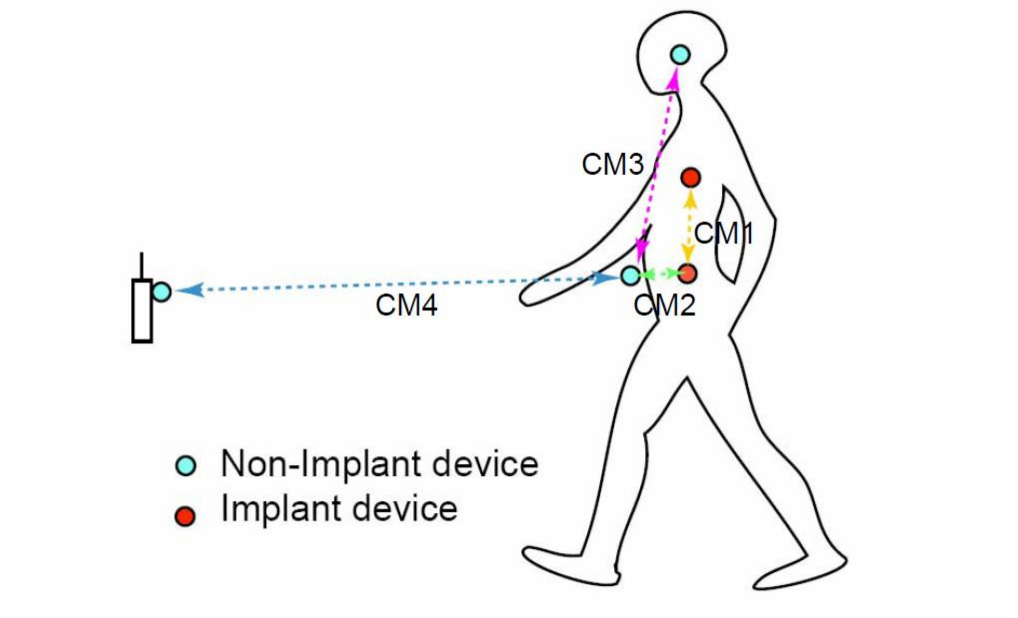
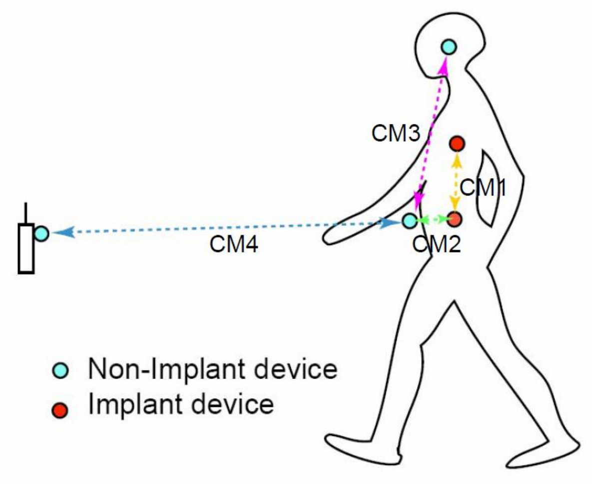


Fig. 1: Possible communication links for Body Area Networking

Channel Characterization

Scenarios

Scenario	Description	Frequency Band	Channel Model
S1	Implant to Implant	402-405 MHz	CM1
S2	Implant to Body Surface	402-405 MHz	CM2
S3	Implant to External	402-405 MHz	CM2
S4	Body Surface to Body Surface (LOS)	13.5, 50, 400, 600, 900 MHz 2.4, 3.1-10.6 GHZ	CM3
S5	Body Surface to Body Surface (NLOS)	13.5, 50, 400, 600, 900 MHz 2.4, 3.1-10.6 GHZ	CM3
S6	Body Surface to External (LOS)	900 MHz 2.4, 3.1-10.6 GHZ	CM4
S7	Body Surface to External (NLOS)	900 MHz 2.4, 3.1-10.6 GHZ	CM4



Possible communication links for Body Area Networking

Model Types

In all cases, two types of model may be generated:

A theoretical or mathematical model

A theoretical model may be traceable back to the fundamental principles of electromagnetic propagation and will permit precise modeling of a specific situation at radio link level.

It will require a detailed description of the propagation environment and is therefore probably not suitable for modeling of macro environments.

An empirical model

An empirical model may be traceable to an agreed set of propagation measurements and is intended to provide a convenient basis for statistical modeling of the channel.

Compared to the theoretical model, the empirical model will use a greatly simplified description of the environment and, although statistically accurate at network level, will not be precise at link level.

Appropriate efforts could be made to ensure that the two sets of models are consistent with each other.

Fading

In the body area network communications, propagation paths can experience fading due to different reasons, such as energy absorption, reflection, diffraction, shadowing by body, and body posture. The other possible reason for fading is multipath due to the environment around the body. Fading can be categorized into two categories; small scale and large scale fading.

Small Scale Fading

Small scale fading refers to the rapid changes of the amplitude and phase of the received signal within a small local area due to small changes in location of the on-body device or body positions, in a given short period of time.

The small scale fading can be further divided into flat fading and frequency selective fading.

Large Scale Fading

Large scale fading refers to the fading due to motion over large areas; this is referring to the distance between antenna positions on the body and external node (home, office, or hospital).

Path Loss

Unlike traditional wireless communications, the path loss for body area network system (on body applications), is both distance and frequency dependent. The frequency dependence of body tissues shall be considered.

The path loss model in dB between the transmitting and the receiving antennas as a function of the distance d is described by:

$$PL(d) = PL_0 + 10n\log_{10}\left(\frac{d}{d_0}\right)$$

where PL_0 is the path loss at a reference distance d_0, and **n** is the path-loss exponent.

The path loss near the antenna depends on the separation between the antenna and the body due to antenna mismatch. This mismatch indicates that a body-aware antenna design could improve system performance.

Channel Characterization

Shadowing

Due to the variation in the environment surrounding of body or even movement of the body parts, path loss will be different from the mean value for a given distance. This phenomenon is called shadowing, and it reflects the path loss variation around the mean.

When considering shadowing, the total path loss PL can be expressed by:

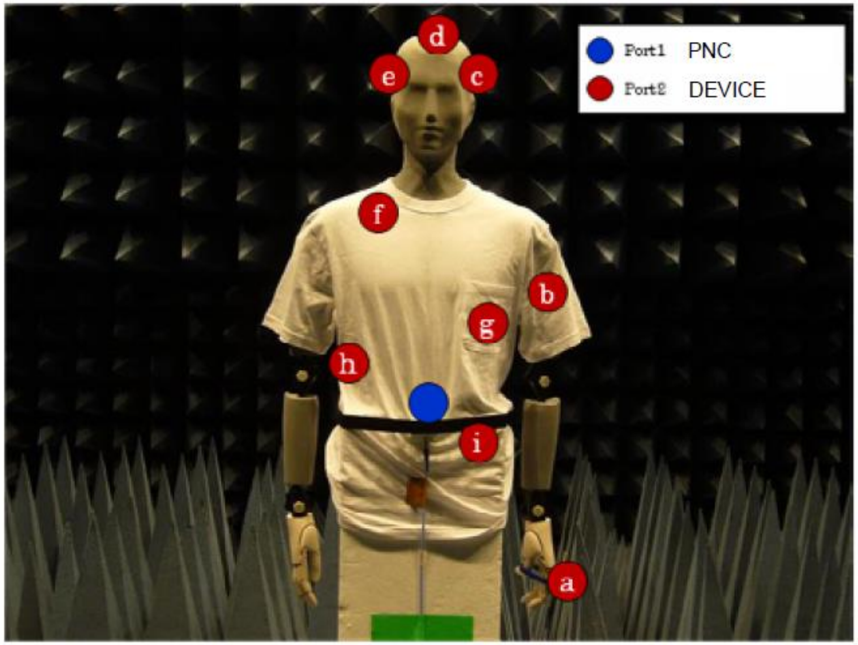
$$PL = PL(d) + S$$

$$PL(d) = PL_0 + 10n\log_{10}\left(\frac{d}{d_0}\right)$$

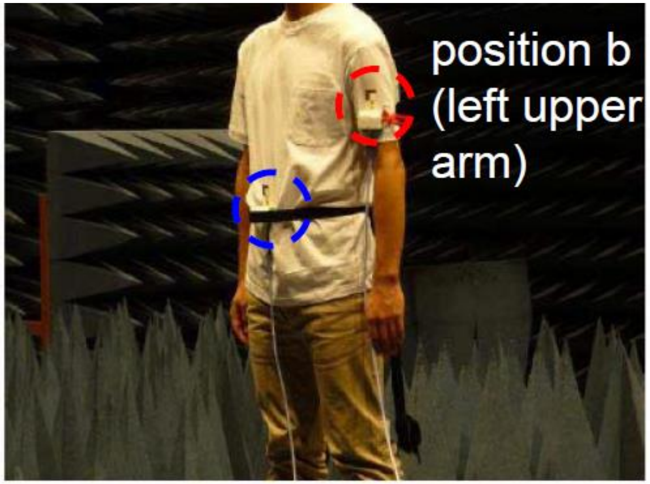
S represents the shadowing component.

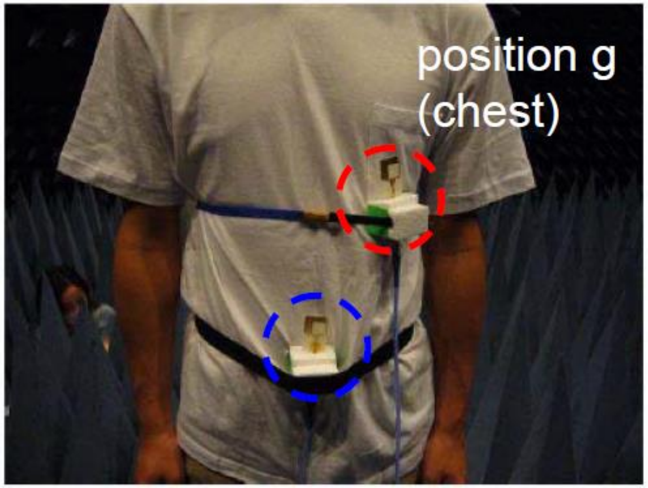
Measurement Setup

- Measurement positions



a	left wrist	f	shoulder
b	left upper arm	g	chest
c	left ear	h	right rib
d	head	i	left waist
e	right ear		





Measurement Environments

1. Hospital room (Size: 7.0 m x 9.0 m x 2.5 m)

2. Anechoic chamber
   – without reflections from the floor

Channel Characterization

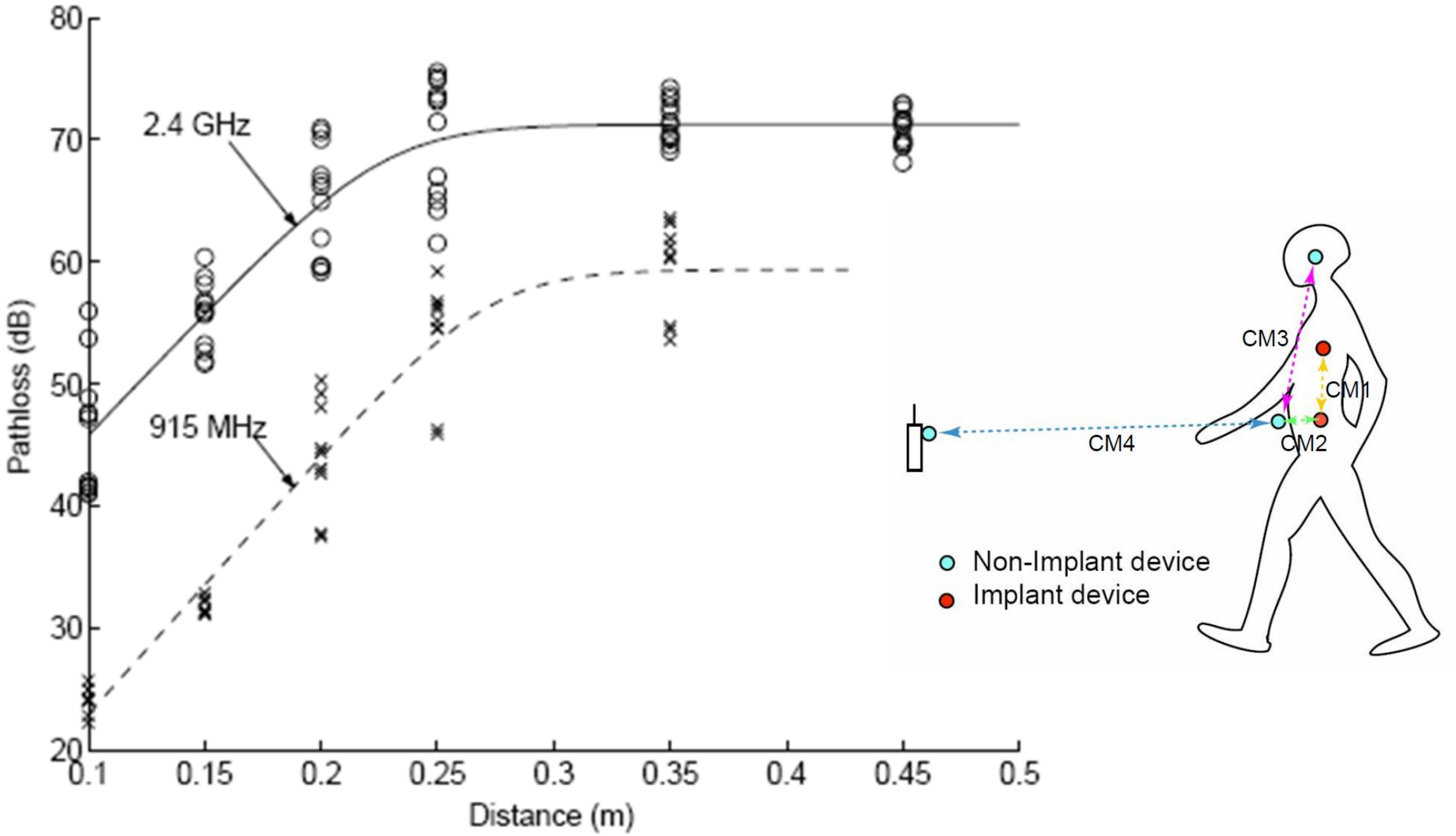


Figure 2: Measured pathloss around the body at 915 MHz and 2.4 GHz for CM3 with 5 mm body-antenna separation.

Models

8.2.6. Body surface to body surface CM3 (Scenario S4 & S5) for 2.4 GHz

8.2.6. A

The following path loss model is based on measurements that cover frequencies of 2.4-2.5GHz. Details of the measurement set up, derivation and data analysis can be found in [27]. The table below summarizes the model and corresponding parameters.

	Hospital Room	Anechoic Chamber
Path loss model	$PL(d)[\text{dB}] = a \cdot \log_{10}(d) + b + N$	
a	6.6	29.3
b	36.1	-16.8
σ_N	3.80	6.89

- a and b : Coefficients of linear fitting
- d : Tx-Rx distance in mm.
- N : Normally distributed variable with standard deviation σ_N

8.2.6. B

The following model is based on measurements at frequency of 2.45 GHz. Details of the measurement set up, derivation and data analysis can be found in [28]. The path loss follows an exponential decay around the perimeter of the body. It flattens out for large distance due to the contribution of multipath components from indoor environment. The table below summarizes the model and corresponding parameters.

Path loss model	$PL(d)[dB] = -10\log_{10}\left(P_0\, e^{-m_0 d} + P_1\right) + \sigma_P n_P$
P_0 [dB]	-25.8
m_0 [dB/cm]	2.0
P_1 [dB]	-71.3
σ_p [dB]	3.6

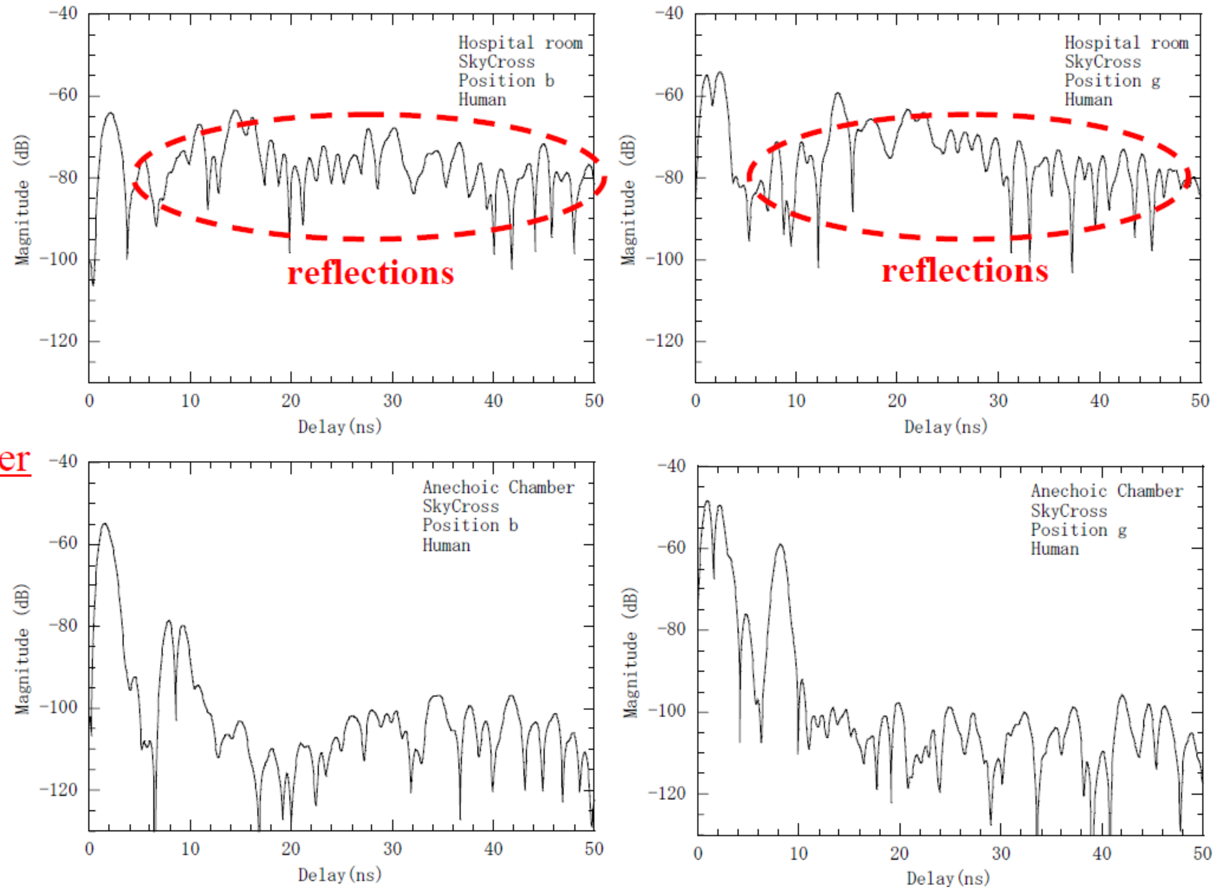
- P_0 : The average loss close to the antenna
- M_0 : The average decay rate in dB/cm for the surface wave traveling around the perimeter of the body

Results

- Time domain waveforms (UWB band)

Hospital room

Anechoic chamber

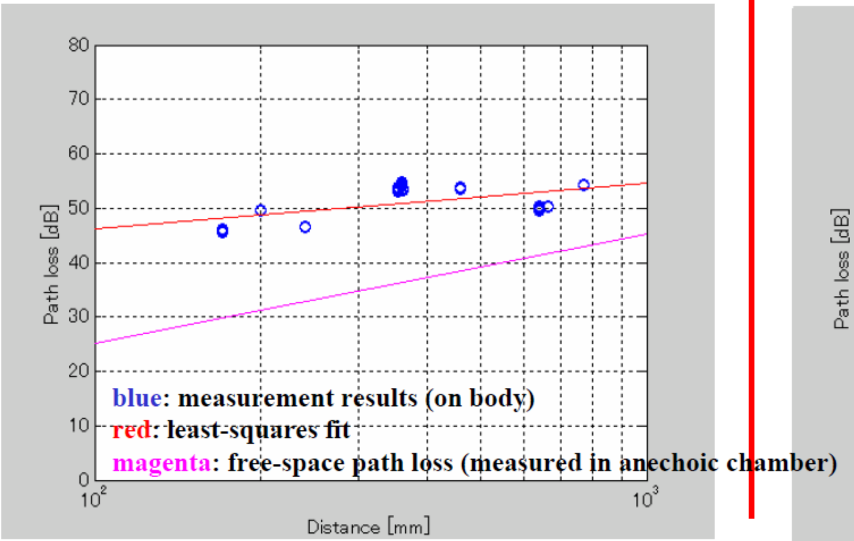


Path loss model **2.4 GHz**

$$PL(d)[\mathrm{dB}] = a \cdot \log_{10}(d) + b + c + N$$

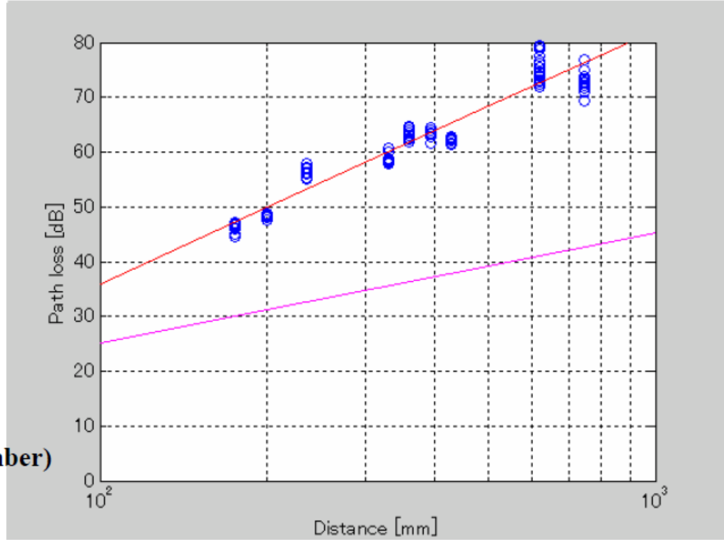
Hospital room

Parameters	value
a	8.32
b	37.2
c	-7.5
σ_N	2.5



Anechoic chamber

Parameters	value
a	46.4
b	-49.4
c	-7.5
σ_N	2.7



Model Types

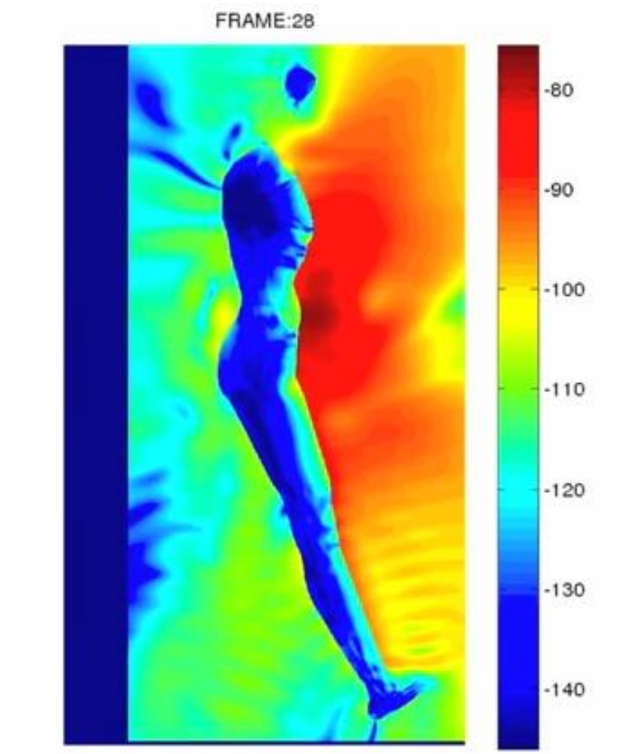
In all cases, two types of model may be generated:

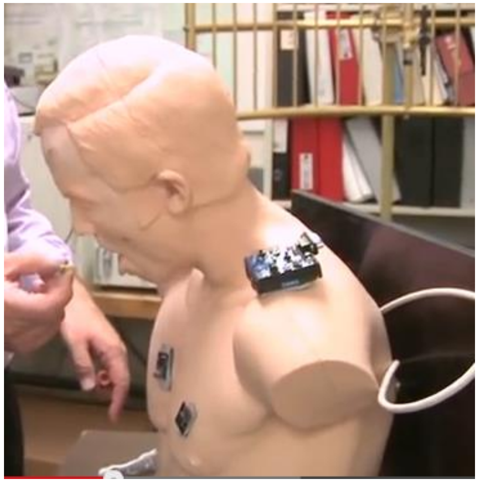
An empirical model

http://www.youtube.com/watch?v=Ijr822gxiZI

A theoretical or mathematical model

http://www.youtube.com/watch?v=vKliA-MJdP0





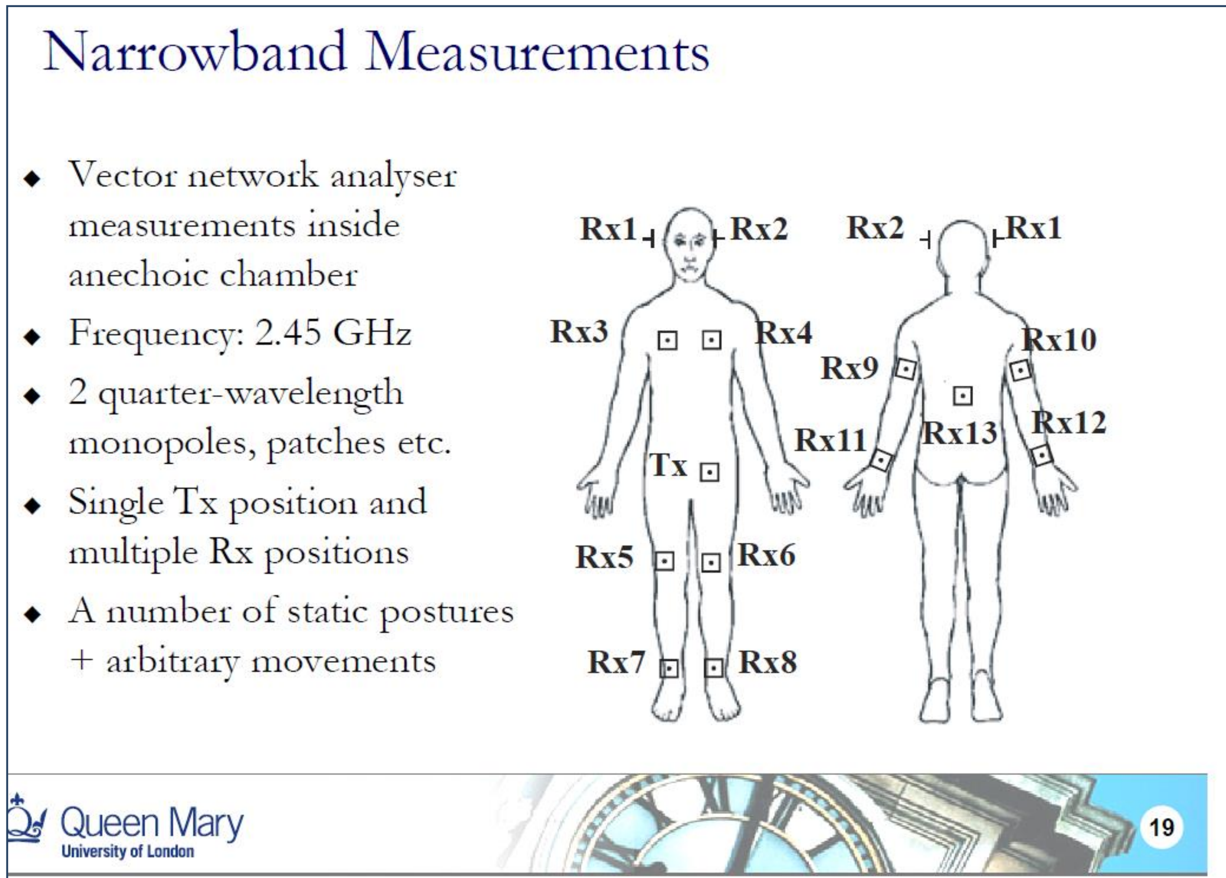
Examples

There are potentially many paths in an on-body network.

Study from the University of Birmingham and Queen Mary and the University of London.

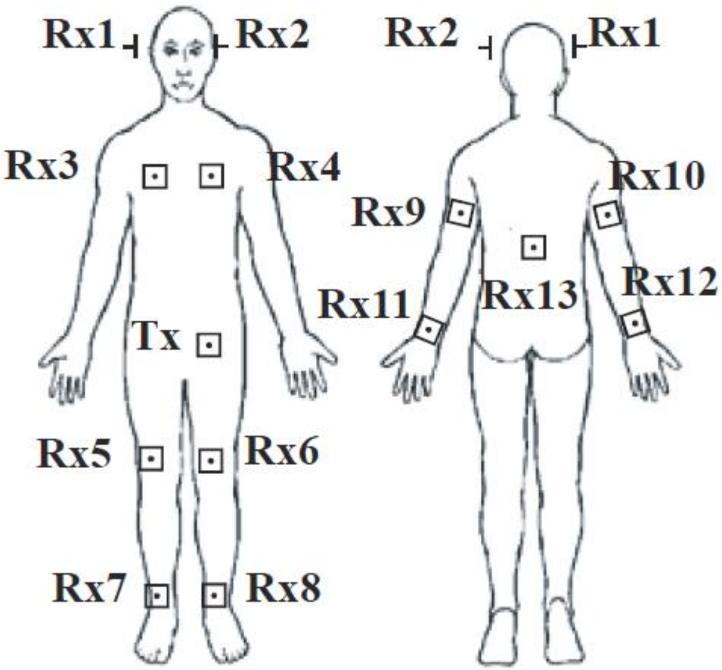
On-Body channel measurement and modeling

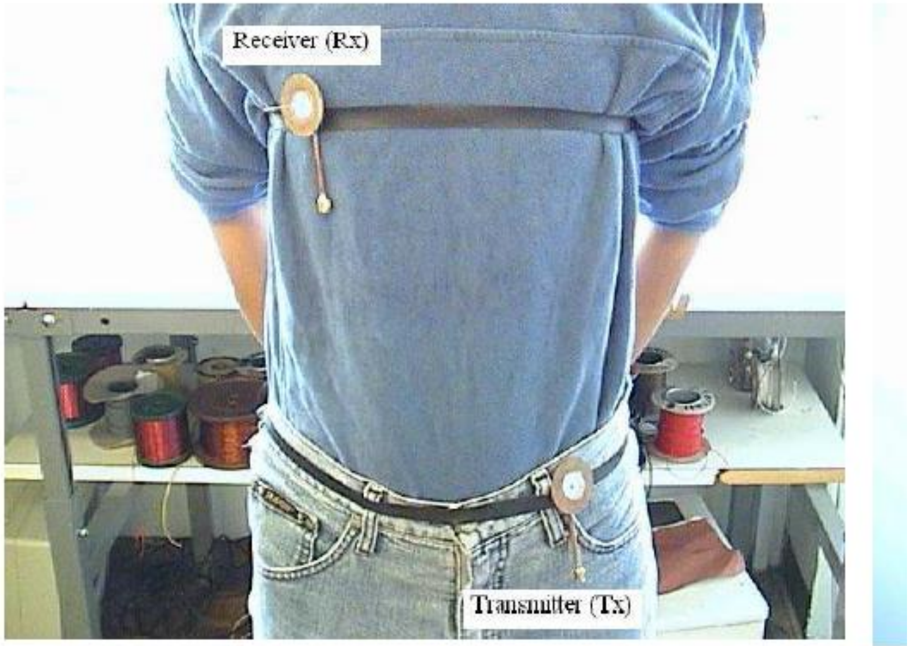
The propagation path loss was measured using a vector analyzer inside and anechoic chamber



Antennas and Propagation for Body-centric Wireless Communications. P.S. Hall and Y. Hao.

Measurement Setup





Queen Mary
University of London

Examples

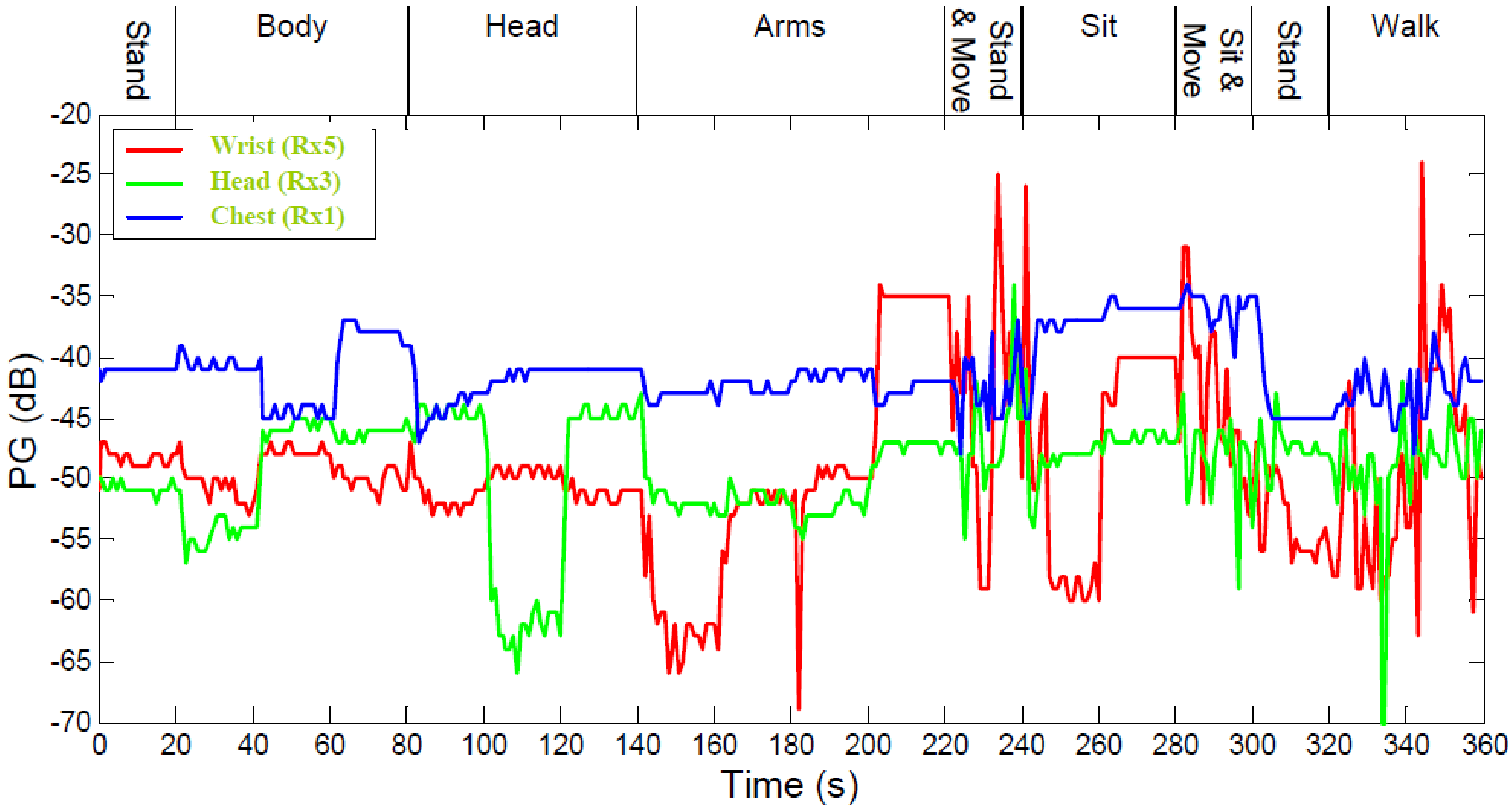
Body Positions

N	Start Time	Category	Position	N	Start Time	Category	Position
1	0	Standing	Upright still	10	180	Arms Movement	Forward
2	20	Trunk Movement	Left turn	11	200		Forearms forward
3	40		Right turn	12	220	Standing & Moving	
4	60		Leaning forward	13	240	Sitting	Arms down the sides
5	80	Head Movement	Leaning forward	14	260		Hands in the lap
6	100		Left turn	15	280	Sitting & Moving	
7	120		Right turn	16	300	Standing	Upright still
8	140	Arms Movement	Sideways	17	320	Walking	Arms close to body
9	160		Upwards	18	340		

Queen Mary
University of London

Examples

Chamber Measurements Results



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Chamber and Room Measurements

Table 3.2 Mean Path Gain and Path Gain Variability (Range)

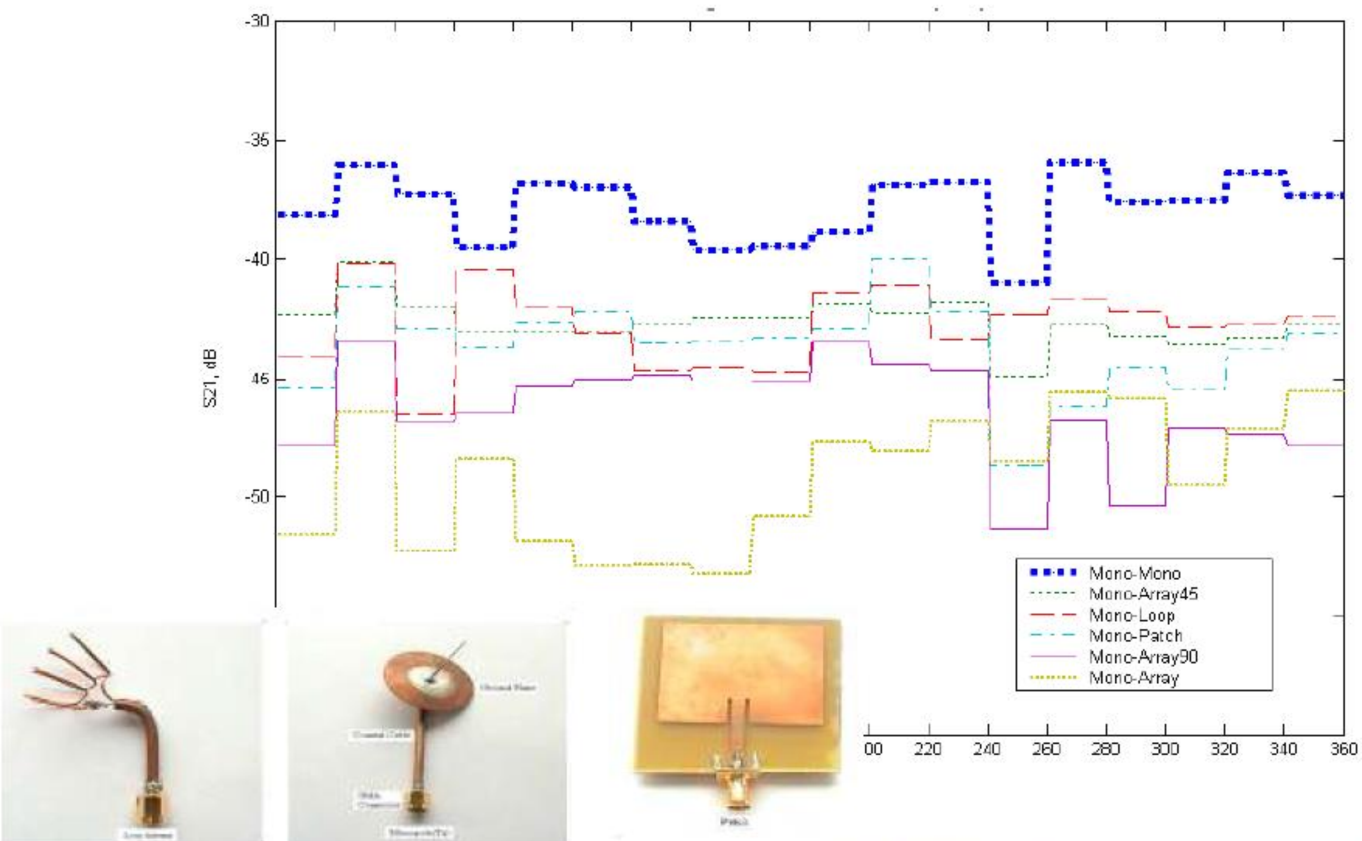
Rx Position		*Path Gain (dB)*			
		Anechoic Chamber		*Laboratory*	
		Mean	*Range*	*Mean*	*Range*
Trunk	Rx3(chest)	−41	14	−44	24
	Rx14(back)	−60	20	−57.5	25
Head	Rx2(left side)	−52	36	−40.5	29
	Rx1(right side)	−53.5	33	−41	38
Wrist	Rx11(left)	−46.5	45	−51.5	37
	Rx12(right)	−55.5	29	−57	26

For posture shown in Figure 3.4 and paths shown in Figure 3.1, Tx on belt, left side; measured with quarter-wave monopoles; frequency = 2.45 GHz.

Antennas and Propagation for Body-centric Wireless Communications. P.S. Hall and Y. Hao.

Examples

Different Antenna Types



Antennas and Propagation for Body-centric Wireless Communications. P.S. Hall and Y. Hao.

Examples

Communication systems using the human body as a transmission channel

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