Communicating On and Around the Human Body

Results and Challenges in Body Area Networks

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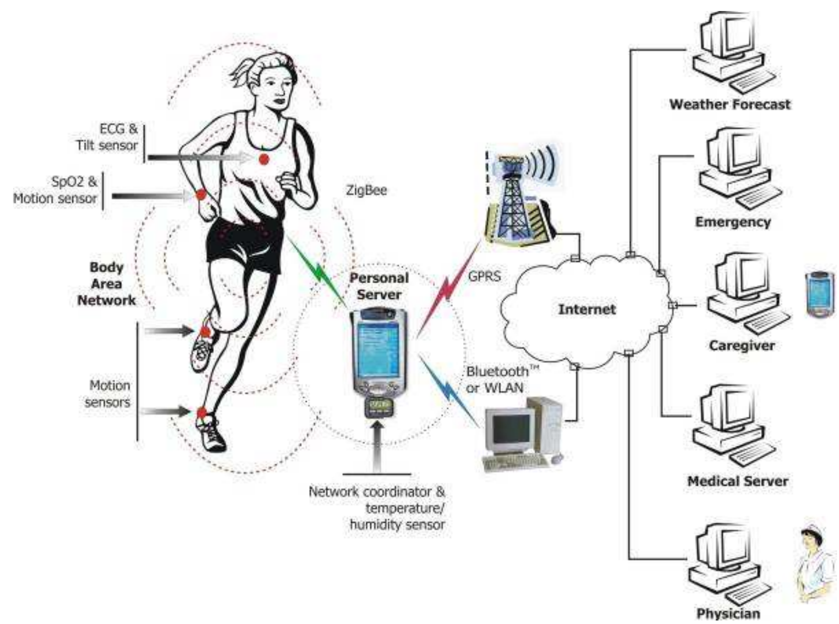
  - Working Group E on Body Communications

Body Area Networks ?

- **One definition** (… among many others)
  - Set of mobile and compact intercommunicating sensors either wearable or implanted into the human body, which monitor (vital) body parameters and movements

- **Many applications**
  - Medical devices/sensors
  - Remote health monitoring
  - Entertainment
  - Body to body communications
  - …



Outline

- Review of BAN requirements and challenges
- Overview of existing or future standards
- Recent results on channel modeling
- Communication theory challenges for BANs
- Conclusions and discussion

BAN General Requirements

- **Interoperability**
  - Seamless data transfer across standards
- **Low complexity and small devices**
- **System and device-level security**
  - Secure and accurate transmission
  - Integrity (make sure that the patient's data is only derived from the dedicated BAN system)
- **Privacy**
- **Data consistency**
  - Cross-check across data sources

BAN Technological Requirements

- Requirements depend on the application [Gorce 2009]

	Body monitoring	Medical warning	Multimedia flows
Max numb of sensors	16	10	4
Max data rate per node	2kbps	10bps	6 Mbps
Peak Data rate[1]		200kbps -1Mbps	20 Mbps
Duty cycle	up to 100%	0,01%	100%
Tolerated Latency	5ms with feedback[2] 125ms without	2 s	20 ms
PER max	0.1%	--	10e-2
Multi-hop relays	If required	No	No
Mobility	Running, human motion	Everyday life movements	
Network topologies	Star, Mesh	Star	P2P, star

Challenges

- **Is a Body Area WSN different from any other WSN ?**

- The main challenge is the **wireless channel**
  - Path loss is very (very ?) large
  - Propagation takes place via two mechanisms
    - On-body wave is quasi-deterministic
    - Off-body wave is related to the environment
- **A few additional challenges**
  - High data rates for some applications (yet, low power, etc.)
  - Security and privacy issues

Standards for BAN

- IEEE 802.15 family
  - Bluetooth LE
    - Intermediate data rates, 40 channels
  - 802.15.3
    - Narrowband, high data rate, but only 4 channels @ 2.45 GHz
  - 802.15.4 (ZigBee)
    - Narrowband, low data rate and 16 channels
  - 802.15.4a (UWB)
    - Direct Sequence UWB, low rate (but can be increased)
  - 802.15.6
    - Dedicated to BAN, but still not defined (TG6)
    - Both narrowband and UWB modes ?

Standard Channel Model

- **IEEE 802.15 TG6 channel model** [IEEE 802.15 2009]
  - Generic channel model (including path-loss, fading and delay dispersion) for different canonical scenarios
  - Some remarks
    - Model is independent of antenna type !
    - Channel dynamics not well captured

Recent Results on Channel Modeling

- On-body vs. off body
- On-body path loss
- Fading and shadowing
- Channel correlation for on-body cooperative networks
- Multipath in UWB systems

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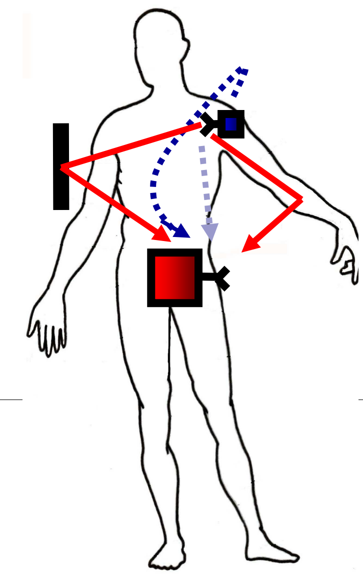
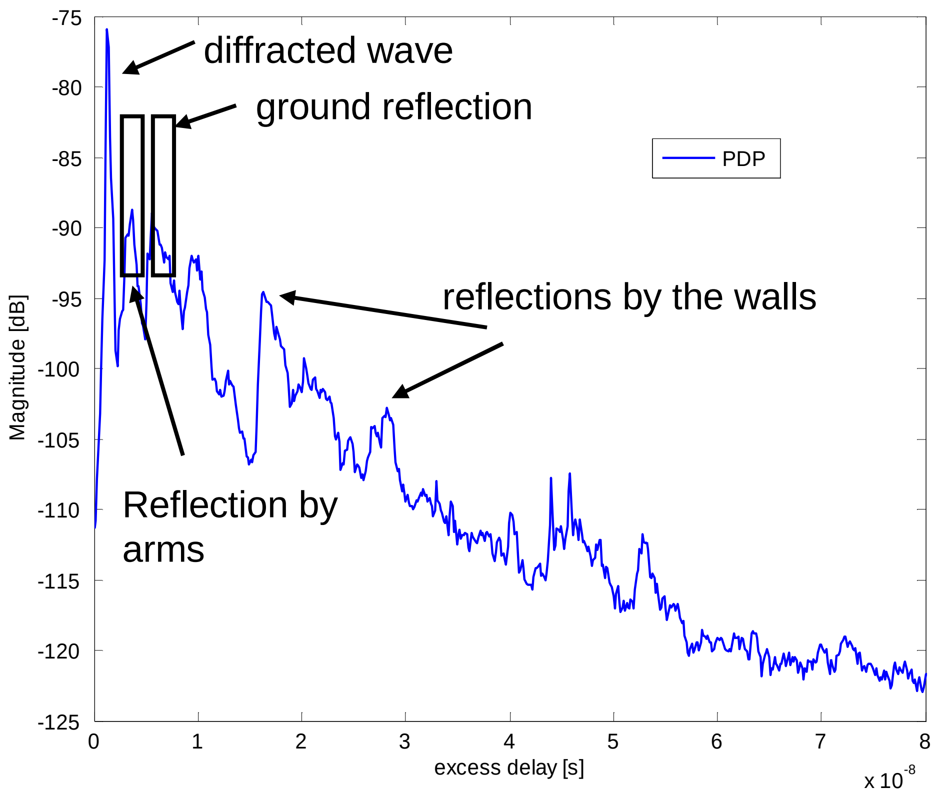
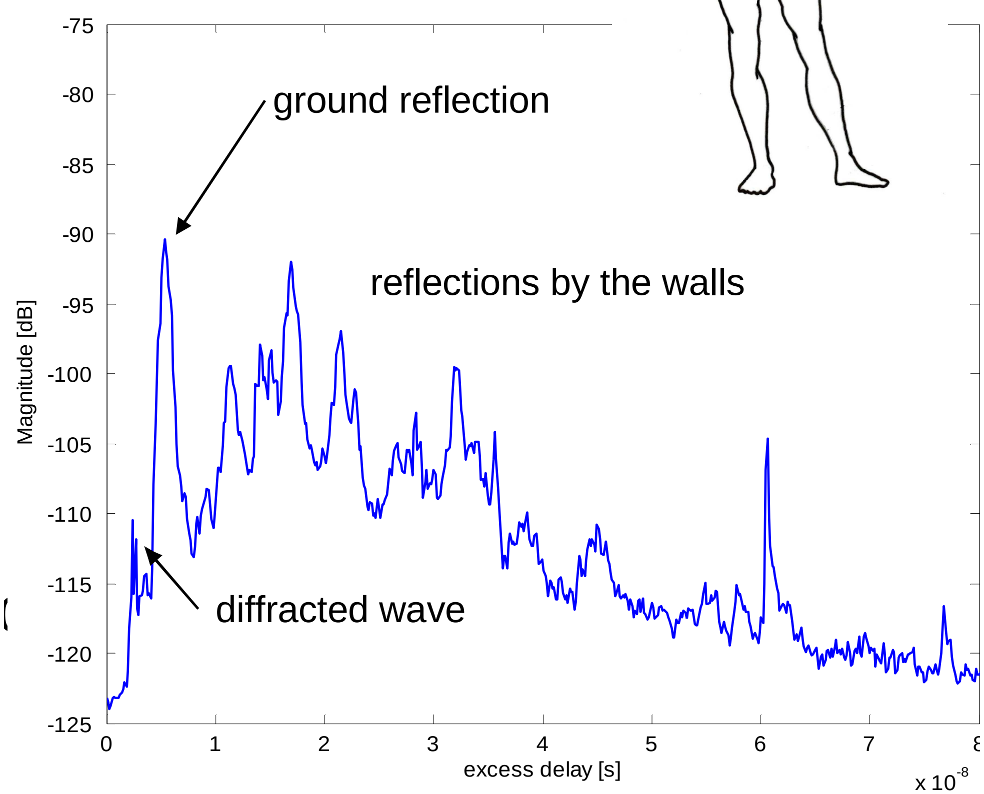
On-Body – Off-Body – In-Body

- On-body vs. off body





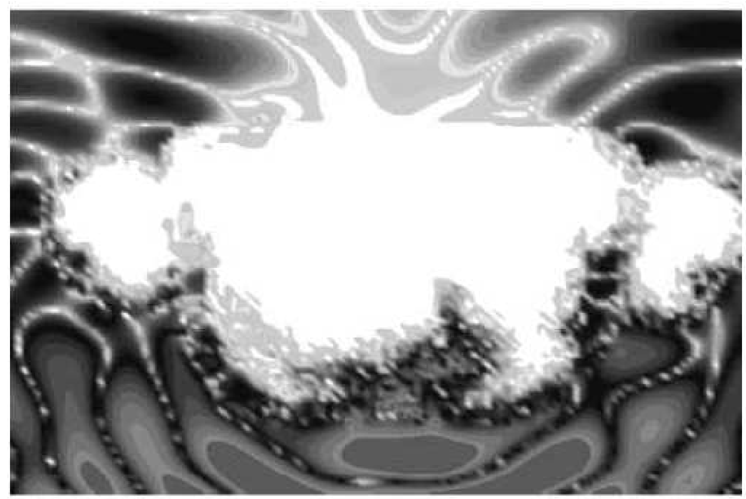


On-Body – Off-Body – In-Body

- On-body vs. off body

- In-body ?
  - ~ 3 dB/cm at 400 MHz
  - ~ 4 dB/cm at 900 MHz
  - ~ 6 dB/cm at 2450 MHz

[Ryckaert, 2004]



On-Body – Off-Body – In-Body

- In-body transmission can be neglected when dealing with external antennas
- On-body vs. off body (integrated from 3 to 10 GHz)

	Diffracted wave [dB]	Reflections [dB]	Total [dB]	Ratio body/total [%]
F2F	-72.96	-70.28	-68.40	35.18
F2B	-100.70	-78.46	-78.43	0.60

  - Transmission from front to back hardly possible without scattering obstacles
  - Need of relaying strategy ?

On-Body Path Loss

- Two current types of models
  - Generic models, derived from measurements and/or electromagnetic simulations [Fort 2007; Fort 2010]
    - Along the body (same side) $$L(dB) = 10m \log_{10}(r/r_0)$$
      - m = 3 to 3.5 in the 900-2500 MHz frequency range
    - Around the body $$L(dB) = \alpha(r - r_0)$$
      - Saturation in the back (for front Tx) caused by interference between right and left waves
      - α = 2 dB/cm at 2.45 GHz $\Rightarrow \sim$ **40-50 dB from front to back**
    - Above models are for dipole antennas parallel to the body

On-Body Path Loss

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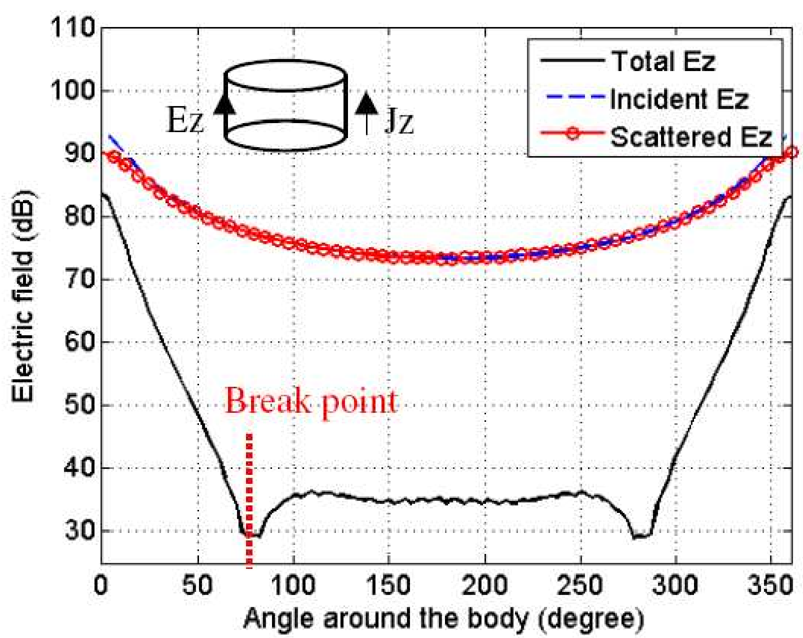
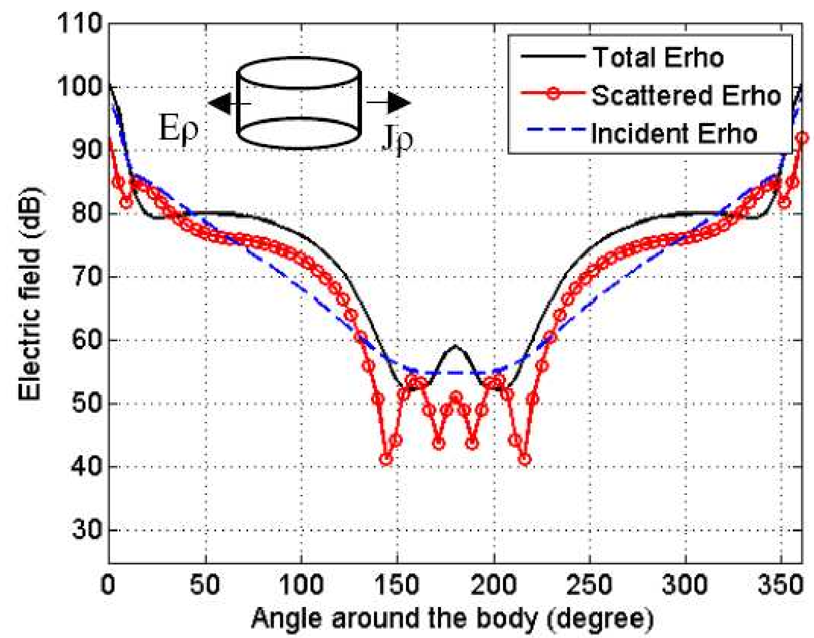


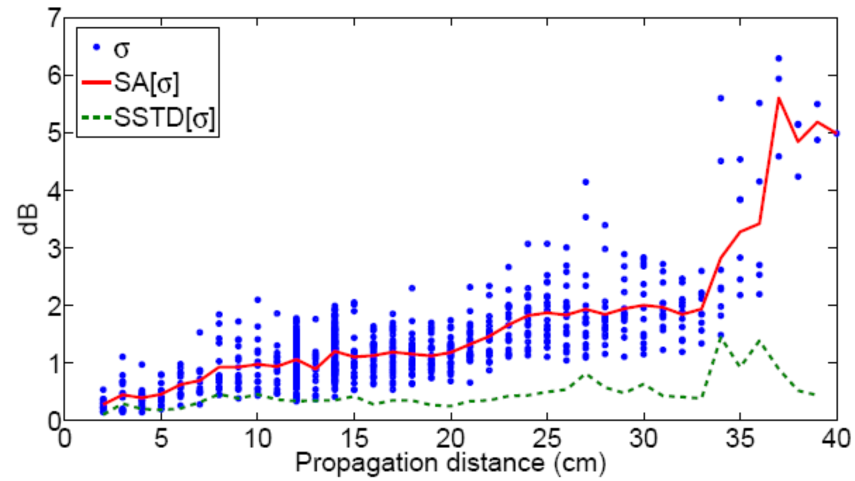


On-Body Path Loss

- Two current types of models
  - Generic models, derived from measurements and/or electromagnetic (EM) simulations [Keshmiri 2010]
    - For antennas perpendicular to the body, path loss can be significantly reduced (via both the slope and the saturation)
  - Scenario-specific models, eg at 2.45 GHz [D'Errico 2009]
    - Hip-to-wrist ~ 58 to 62 dB (indoor), ~ 62 to 65 dB (anechoic)
    - Hip-to-foot ~ 58 to 60 dB (indoor), ~ 67 to 71 dB (anechoic)
    - Left ear to right ear ~ 60 (indoor) to ~ 63 dB (anechoic)
  - In all cases, path loss also depends on the human body type (shape, dimensions)

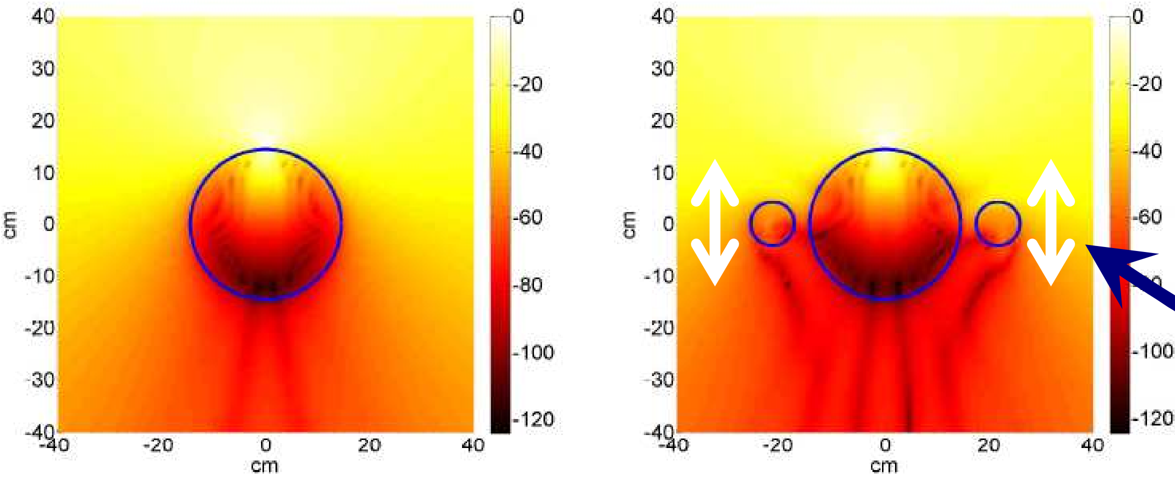
Shadowing

- Shadowing (or slow fading) is the dominant time-varying effect
  - It is mostly related to the body motion (swinging arms, walking), and is larger in anechoic condition
  - Well represented by a lognormal variable with given standard deviation [D'Errico 2009, Liu 2009]
    - Hip-to-wrist: std of 0.5 (still, indoor) to 4 dB (running, anechoic)
    - Around the waist

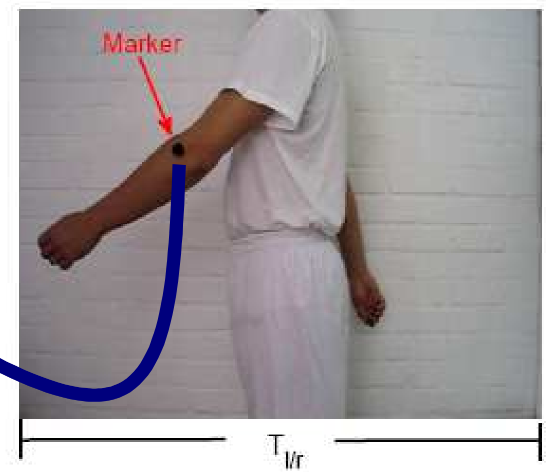


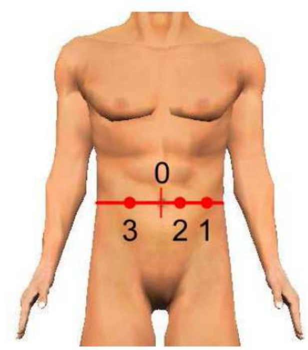
Shadowing

- Electromagnetic model of dynamic shadowing [Liu 2009]



(a) Single cylinder scattering (b) Multiple cylinder scattering





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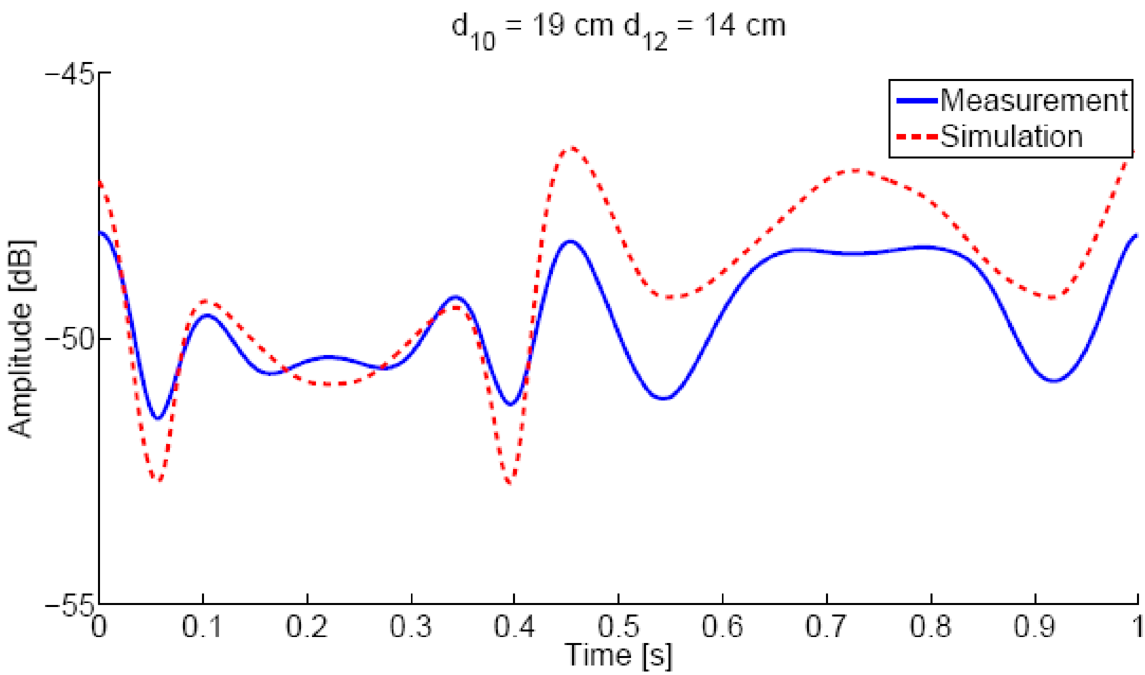
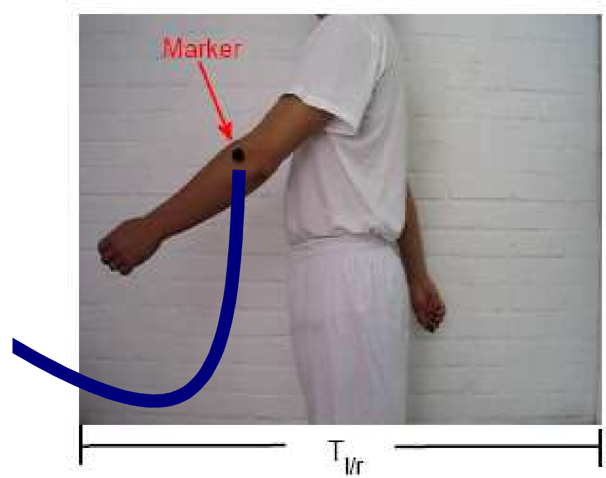
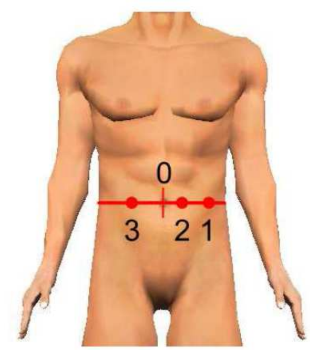
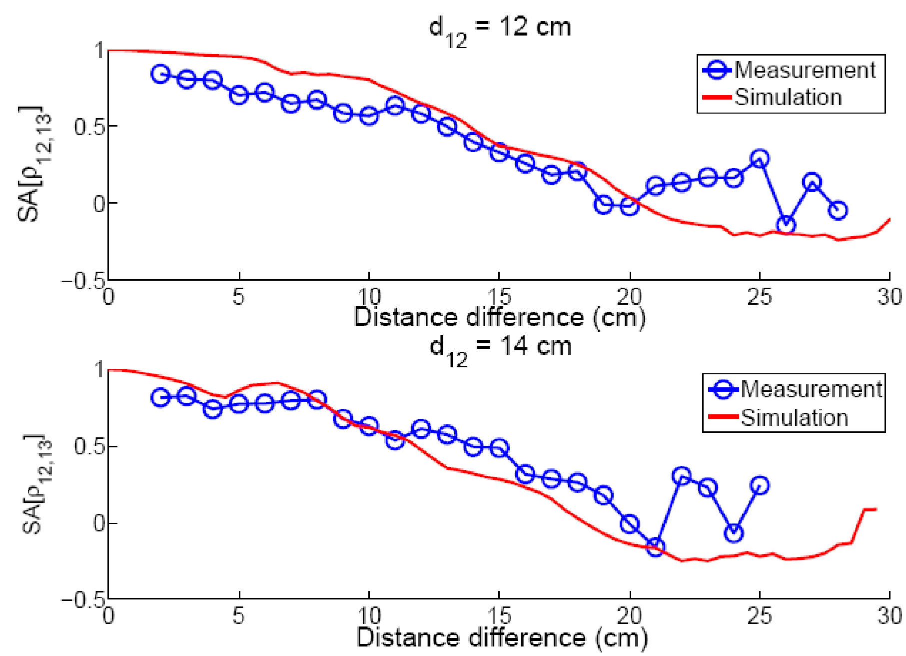






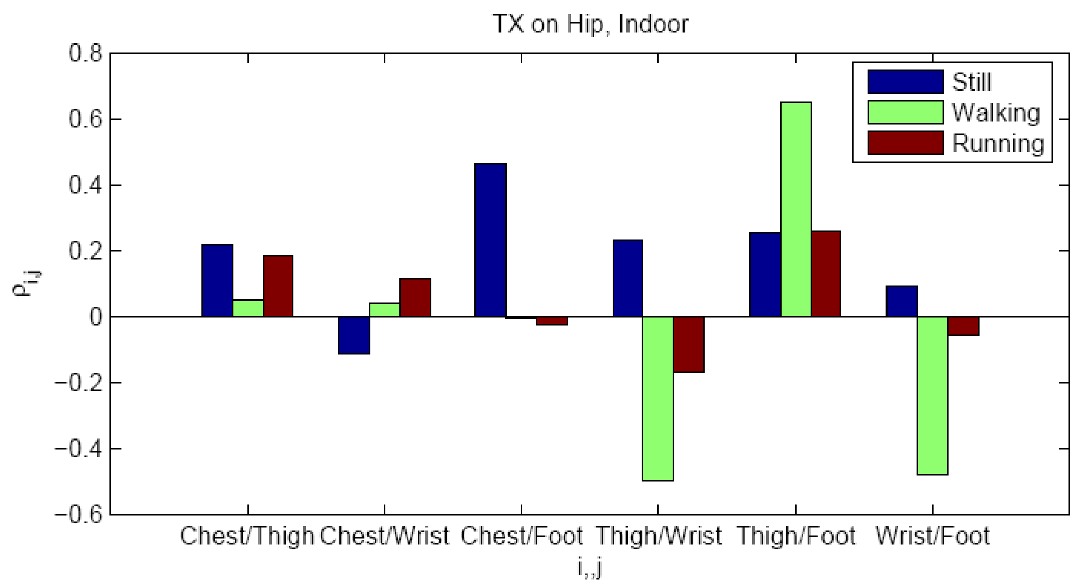
Shadowing Correlation

- Shadowing correlation is an important parameter in cooperative schemes
- Shadowing correlation model based on EM model (around the body) [Liu 2009, Liu 2010]



Shadowing Correlation

- Shadowing correlation is an important parameter in cooperative schemes
- Shadowing correlation model based on EM model (around the body) [Liu 2009, Liu 2010]
- Empirical model based on specific scenarios [D’Errico 2009]



Fading and Multipaths

- Fast-fading is mostly Ricean distributed [Fort 2007]
  - Coherent part is the body diffracted wave
  - Scattered part is mostly caused by the environment

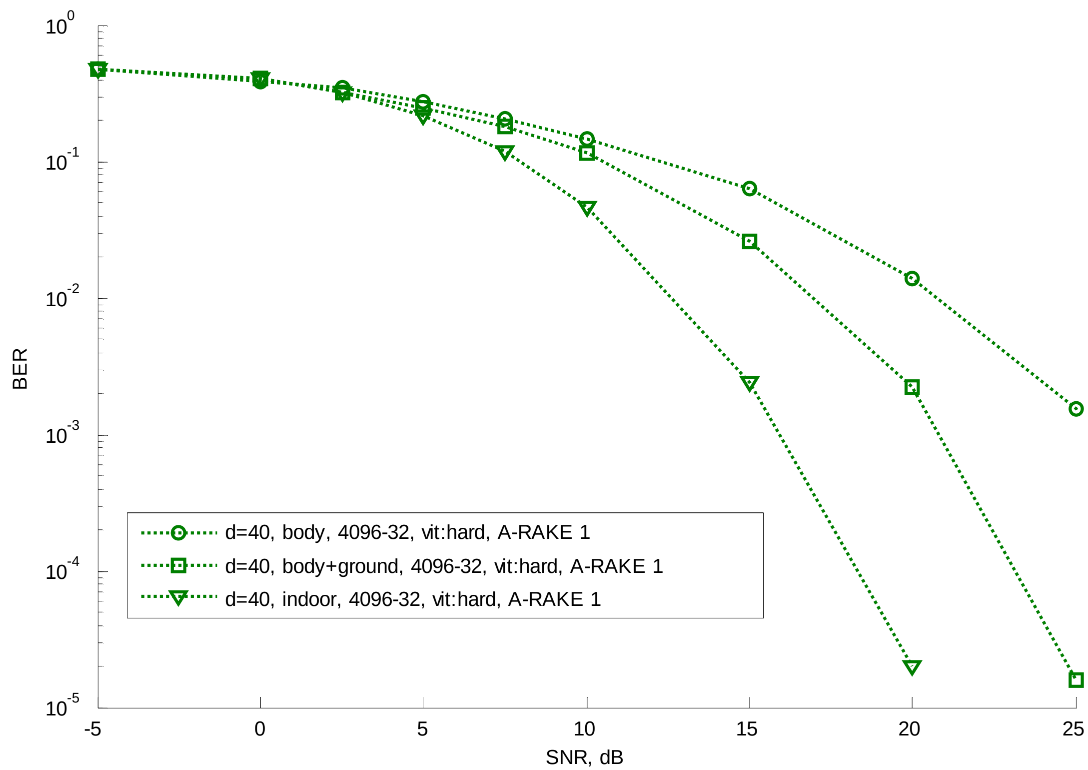
  - As a consequence, the larger the path loss, the lower the K-factor

Communication Theory for BANs

- **Which techniques ?**
  - UWB
  - MIMO
  - MIMO + UWB
  - Cooperation
  - Distributed MIMO

Communication Theory for BANs

- **UWB**
  - UWB is implemented in 802.15.4a (and in TG6 ?)
  - Impact of channel condition on 802.15.4a performance



Communication Theory for BANs

- MIMO
  - MIMO BANs have been analyzed in several papers, e.g. [Neyrynck 2007]
    - On-body wave causes the signals to be highly correlated
    - Off-body contribution provides decorrelation, but is unreliable
  - Use of polarization diversity appears attractive
    - Reduced correlation of the on-body wave
    - Beware of cross-polar loss when estimating the spectral efficiency gain !

Communication Theory for BANs

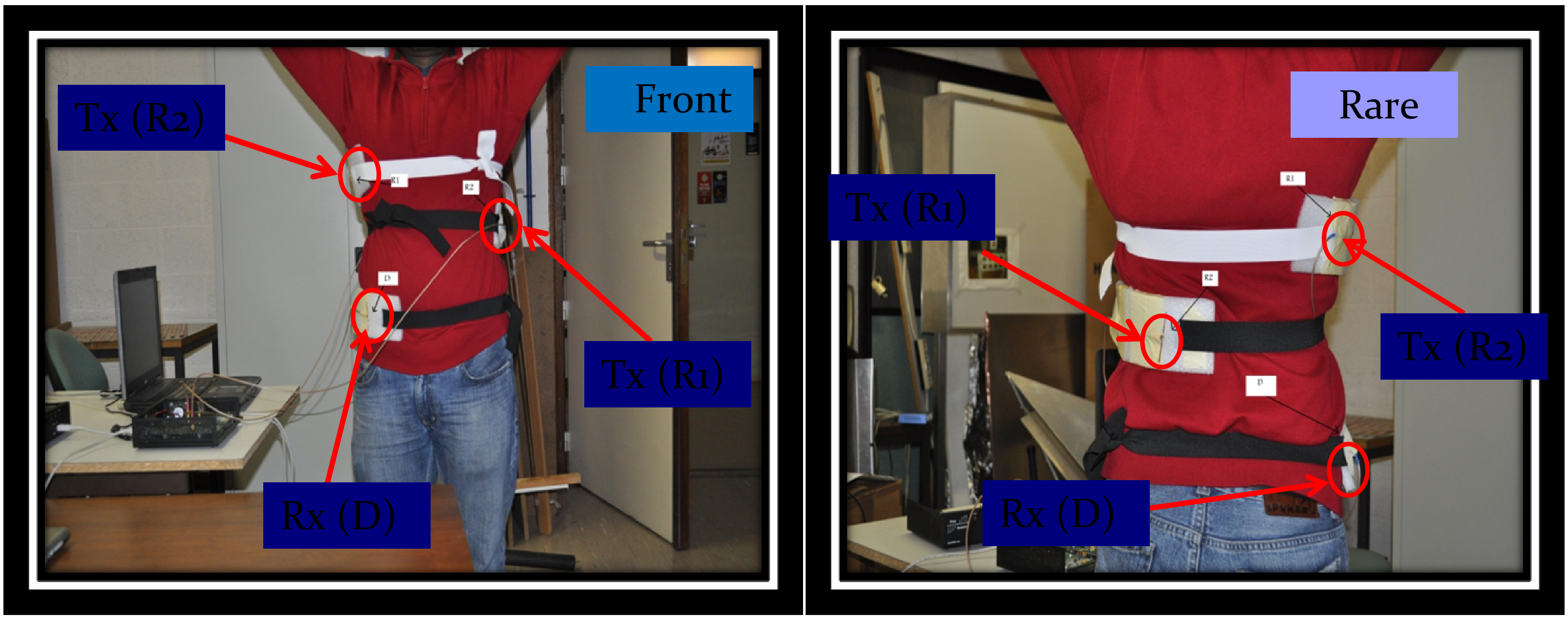
- MIMO UWB
  - Why MIMO and UWB ?
    - Some claim that UWB means no fading, making MIMO useless
    - Actually, MIMO + UWB still offer improvement [Molisch 2010], in particular in terms of SNR
      - This is a welcome effect, especially in BAN owing to the high path loss
  - Challenges
    - Channel modeling: 802.15.4a is essentially a SISO model

      $\Rightarrow$ Model was extended to MIMO scenarios in [van Roy 2010]
    - UWB is usually intended for simple Rx structures, while MIMO often means high complexity !

      $\Rightarrow$ Need of a compromise

Communication Theory for BANs

- Cooperative/relay schemes
  - USRP board used a test bed for implementing cooperative MIMO on body (UCL-led WALIBI project in Belgium)



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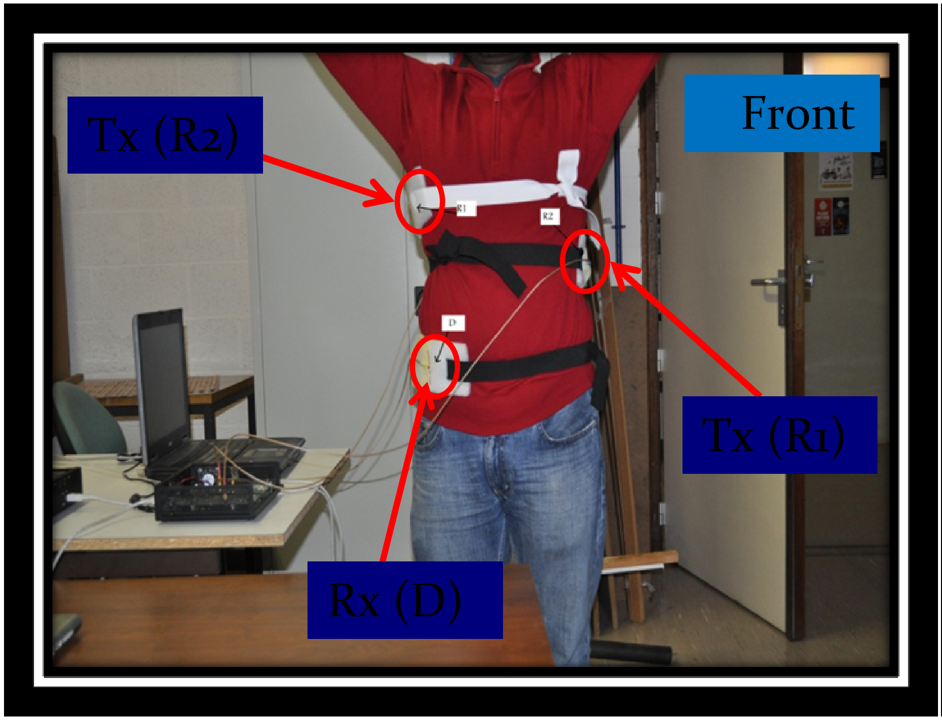
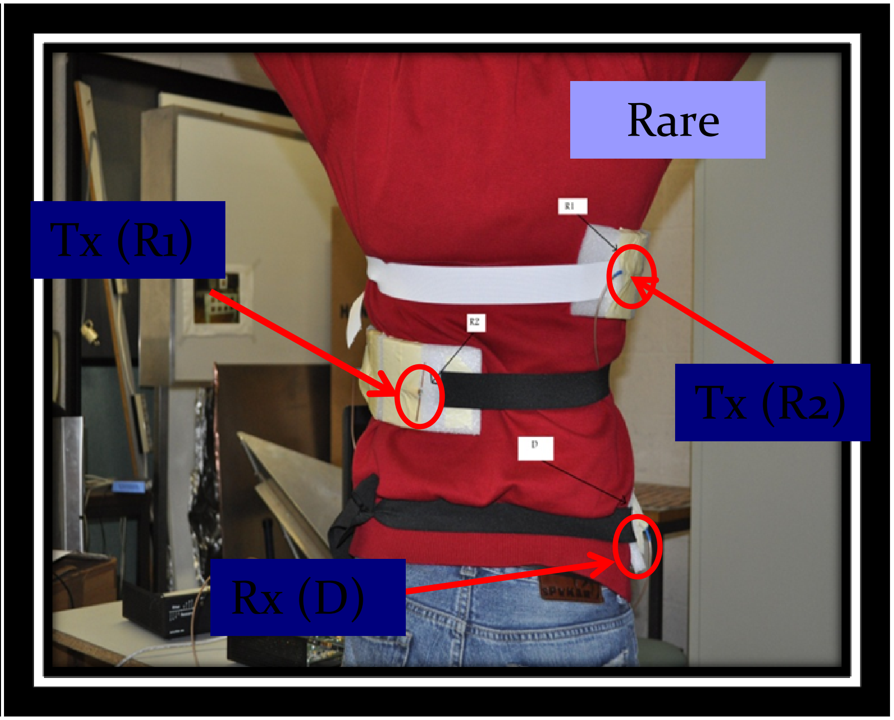




Communication Theory for BANs

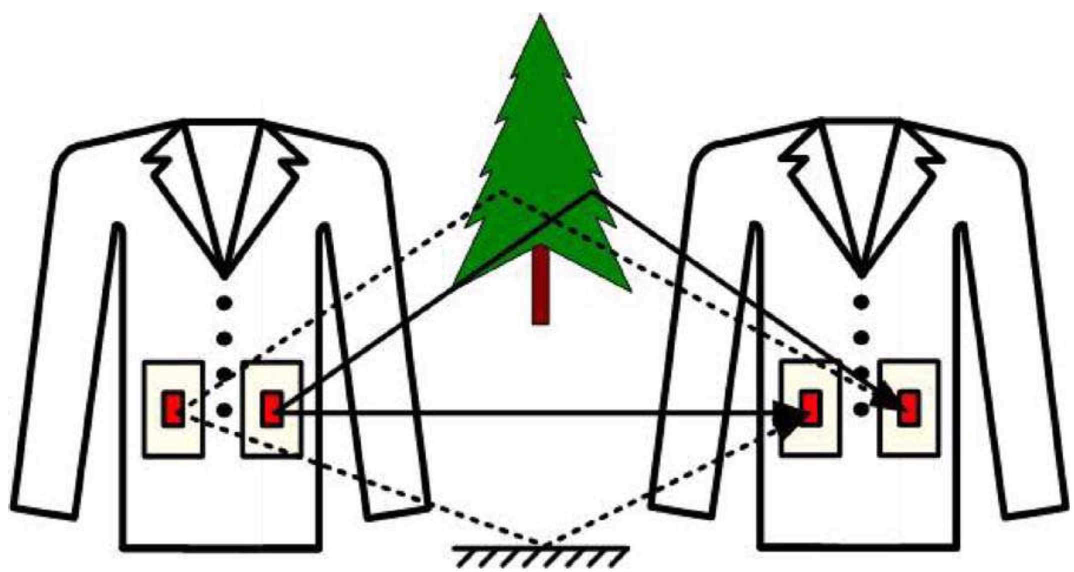
- Cooperative/relay schemes
  - USRP board used a test bed for implementing cooperative MIMO on body (UCL-led WALIBI project in Belgium)
  - Observed diversity order matches theory

  - Challenges
    - MIMO is complex and energy-consuming, yet wireless body sensor networks must be low-power and secure
      - Power has to be dedicated to cryptography
      - Use of channel-based cryptography ?

Communication Theory for BANs

- Distributed MIMO [Ouyang, Love et al. 2009]
  - Measurement of distributed MIMO schemes using wearable antennas

    ⇒ ~ 300 % increase of spectral efficiency in indoor scenarios using patch antennas



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Conclusions

- Body area communications are in many ways different from classical wireless networks
  - Most existing solutions are still based on classical standards
  - Need for a true cross-layer approach (from antenna design and channel modeling to PHY and MAC layers)
- On-going and future research
  - In-body and in-to-out-body communications (implants)
  - Nano-networks [Akyildiz 2010]
    - How different are nano-networks from classical networks ?
  - Interaction with biological mechanisms

Selected References

- Antennas and Propagation for BANs

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