UNIVERSITY OF BIRMINGHAM

Radio Propagation and Networks Research

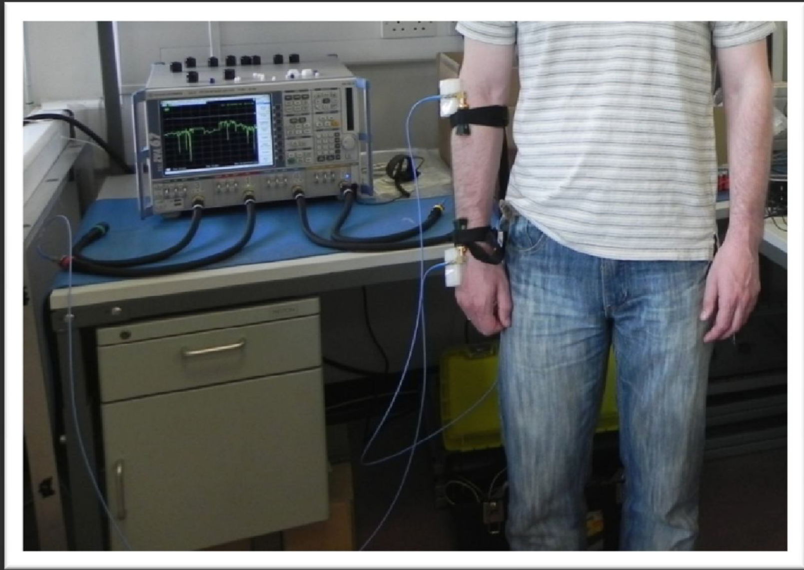
Costas Constantinou
School of Electronic, Electrical & Computer Engineering
10 June 2013

Introduction

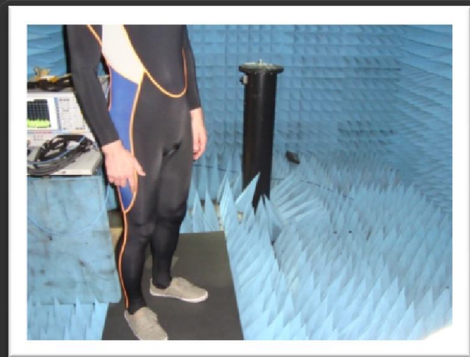
- Healthcare
  - 40 % of critical-care time spent manually recording patient data in hospitals can be automated using BANs
  - ICU spaghetti syndrome
- Defence
  - Monitor vital soldier signs, provide on-body hi-res video links
- Why mm wave BANs?
  - Good covertness
  - Reduced interference
  - Unobtrusiveness
  - Expensive (not for long)
  - Strong shadowing

UNIVERSITY OF BIRMINGHAM

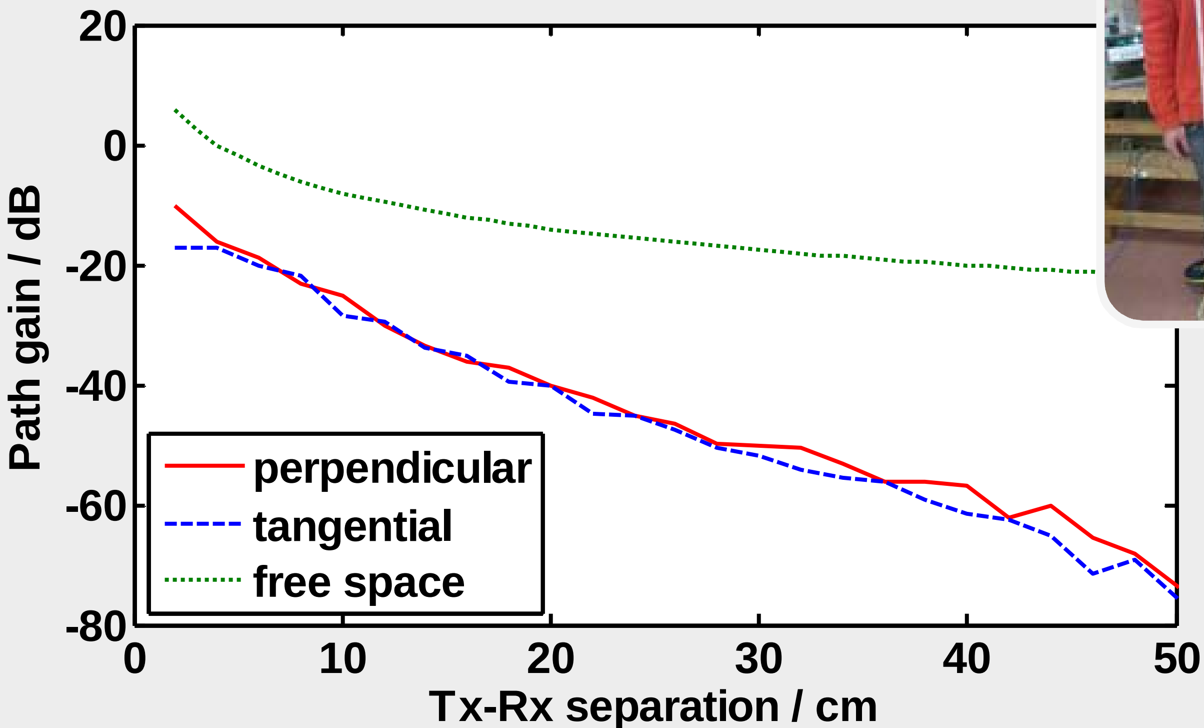
Experimental facilites



- Rhode&Schwarz ZVA67
- 20dBi horns & monopoles
- Flexible 2m coaxial cables
- Laboratory, outdoor and anechoic chamber environment

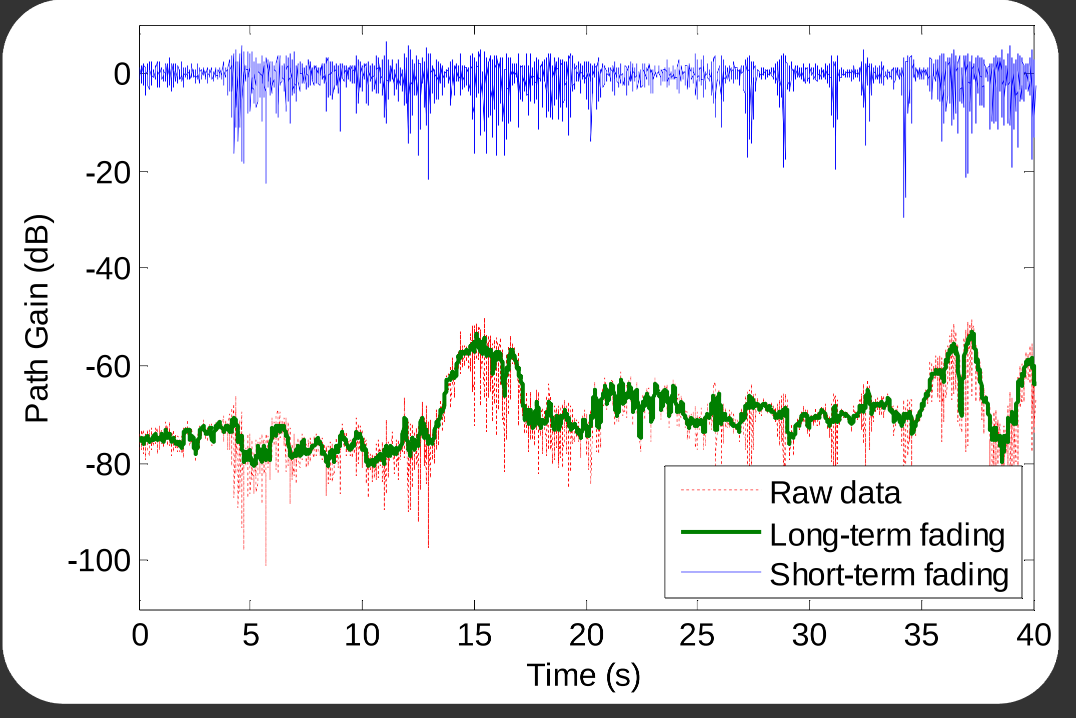


On-body path gain distance dependence



UNIVERSITY OF BIRMINGHAM

Signal variability



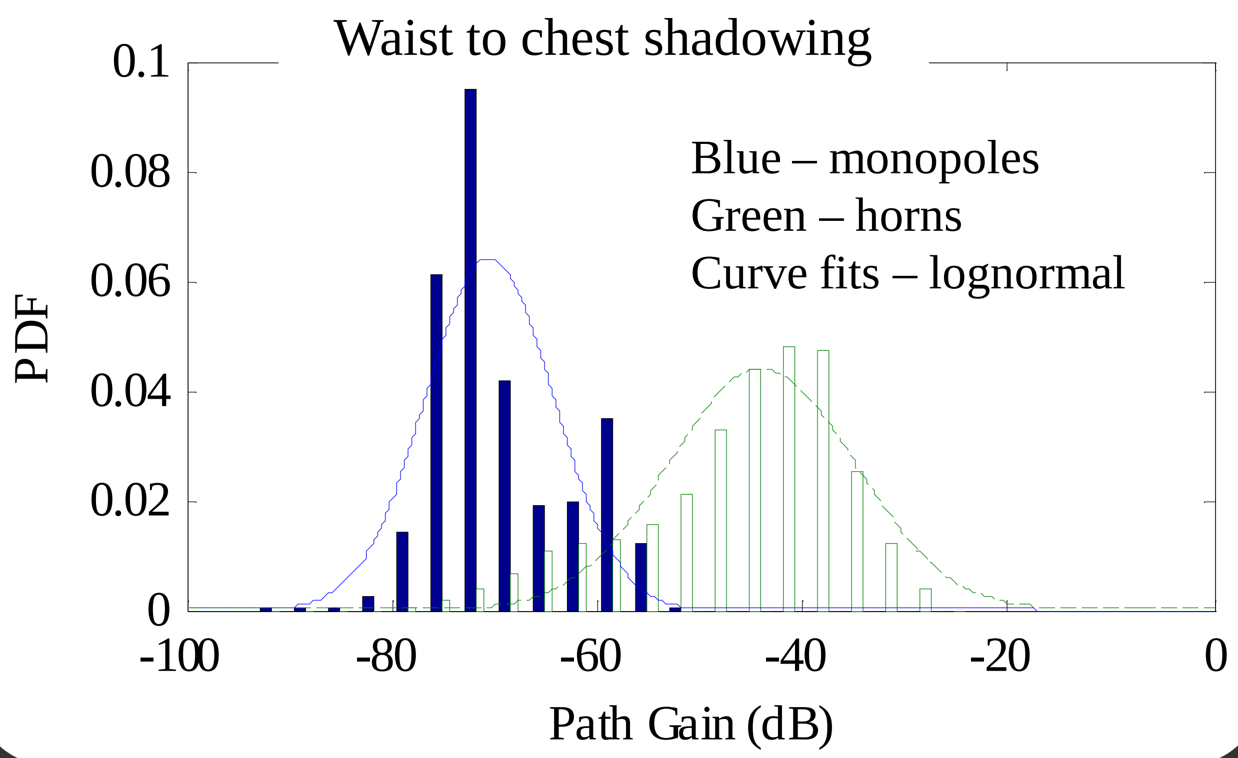
Moving body; waist to chest channel

$$p(s,l) = p(l)\,p(s\,|\,l)$$

- Two types of fading cannot be unambiguously attributed to unique physical mechanisms
- The time-scales that characterise these can be comparable for fast-moving bodies
- Mechanisms include:
  - Small and large-scale movements of body
  - Motion-induced antenna misalignment and depolarisation
  - On-body multipath

UNIVERSITY OF BIRMINGHAM

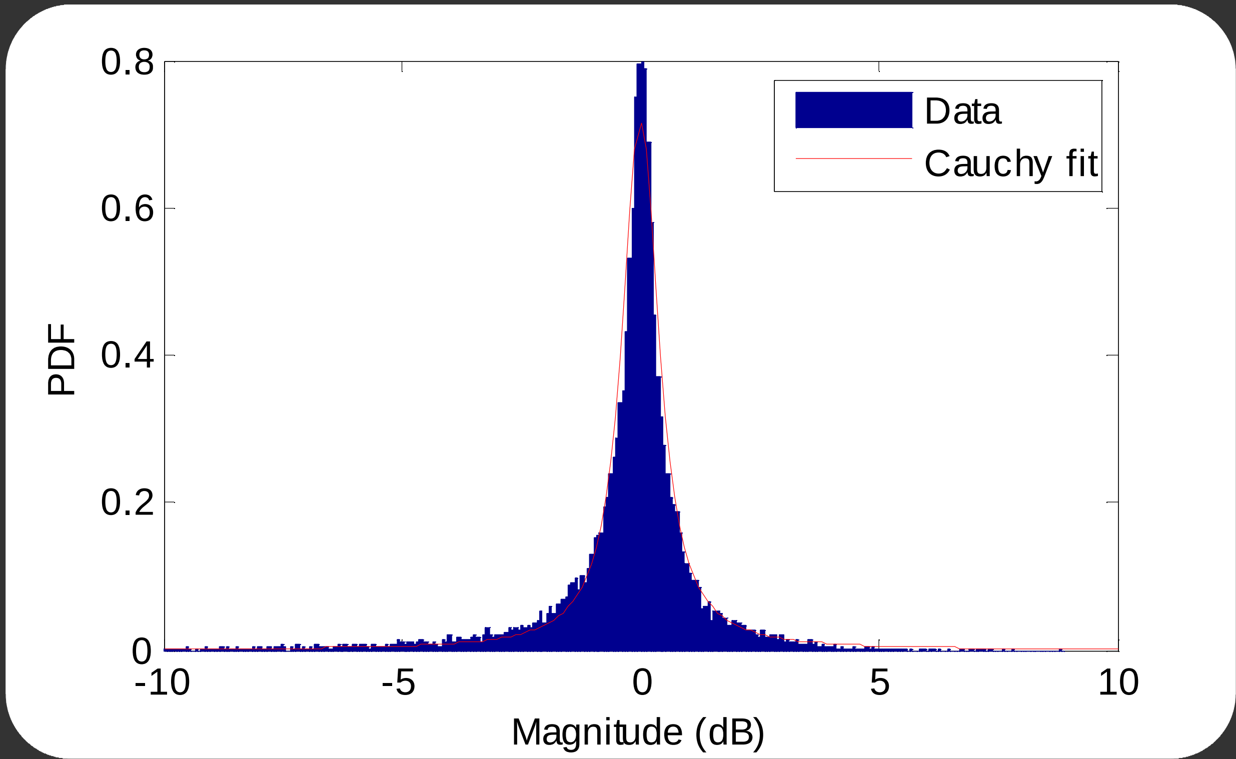
Signal variability – long-term fading



$$p\left(l_{dB}\right) \approx \frac{1}{\sigma\sqrt{4\pi}} \exp\left(-\frac{l_{dB}^2}{2\sigma^2}\right)$$

UNIVERSITY OF BIRMINGHAM

Signal variability – short-term fading

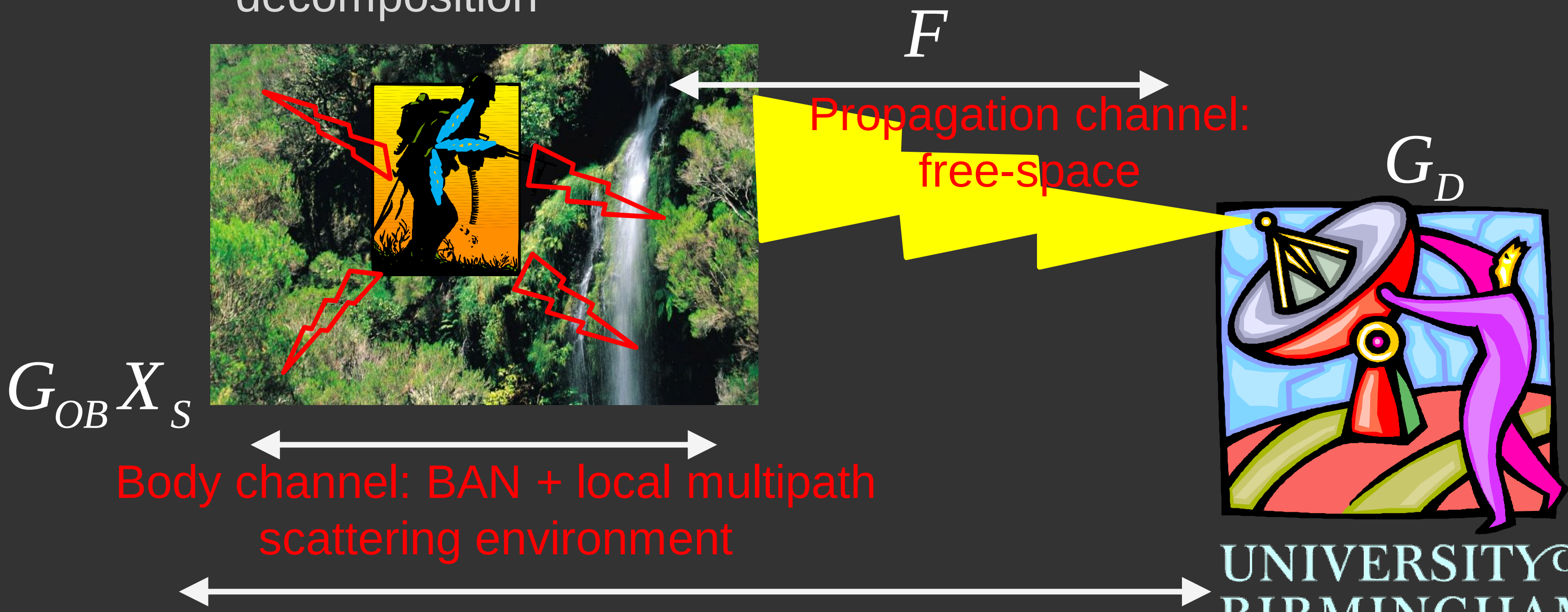


$$p(s) = \int_{-\infty}^{\infty} p(s|l)\,dl \approx \frac{\gamma/\pi}{s^2 + \gamma^2}$$

UNIVERSITY OF BIRMINGHAM

Off-body paths: Covertness

- Empirical Observability Study
  - Characterise an off-body channel of a 60 GHz BAN within a variety of scattering environments
  - Propose an observability estimation model using channel decomposition

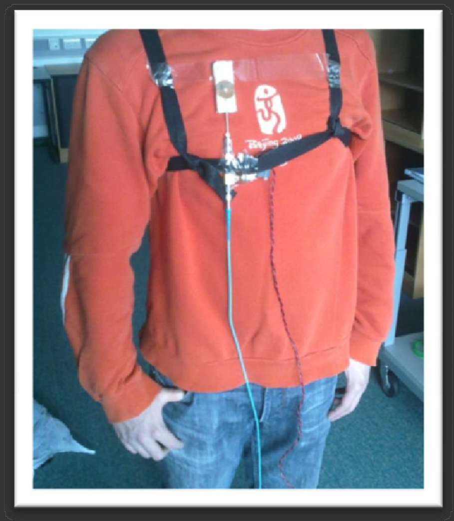


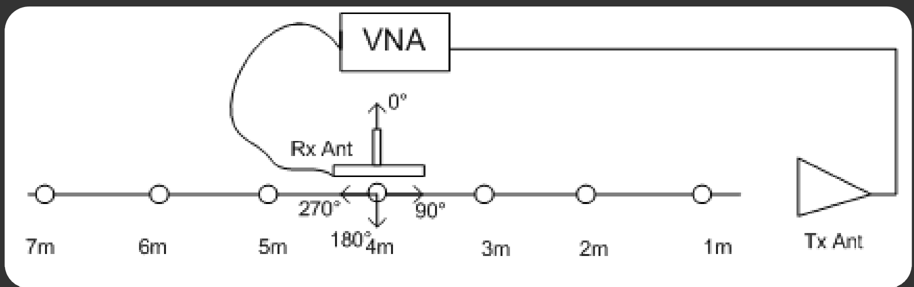
UNIVERSITY OF BIRMINGHAM

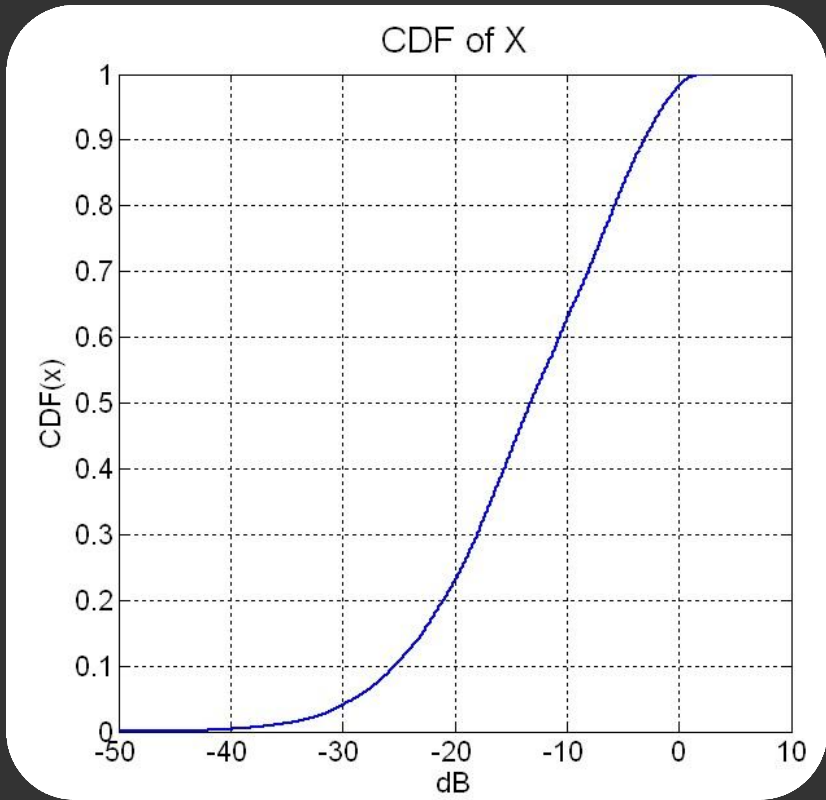
Detection channel $W_R = W_T G_{OB} G_D F X_S$

Off-body paths: Covertness

No *strong* distance dependence implies immersion in scattering environment
Antenna de-embedding is not possible







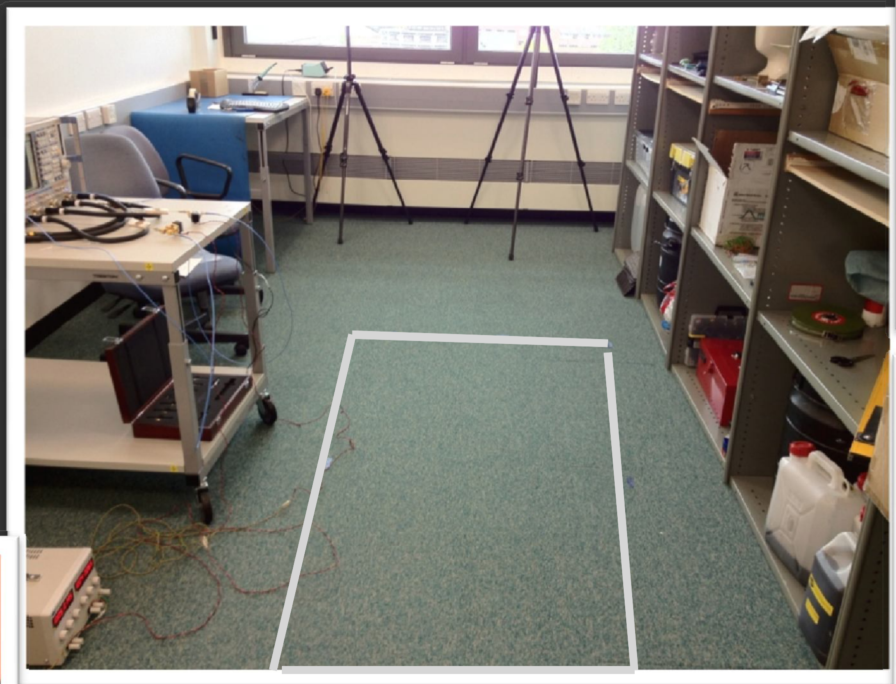
$$X = G_{OB} X_S$$

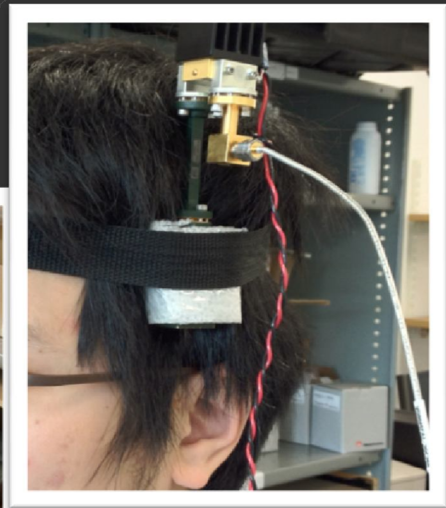
UNIVERSITY OF BIRMINGHAM

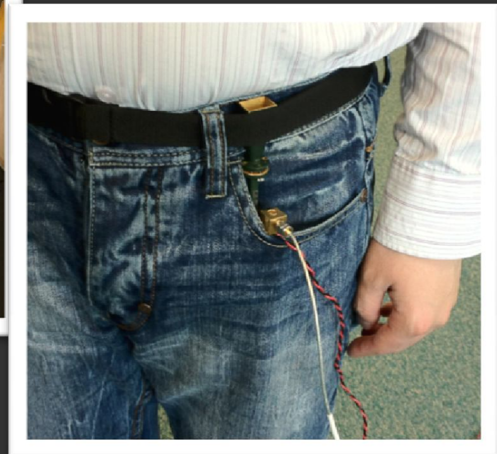
Observability: 60 GHz vs. 2.45 GHz

- The 60 GHz 1% observability probability threshold distance for a realistic system both indoors and outdoors was estimated from measurement to be 48 m
- The corresponding open environment threshold distance at 2.45 GHz keeping all system parameters unchanged was found to be 808 m
- Assuming a more realistic microwave system at 2.45 GHz, the 1% observability distance threshold is 1,437 m (or using a two ray model 576 m)

Off body paths: Interference

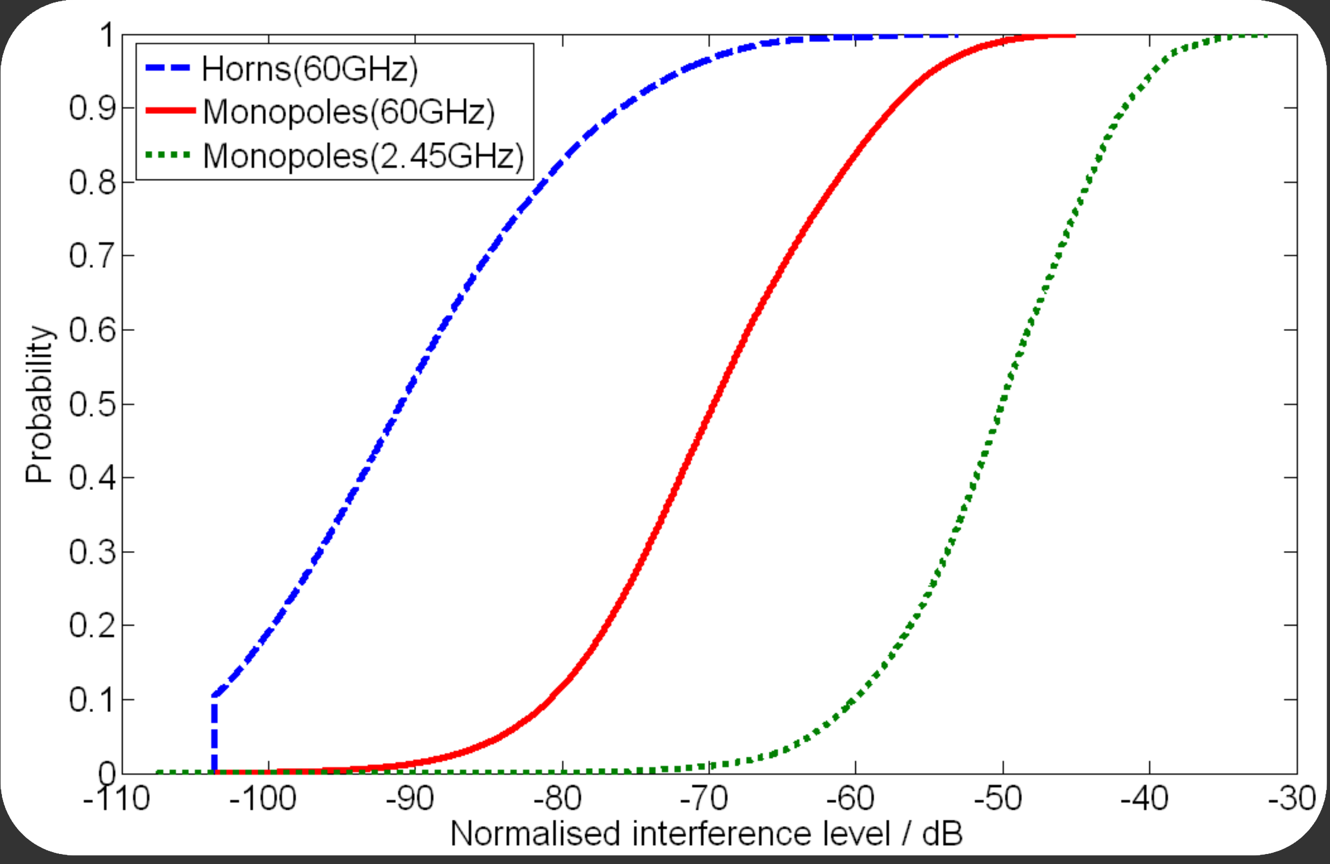






UNIVERSITY OF BIRMINGHAM

Off-body paths: Interference



Head-to-belt channel with belt-to-belt channel:
CDF of directly measured SIR on 4-port VNA

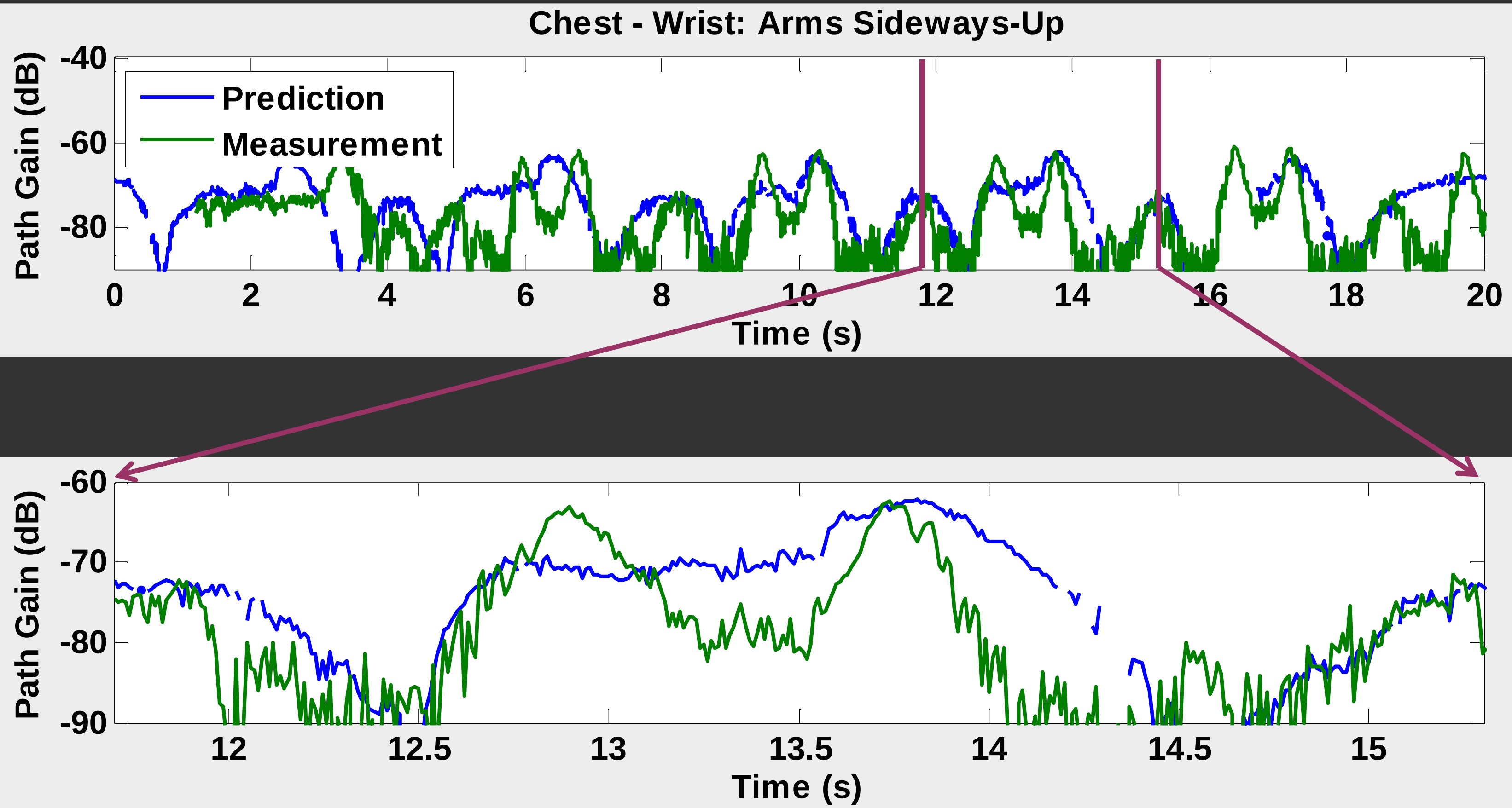
UNIVERSITY OF BIRMINGHAM

Motion Capture Setup

- Subject: male (178cm, 74 kg) wearing wetsuit
- Groups of 3 or 4 markers ("virtual antennas") placed on head, chest, waist, knee and 4 positions on the right arm
- Movements:
  - Simple repeated movements (e.g. twisting or tilting body or head, raising or twisting arms etc.) – 20s
  - Random movements – 180s

UNIVERSITY OF BIRMINGHAM

GO Predictions vs Measurements



UNIVERSITY OF BIRMINGHAM

Time-varying on-body link geometry

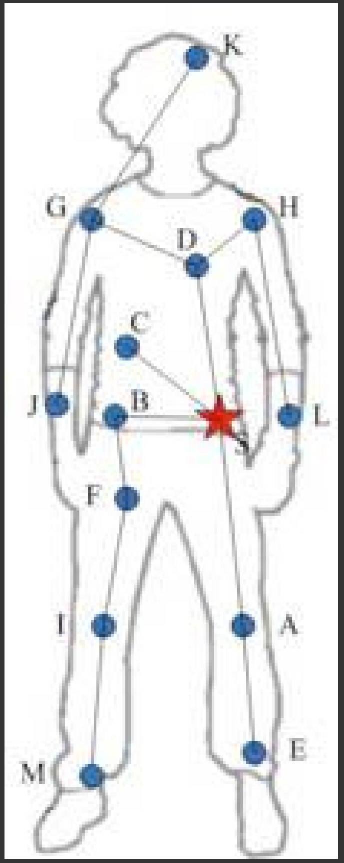
Tx	$\Delta\theta_T$ (deg)	$\Delta\phi_T$ (deg)	D_T (dBi)	Ant	Rx	$\Delta\theta_R$ (deg)	$\Delta\phi_R$ (deg)	D_R (dBi)	Ant
Head	64	74	8.7	Low gain	**Upper Arm**	36	49	23.4	High gain
Head	72	360	1.6	Omni	**Wrist**	51	103	7.8	Low gain
Upper Arm	48	59	14.4	High gain	**Wrist**	27	40	38.0	High gain

The elevation and azimuth direction variability of the markers translates to antenna beamwidth requirements and thus directivity

UNIVERSITY OF BIRMINGHAM

BAN antennas for 60 GHz on body paths

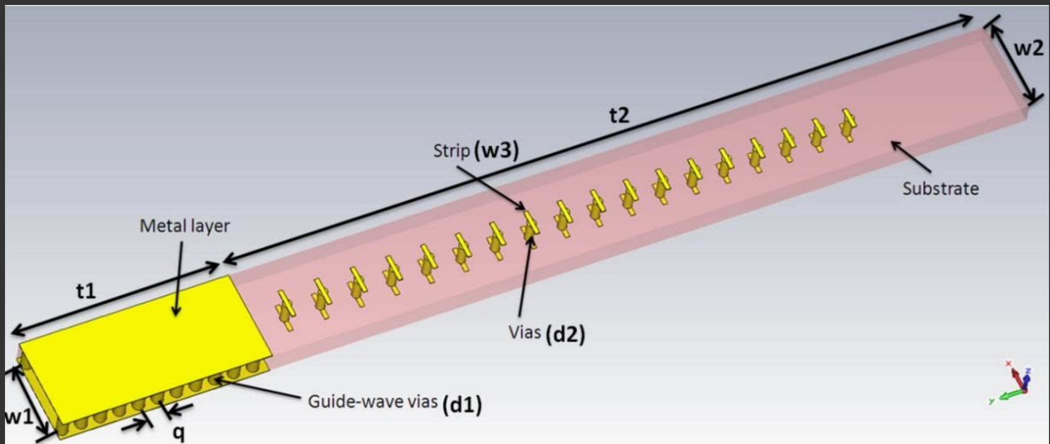
- Channel features
  - Path loss high so only short link viable
  - Need high gain antennas so fading due to beam misalignment



Printed Yagi-Uda array gain ~20 dBi

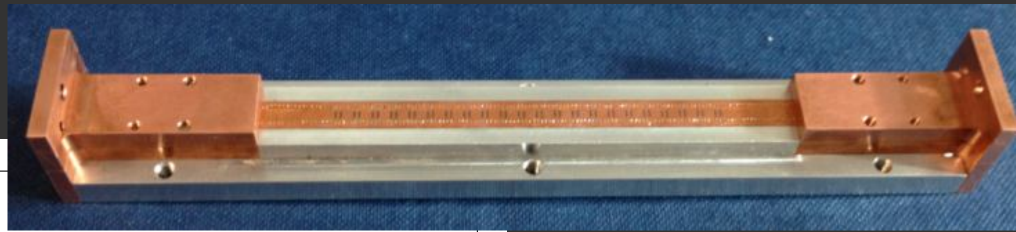
UNIVERSITY OF BIRMINGHAM

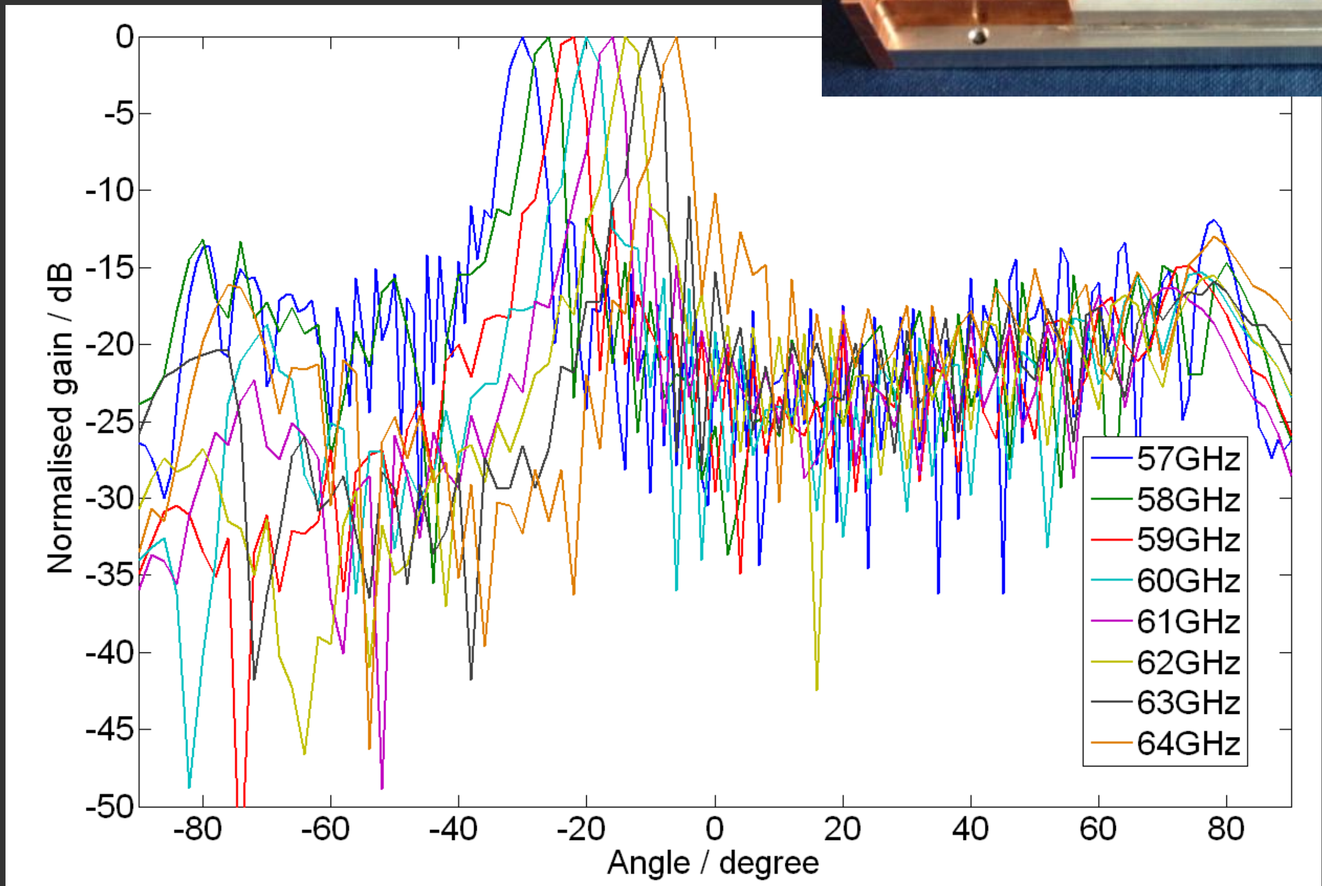
Novel SIW Yagi-Uda Array



UNIVERSITY OF BIRMINGHAM

Linearly Polarised SIW Frequency Scanning Antenna: Fabrication and Measurement





UNIVERSITY OF BIRMINGHAM

SIW Antenna vs. Horn & Monopole

Offsets body movement for highly mobile antenna locations (e.g. on wrist)

State 4

State 1

State -4

Max. Path Gain (dB)

	State4	State3	State2	State1	State0	State-1	State-2	State-3	State-4
SIW antenna	-43.1	-43.4	-41.3	-32.9	-50.9	-45.8	-51.8	-53.2	-52.1
Horn	×	×	-59.7	-45.2	-50.8	-50.1	-57.9	-58.3	×
Mono	×	-60.8	-51.4	-43.8	-56.9	-51.3	-54.2	-63.9	×

Conclusions

- 60 GHz/mm wave technologies
  - Advantages
    - Good BAN-BAN isolation
    - Greatly reduced EM emissions signature
  - Disadvantages
    - Quasi-optical links necessitate multi-hop BANs
    - Good radiation control requires careful antenna design

Future challenges

- Electromagnetic modelling is a challenge & lags behind empirical work
  - Time-varying boundary conditions
  - Electrically large problems
  - Unexpected polarisation independence of attenuation for near LOS paths
- Variability of body geometries and of electrical properties of skin and clothing layers is largely unexplored
- More realistic (small, conformal) adaptive antennas for better radiation control?

UNIVERSITY OF
BIRMINGHAM