Ref. Ares(2018)3526743 - 03/07/2018

Horizon 2020
European Union funding
for Research & Innovation

Horizon 2020 Grant Agreement Number 734798

indoor small-cell Networks with 3D MIMO Array Antennas (is3DMIMO)

D4.4

Project Workshop (Year 1)

Authors(s)	Xiaoli Chu, Jiliang Zhang, Andres Alayon Glazunov, Jian Yang, Haonan Hu, Bleron Klaiqi, Hanye Hu
Author(s) Affiliation	USFD, UK; LZU, China; Chalmers, Sweden; UT, Netherland; Ranplan, UK
Editor(s):	Xiaoli Chu, Songjiang Yang
Status-Version:	Final-1.0
Project Number:	734798
Project Title:	indoor small-cell Networks with 3D MIMO Array Antennas
Project Acronym:	is3DMIMO
Work Package Number	4

Abstract

The is3DMIMO project workshop (year 1) consists of 6 oral presentations on the research & innovation work carried out within the is3DMIMO project in year 1. The workshop was held on at Chalmers University of Technology in Gothenburg, Sweden, on 23 May 2018. This deliverable includes the workshop agenda, the list of attendees, the list of presentations, and the slides of the technical presentations, which also include the secondment experiences of the corresponding researchers within the project in year 1.

Keywords

Project workshop, presentation, massive MIMO, 3D MIMO, antenna arrays, indoor channel measurement, indoor MIMO channel modeling, small cells, indoor coverage.

Marie Sklodowska-Curie Research and Innovation Staff Exchanges (Project No. 734798)

Indoor Small-cell Networks with 3D MIMO Array Antennas (is3DMIMO)

is3DMIMO Year-1 Workshop Agenda

Gothenburg, Wednesday 23 May 2018

EL42, Hörsalsvägen 11, ED-Building Main Entrance, 4th Floor
Dept. of Electrical Engineering, Chalmers Univ. of Technology, S-412 96, Gothenburg, Sweden
http://maps.chalmers.se/#85836dd1-2322-4db0-bfd8-af8c19a19e35
Tel: +46 31 7721736 Email: jian.yang@chalmers.se, x.chu@sheffield.ac.uk

Time	Theme	Presenter(s)
9:00 – 9:45	Workshop opening and project overview	Xiaoli Chu
9:45 – 10:15	Coffee break	
10:15 – 12:00	Researcher individual presentations, each presentation (30 minutes) consisting of: • Secondment presentation (10 minutes): ○ Background (education/research/experience and home institution); ○ Secondment info (when/where/accommodation/which office/which WP/tasks/financial support), knowledge gained, impact on the project and on career. • Technical presentation (20 minutes): research findings and results on a topic that is relevant to the project.	Jiliang Zhang Andres Alayon Glazunov Jian Yang
12:00 – 13:30	Lunch	
13:30 – 15:00	Researcher individual presentations (30 minutes each)	Haonan Hu Bleron Klaiqi Hanye Hu
15:00 – 15:15	Coffee break	
15:15 – 16:30	Project management meeting • Summary of Project Workshop Year 1 • Mid-term meeting agenda walkthrough • Review of deliverables/milestones • Review of secondments and planning from each site • Dissemination and outreach activities (project website, project logo, YouTube video, social media, acknowledgement of EU funding, Project Workshop Year 2, etc.)	Xiaoli Chu Andres Alayon Glazunov Jian Yang Charlotte Elmquist Lars-Inge Sjöqvist Jiliang Zhang Haonan Hu Songjiang Yang

18:00 – 20:00	Dinner[1]	

List of Attendees:

- Jian Yang (Chalmers University of Technology)
- Xiaoli Chu (University of Sheffield)
- SongJiang Yang (University of Sheffield)
- Haonan Hu (University of Sheffield)
- Bleron Klaiqi (University of Sheffield) via Skype
- Andres Alayon Glazunov (Chalmers University of Technology/University of Twente)
- Charlotte Salmenius (Gapwaves)
- Lars-Ingen Sjöquist (Gapwaves)
- Hanye Hu (Ranplan) via Skype
- Jiliang Zhang (Lanzhou University) via Skype
- Changfu Zou (Chalmers University of Technology)
- Li Yan (Chalmers University of Technology)
- Chao Fan (Chalmers)
- Ashraf Zaman (Chalmers University of Technology)
- Sadegh Mansouri Moghaddam (Chalmers University of Technology)

Technical presentations:

- Indoor 3D MIMO Channel Modelling (Jiliang Zhang, Lanzhou University)
- Single and Array Antennas Designs for Millimeter-Wave Applications (Andres Alayon Glazunov, University of Technology/University of Twente)
- Development of Massive MIMO Antenna Arrays for 5G Wireless Systems (Jian Yang, Chalmers University of Technology)
- Coverage Analysis of Ultra-densely Deployed Indoor Small-Cell Networks (Haonan Hu, University of Sheffield)
- Massive MIMO Relaying with Irregular Antenna Arrays (Bleron Klaiqi, University of Sheffield)
- 3D MIMO Modelling and Profilling in Ranplan Planning Tool (Hanye Hu, Ranplan)

[1] Prof. Yang has booked a restaurant for dinner. Attendees are expected to pay for themselves and then claim the expenses back from their institution/company.

European Union's Horizon 2020 research and innovation programme project
Indoor Small-Cell Network with 3D MIMO Array Antennas (is3DMIMO)

Midterm Report for WP1 of is3DMIMO
Indoor 3D MIMO Channel Modelling

Dr. Jiliang Zhang
Associate Professor
School of Information Science and Engineering
Lanzhou University, China

WP Introduction

Title
Indoor 3D MIMO channel modelling

Tasks
Task 1: Indoor 3D ray launching channel simulation incorporating elevation sub-path generation
Task 2: 3D SCME MIMO channel characterization
Task 3: Indoor 3D MIMO channel measurements

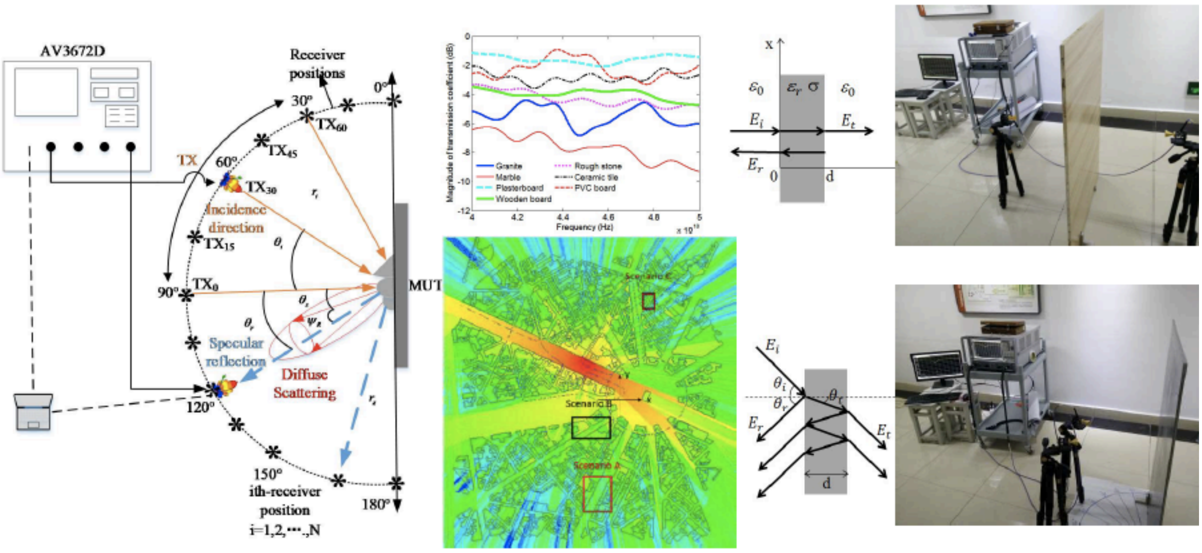
Objectives
(i) to investigate the mechanism of elevation sub-path generation for 3D ray launching based simulation;
(ii) to construct an indoor 3D SCME MIMO channel model based on 3D ray launching simulation;
(iii) to verify and calibrate the indoor 3D SCME MIMO channel model by indoor 3D MIMO channel measurements.

Deliverables
D1.1 : Report on mechanism of sub-path generation in 3D ray launching [12]
D1.2 : Report on characterization of 3D SCME in typical indoor environments [24]
D1.3 : Database of 3D indoor channel measurements [36]
D1.4 : Report on comparison between 3D MIMO channel measurements and model predictions [48]

Milestones
MS1: mechanism of sub-path generation in 3D ray launching
MS5: characterization of 3D SCME in typical indoor environments
MS8: Database of 3D indoor channel measurements
MS10: comparison between 3D MIMO channel measurements and model predictions

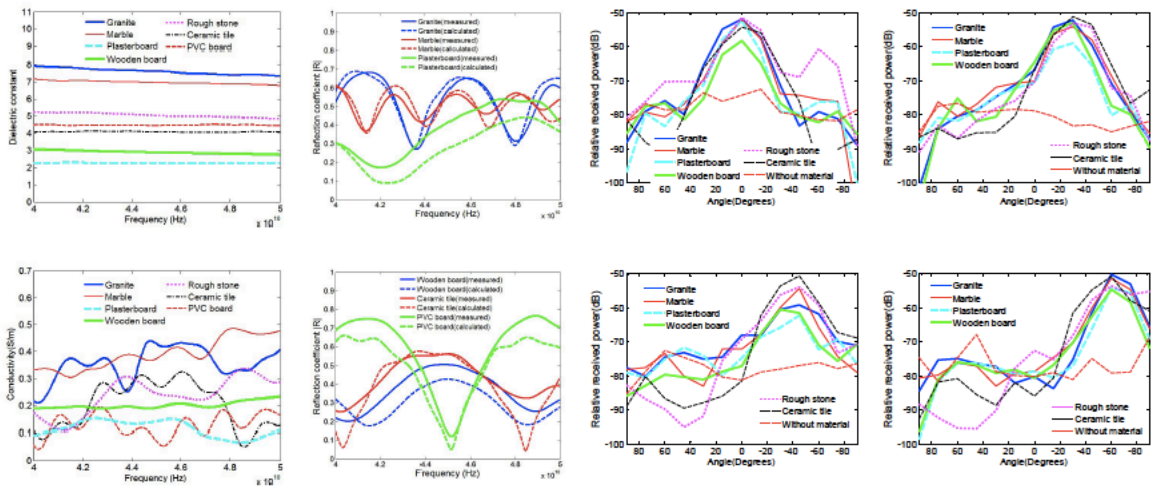
T1.1 Indoor 3D ray launching channel simulation

European Commission | Horizon 2020 European Union funding for Research & Innovation

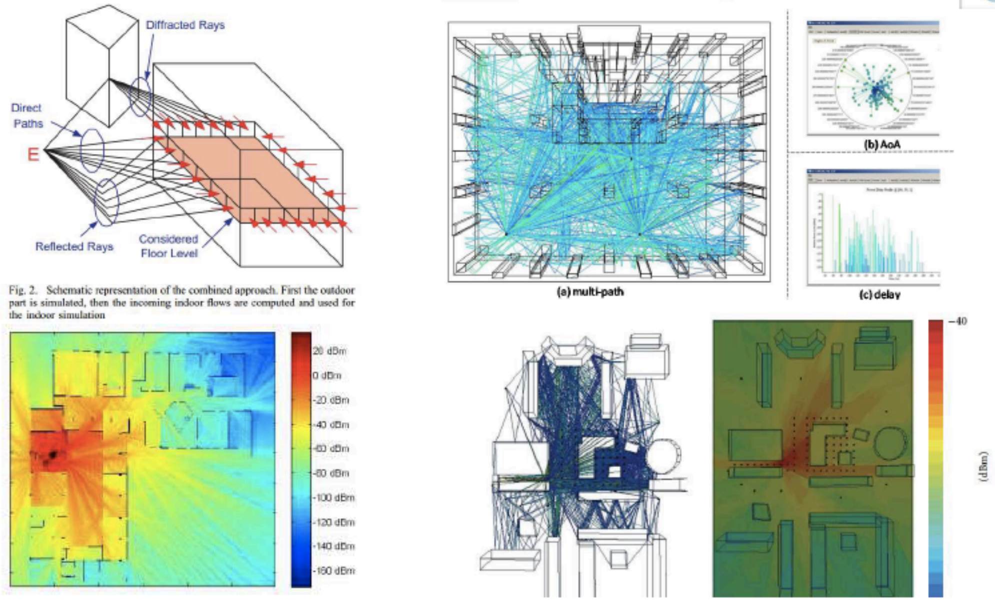


T1.1 Results

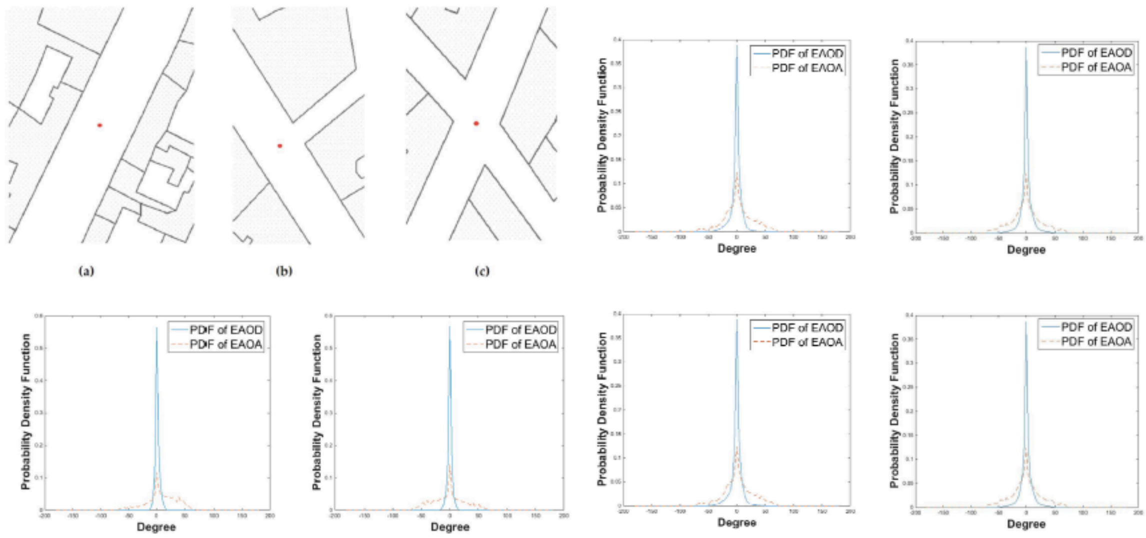
European Commission | Horizon 2020 European Union funding for Research & Innovation



T1.1 Results



T1.2 3D SCME MIMO channel characterization

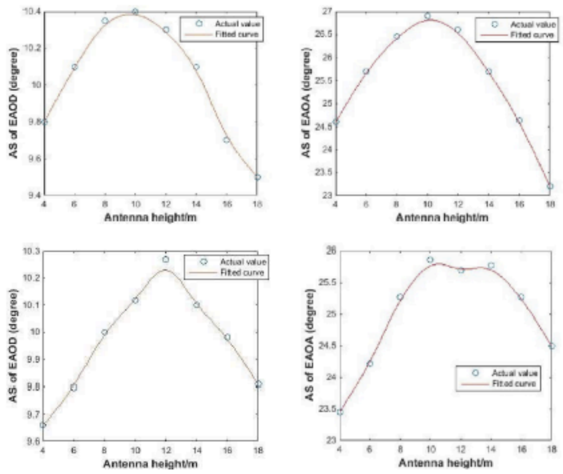


T1.2 Results

European Commission | Horizon 2020 European Union funding for Research & Innovation

$$f_{EAOD}(x) = \begin{cases} \lambda_{1EAOD} e^{-\lambda_{1EAOD} x}, & x < 0 \\ \lambda_{2EAOD} e^{-\lambda_{2EAOD} x}, & x > 0 \end{cases}$$

$$f_{EAOA}(x) = \begin{cases} \lambda_{1EAOA} e^{-\lambda_{1EAOA} x}, & x < 0 \\ \lambda_{2EAOA} e^{-\lambda_{2EAOA} x}, & x > 0 \end{cases}$$

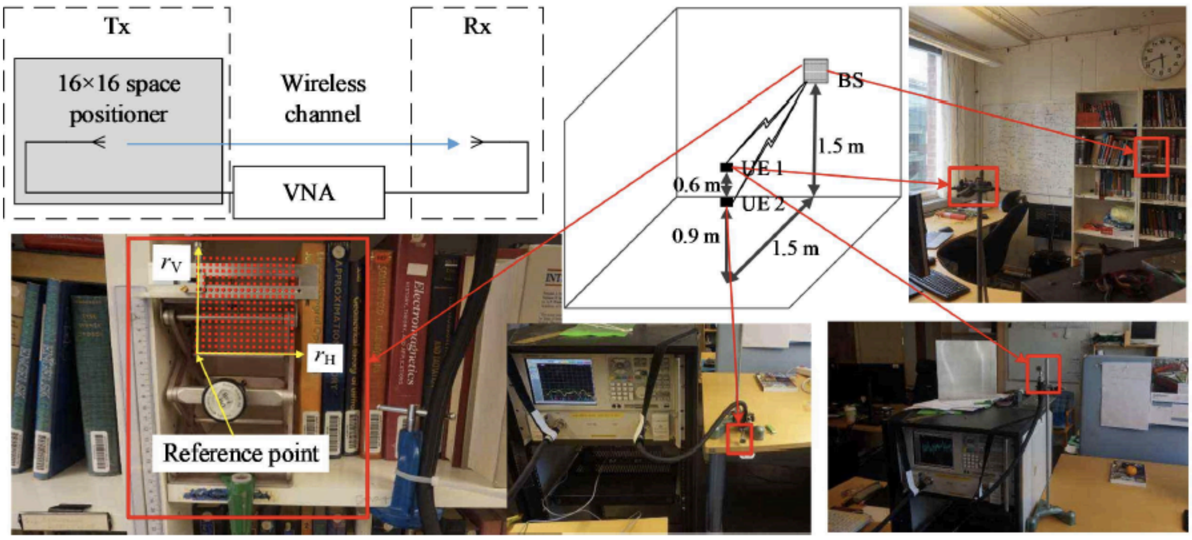


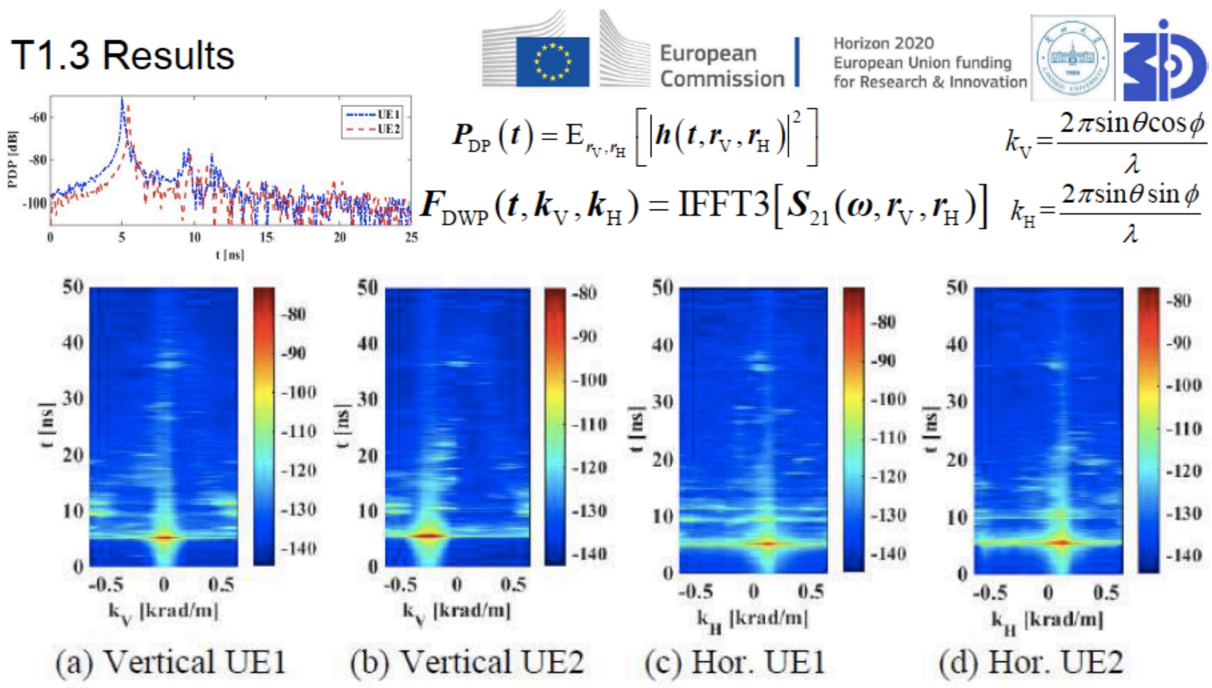
For more information please refer to:

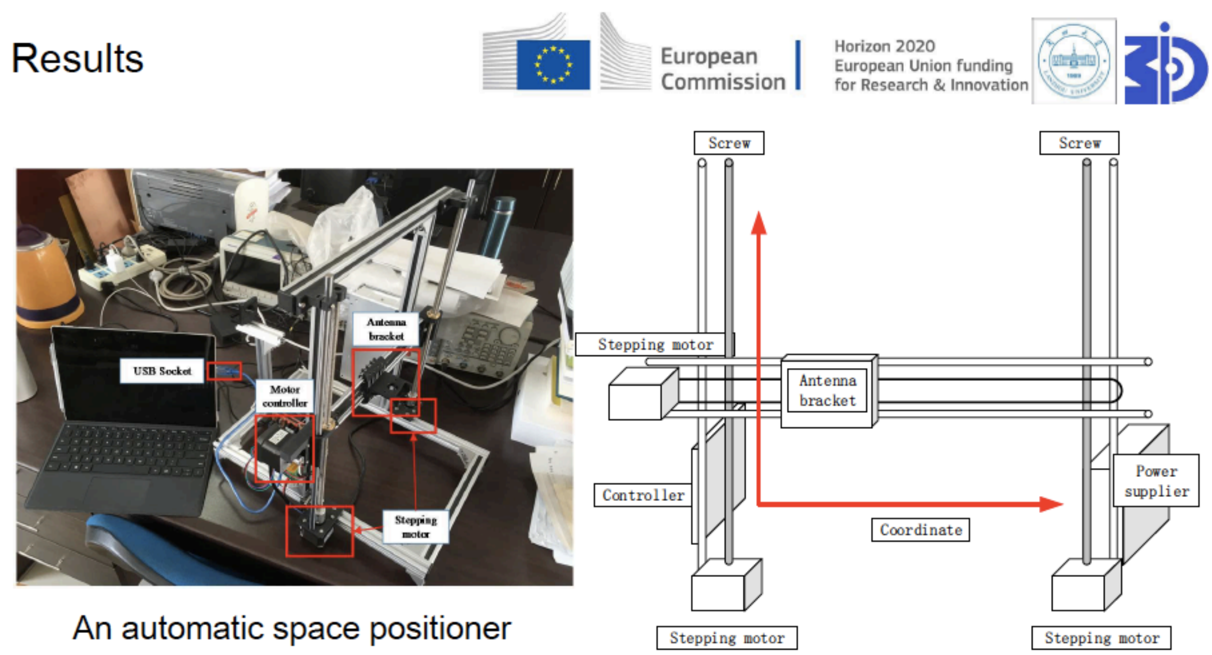
[1] The impact of antenna height on 3D channel: a ray launching based analysis, Electronics, vol. 7, no. 1, 2018.

T1.3 Indoor 3D MIMO channel measurements

European Commission | Horizon 2020 European Union funding for Research & Innovation




T1.3 Results
European Commission
Horizon 2020
European Union funding
for Research & Innovation
$P_{DP}(t) = E_{r_V, r_H}\left[\left|h(t, r_V, r_H)\right|^2\right]$
$F_{DWP}(t, k_V, k_H) = IFFT3\left[S_{21}(\omega, r_V, r_H)\right]$
$k_V = \frac{2\pi \sin\theta \cos\phi}{\lambda}$
$k_H = \frac{2\pi \sin\theta \sin\phi}{\lambda}$
PDP [dB]
t [ns]
UE1
UE2
k_V [krad/m]
k_H [krad/m]
(a) Vertical UE1
(b) Vertical UE2
(c) Hor. UE1
(d) Hor. UE2


Results
European Commission
Horizon 2020
European Union funding
for Research & Innovation
USB Socket
Motor controller
Antenna bracket
Stepping motor
An automatic space positioner
Screw
Screw
Stepping motor
Antenna bracket
Controller
Power supplier
Coordinate
Stepping motor
Stepping motor

Deliverables/Implementation

European Commission | Horizon 2020 European Union funding for Research & Innovation

Submitted deliverable

D1.1: Report on mechanism of sub-path generation in 3D ray launching. [M12]

Achieved milestones

MS1: mechanism of sub-path generation in 3D ray launching. [M12]

Published Publications

[1] Q Hong **(USFD)**, J Zhang **(LZU)**, H Zheng **(USFD)**, H Li **(USFD)**, H Hu **(USFD)**, B Zhang **(USFD)**, Z Lai **(RPN)** and J Zhang **(USFD/RPN)**, The impact of antenna height on 3D channel: a ray launching based analysis, Electronics, vol. 7, no. 1, 2018.
[2] H Li **(USFD)**, J Zhang **(LZU)**, Q Hong **(USFD)**, H Zheng **(USFD)**, and J Zhang **(USFD/RPN)**, Exploiting adaptive modulation in E-band software-defined backhaul network, IEEE CCWC, 2018.
[3] J Zhang **(LZU)**, Y Wang **(HITSZ)**, J Zhang **(USFD/RPN)**, L Ding **(HITSZ)**, Polarization Shift Keying (PolarSK): System Scheme and Performance Analysis, IEEE Trans. Veh. Tech., vol. 66, no. 11, 2018.

Publications under Review

[1] X Liao **(CQUPT)**, Y Shao **(CQUPT)**, Y Wang **(CQUPT)** and J Zhang **(USFD/RPN)**, Measurements of electromagnetic characteristics of typical construction materials over 40-50 GHz, IEEE Trans. Ant. Propag. Submitted.
[2] J Zhang **(LZU)**, A A Glazunov **(Chalmers/UT)**, J Yang **(Chalmers)**, X Chu **(USFD)**, and J Zhang **(USFD/RPN)**, An indoor massive 3D-MIMO channel sounding, IEEE ISAP, Submitted.

Publications under Preparation

[1] **(LZU,Chalmers,UT,CQUPT,USFD,RPN)**, A Minimum least squares inspired reflection rays resolution algorithm for thin material electromagnetic properties measurement, Under preparation.

Secondments

European Commission | Horizon 2020 European Union funding for Research & Innovation

First Name	Last Name	From	To	Start Date	End Date	Duration	Task	Deliverable	MS
Lars-Inge	Sjöqvist	Gapwaves	USFD	26-01-2017	26-01-2017	0.03			
Errong	Pei	CQUPT	USFD	01-01-2017	27-02-2017	1.9			
Bleron	Klaiqi	USFD	Gapwaves	01-05-2017	30-11-2017	7			
Jie	Zhang	USFD	CQUPT	13-04-2017	29-04-2017	1.4			
				14-07-2017	07-08-2017				
Haonan	Hu	USFD	CQUPT	27-03-2017	06-05-2017	1.33			
Xiaoming	Tu	Ranplan	CQUPT	20-05-2017	05-06-2017	0.57			
Bo	Ma	USFD	CQUPT	07-06-2017	22-06-2017	0.53			
Yang	Wang	HITSZ	USFD	18-06-2017	28-07-2017	1.37	T1.1	D1.1	MS1
Zhiqiang	He	HITSZ	USFD	18-06-2017	28-07-2017	1.37	T1.1	D1.1	MS1
Qi	Hong	USFD	CQUPT	24-01-2017	19-04-2017	2.9	T1.1	D1.1	MS1
Fuyou	Li	USFD	CQUPT	14-06-2017	26-07-2017	1.43			
Xiaoli	Chu	USFD	CQUPT	24-07-2017	27-08-2017	1.13			
Qiaoshou	Liu	CQUPT	USFD	24-08-2017	17-08-2018	11.83			
Jian	Yang	Chalmers	HITSZ	29-06-2017	09-08-2017	1.4			
Andrés	Alayon Glazunov	Chalmers	HITSZ	29-09-2017	29-10-2017	1.03			
Mouhamed	Abdulla	Chalmers	HITSZ	04-07-2017	04-08-2017	1.03			
Jiliang	Zhang	LZU	Chalmers	01-07-2017	28-02-2018	8	T1.3	D1.3	MS8
Peng	Wu	HITSZ	USFD	06-02-2018	25-02-2018	0.67	T1.2	D1.2	MS5
Wenfei	Yang	USFD	HITSZ	07-09-2017	05-12-2017	2.97	T1.2	D1.2	MS5
Songjiang	Yang	USFD	HITSZ	11-09-2017	22-12-2017	3.4	T1.1	D1.1	MS1
Ju	Tan	USFD	HITSZ	26-09-2017	12-11-2017	1.6	T1.1	D1.1	MS1
Hanye	Hu	Ranplan	CQUPT	24-01-2017	06-02-2017	0.93	T1.3	D1.3	MS8
Xiaoming	Tu	Ranplan	CQUPT	04-02-2018	26-02-2018	0.77			
Yuhua	Wu	Ranplan	CQUPT	14-07-2017	14-08-2017	1.03			
Bing	Xia	Ranplan	HITSZ	02-02-2018	24-02-2018	0.77			
Jiaqi	Wang	USFD	HITSZ	28-02-2018	28-05-2018	3.03			
Ju	Tan	USFD	CQUPT	04-04-2018	08-05-2018	1.17			

Secondments in 2017 for WP 1
From EU to CN

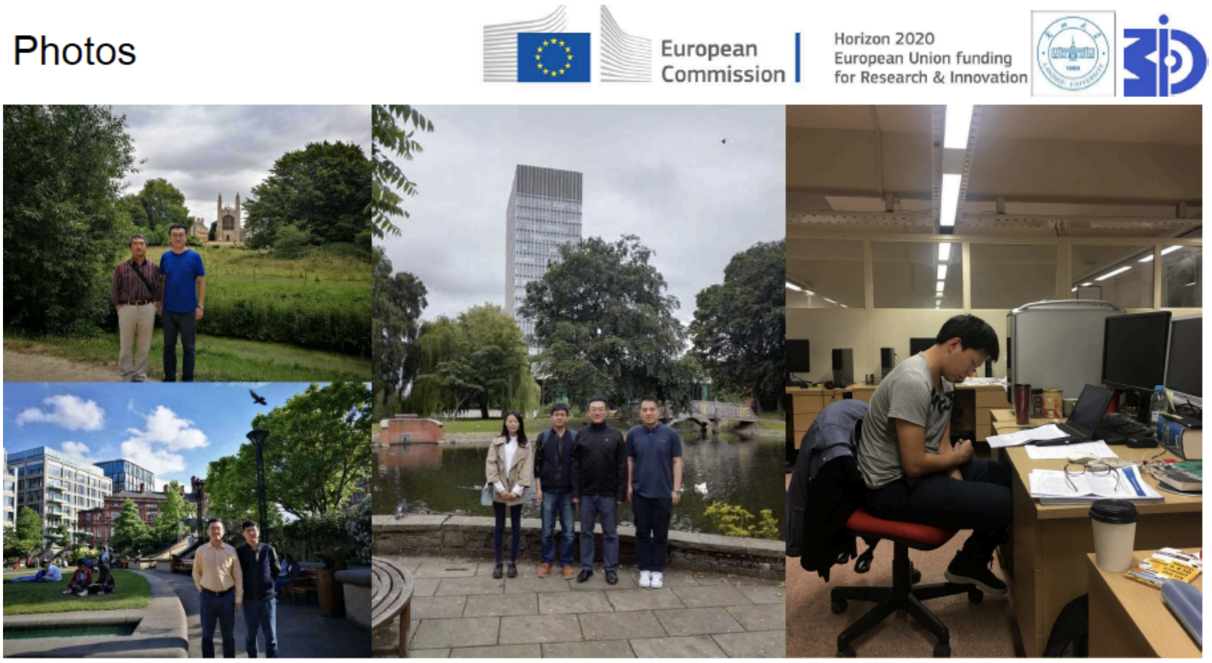
Planned secondments	22 PMs
Finished secondments	11.8PMs

Secondments in 2017 for WP 1
All

Planned secondments	35 PMs
Finished secondments	22.54 PMs

In the moment, finished secondments are behind the schedule


Photos
European Commission
Horizon 2020
European Union funding
for Research & Innovation


Photos
European Commission
Horizon 2020
European Union funding
for Research & Innovation

Future implementation

European Commission | Horizon 2020 European Union funding for Research & Innovation

Profile	From	Country	To	Country	Starting month	Duration	Task
ESR	USFD	UK	LZU	CN	17	0.62	T1.2
ER	LZU	CN	CHALMERS	SE	18	6	T1.2
ESR	USFD	UK	LZU	CN	25	2.58	T1.2
ESR	HIT	CN	CHALMERS	SE	25	12	T1.3
ER	CHALMERS	SE	HIT	CN	24	1	T1.2
ESR	CHALMERS	SE	HIT	CN	31	3	T1.2
ESR	CHALMERS	SE	HIT	CN	37	3	T1.3
ER	HIT	CN	RPN	UK	27	2.59	T1.3
ESR	LZU	CN	RPN	UK	40	4	T1.3
ER	CHALMERS	SE	RPN	UK	27	2	T1.2
ESR	CHALMERS	SE	RPN	UK	27	3	T1.3
ESR	CHALMERS	SE	RPN	UK	40	3	T1.3
ER	RPN	UK	CHALMERS	SE	20	3	T1.3
ESR	RPN	UK	CHALMERS	SE	20	6	T1.2
ESR	RPN	UK	CHALMERS	SE	23	6	T1.3

Secondments for WP 1
From EU to CN

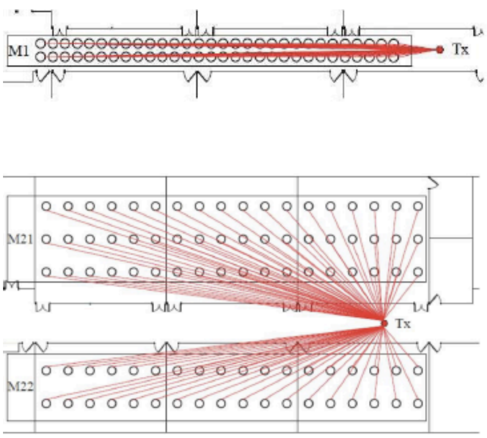
Planned secondments	45 PMs
Finished secondments	11.8 PMs
Remaining secondments	31.2 PMs

Secondments for WP 1
All

Planned secondments	81 PMs
Finished secondments	23.21 PMs
Remaining secondments	57.79 PMs

Future implementation

European Commission | Horizon 2020 European Union funding for Research & Innovation



European Commission | Horizon 2020 European Union funding for Research & Innovation

Thank you!

WP2 OTA aided 3D MIMO array antenna optimization for indoor small cells [WP lead partner: Chalmers]

D2.1 Single and Array Antennas Designs for Millimeter-Wave Applications

Andrés Alayón Glazunov, PhD, Docent.
Associate Professor, TE, University of Twente, The Netherlands.
Affiliate Associate Professor, E2, Chalmers University of Technology, Sweden.

D2.1 Deliverable: Single and Array Antennas Designs for Millimeter-Wave Applicationsan

D2.1 **Authors:**

- Sadegh Mansouri Moghaddam, E2, Chalmers University of Technology, Gothenburg, Sweden;
- Andrés Alayón Glazunov, E2, Chalmers University of Technology, Gothenburg, Sweden;
- Jian Yang , E2, Chalmers University of Technology, Gothenburg, Sweden;
- Yang Wang, Harbin Institute of Technology, Shenzhen Graduate School, China.

Editors:

- Andrés Alayón Glazunov

WP2 Objectives

WP2: OTA aided 3D MIMO array antenna optimization for indoor small cells

Goals: WP2 aims to characterize and optimize the performance of 3D MIMO array antennas for indoor small-cell APs, by

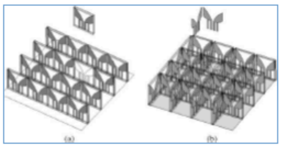
- Over-The-Air (OTA) aided optimization of array antennas for 3D SMX and 3D beamforming;
- OTA characterization of array antennas in rich isotropic multi-path (RIMP) and random-line-of-sight (RLOS) environments;
- Testing if array antennas designed to work well in RIMP and RLOS environments will work well in any other environment.

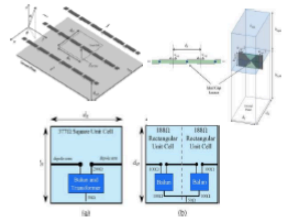
D2.1 Single and Array Antennas Designs for Millimeter-Wave Applications

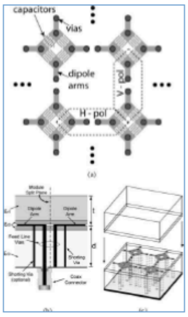
- Needs:
  - High data-rate communications has drawn lots of attention towards the millimeter-wave (mm-wave) frequencies due to the availability of large chunks of bandwidth.
  - The applications are many, e.g., high resolution imaging and wireless communications over short distance at the V-band (60 GHz), but also over longer ranges at 20-40 GHz, suitable for 5G wireless systems.
- Array antenna characteristics capable of delivering desired performance:
  - Ultra-wideband (UWB),
  - wide-scanning,
  - dual-polarized phased array antennas;
  - Such array antennas offer multi-channel and multi-function configurations with the ability to electronically scan the beam.
- Requirements:
  - Desired performance as described above
  - Easy to manufacture and assemble
  - Low cost

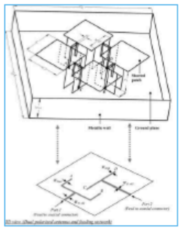
D2.1 Single and Array Antennas Designs for Millimeter-Wave Applications

- State of the art:
  - *Tapered-slot arrays* can provide a large bandwidth of 10:1 [5]. However, these antennas are relatively bulky and difficult to assemble.
  - *Planar dipoles* are low-profile and versatile candidates. Using the Wheeler's current sheet [6], tightly-coupled dipoles above the ground plane can provide a relatively large bandwidth of 9:1 [7]. However, these arrays need a wideband balun for each element to sustain their performance. In [8-10], tightly-coupled dipoles are used together with a passive Marchand baluns.
  - To eliminate the complexity of the external balun, ***planar ultra-wideband modular arrays (PUMAs)*** are proposed in [11,12]. PUMAs are planar structures with an integrated feeding network which can be manufactured by using simple multilayer PCB. Because of the integration of the feed, the need to have an external balun is eliminated in these antennas.
  - Another example of wideband antennas with integrated feeding network are the ***Magneto-Electric Dipoles (MED)*** [13-15]. However, these antennas are mostly considered for single-antenna structures.
- **All** the above-mentioned UWB arrays **will face scalability problems** in terms of manufacturing and assembling as we move up to higher mm-wave frequencies.
- Although, there are **many array antennas designed for mmW bands**, most of them are relatively **narrow band** [16] or require a more **complex and expensive manufacturing process** [17].









European Commission | Horizon 2020 European Union funding for Research & Innovation

D2.1 Single and Array Antennas Designs for Millimeter-Wave Applications

- Proposed Solutions:
  - Designed an ultra-wideband bowtie antenna structure, of which the feeding mechanism is an integrated feeding network, implemented by multilayer PCB and via holes, the bandwidth of 2.6:1 is achieved with a reflection coefficient better than -8 dB for the single antenna, the radiation pattern is stable, and the directivity is between 5.8-8.3 dBi over the frequency band of 20-50 GHz.
  - Designed a dual-polarized ultra-wideband element based on tightly-coupled dipoles together with an integrated feeding network, where dual-polarization is implemented by using dual-offset configuration, and the relative bandwidth of 2.3:1 is achieved in terms of VSWR < 3 for scanning angles up to 60 GHz.
- **One can see the resemblance of the proposed structure to the tightly-coupled dipoles fed with Marchand baluns, the MEDs and the PUMAs.**
- **Many different elements are combined in the design leading to a synergetic solution!**

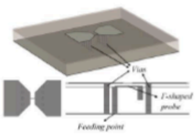


Figure 1: The proposed antenna structure.

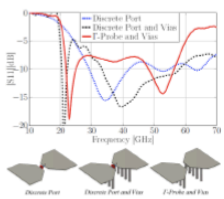


Figure 2: The comparison of the reflection coefficient for three different excitations.

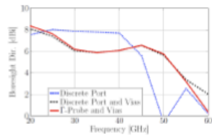


Figure 3: The comparison of the boresight directivity for three different excitations.

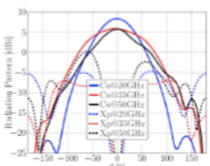


Figure 4: The radiation pattern of the proposed antenna in 45°-plane (D-plane), at three different frequencies of 20 GHz, 35 GHz and 50 GHz.

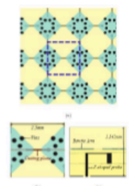


Figure 5: The geometry of the proposed antenna.

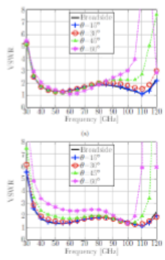


Figure 6: Simulated active VSWR versus frequency for different scanning angles at a) E-plane and b) H-plane.

European Commission | Horizon 2020 European Union funding for Research & Innovation

European Commission | Horizon 2020 European Union funding for Research & Innovation

Achievements

In WP2, scientific research work has been carried out for D2.1, which has resulted in

- an ultra-wideband bowtie antenna structure suitable for mm-wave applications and
- a dual-polarized ultra-wideband element in an infinite array environment for phased array antenna for mm-wave applications.

D2.1 presents the necessary groundwork to produce optimized array antennas for 3D Spatial Multiplexing (SMX) and 3D Beamforming that are parts of Task 2.1. The results of this deliverable lay the ground to work produced in Task 2.1 and is the input to work produced Task 2.2, Task 1.2 and Task 1.3.

On the personal level

- ***It was great experience to visit HITSZ and to meet new researchers and to make new friendships!***
- ***The project has helped to widen my scientific collaborations and to get tenure at the University of Twente!***

European Commission | Horizon 2020 European Union funding for Research & Innovation

CHALMERS Chalmers University of Technology

Development of Massive MIMO Antenna Arrays for 5G Wireless Systems

Jian Yang
Chalmers University of Technology
May 23th, 2018

European Commission | Horizon 2020 European Union funding for Research & Innovation

CHALMERS Chalmers University of Technology

Background

- Professor at Antenna Group, Chalmers University of Technology, Gothenburg, Sweden
  - PhD 2001 at Chalmers
  - Research engineer at Chalmers up to 2004,
  - 2004-2005 senior engineer at COMHAT
  - 2005 Assistant professor at Chalmers
  - 2010 Associated Professor at Chalmers
  - 2016 Professor at Chalmers

CHALMERS Chalmers University of Technology

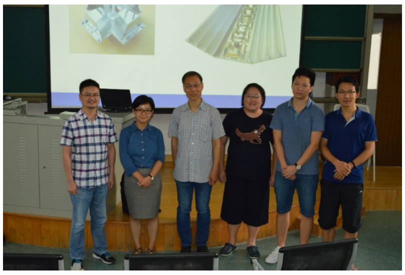
Background

- Main Research Area
  - mmWave PCB/Sillicon antennas
  - mmWave multilayer phased array antennas
  - mmWave SWE (sheet waveguide element) antennas
  - Gap waveguide antennas
  - ultra-wideband (UWB) antennas
  - Over-the-Air measurement technologies
  - THz antenna
  - UWB radar systems
  - computational electromagnetics,
  - hat-fed antennas and reflector antennas
  - microwave components

CHALMERS Chalmers University of Technology

Secondment

- Seconded from Chalmers to HITSZ (Harbin Institute of Technology Shenzhen Graduate School), Shenzhen, China, 20170628-20170809.
  - Seminar: delivery of knowledge to HITSZ
  - Several discussion meetings: Channel sounding, Channel modeling, etc. (Receiving knowledge)
- Planning 2nd secondment at Ranplan 20180625-20180726



CHALMERS Chalmers University of Technology

Contribution to the project

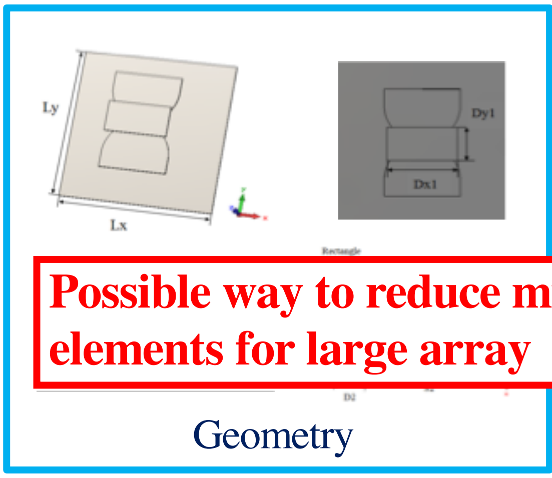
- Contribution to the WP2
- OTA aided 3D MIMO array antenna optimization for indoor small cells
- K. Wan[1], C. Xie[1], Y. Zheng[1], J. Yin[1], **Jian Yang[3]** "A Multilayer-Stacked UWB Yagi Antenna," ISAP2017 in Thailand, Nov. 2017.
- Y. Zheng[1], J. Yin[1], X. Wang[2], X. Wan[2], Runqi Wu[1], Z. Liu[1] and Jian Yang[3] "Dual-polarized Broadband Capped Bow-tie Antenna Subarray for 5G Communication" PIERS, July 2018.

[1]Hunan University, China [2]State Grid Hunan Electric Power Company, China

[3]Chalmers University, Sweden

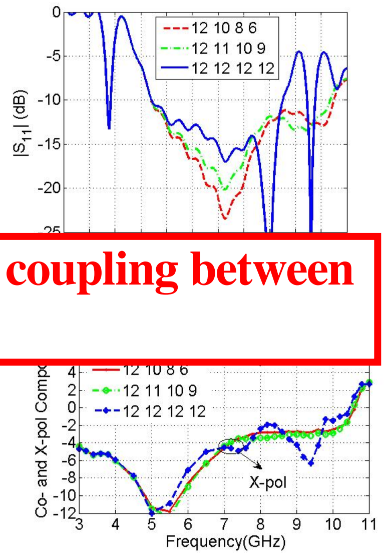
CHALMERS Chalmers University of Technology

A Multilayer-Stacked UWB Yagi Antenna



Possible way to reduce mutial coupling between elements for large array

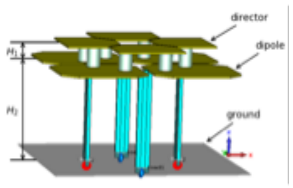
Geometry

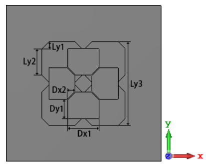


S11 and co-polar directivity and cross-polar directivity vs. different y-axis width directors. The marking of 12 10 8 6 means the width of the 1st (closest to the driver dipole), 2nd, 3rd, and 4th director, respectively.

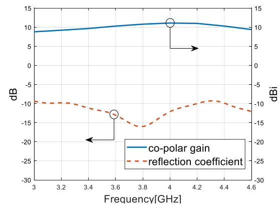
CHALMERS Chalmers University of Technology

Dual-polarized Broadband Capped Bow-tie Antenna Subarray for 5G Communication



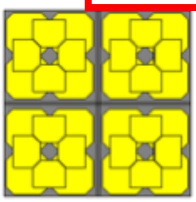


Geometry of the dual- polarized element antenna

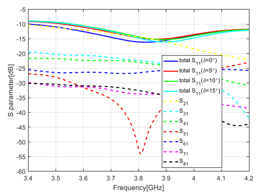


Reflection coefficient and co-polar gain of the element antenna

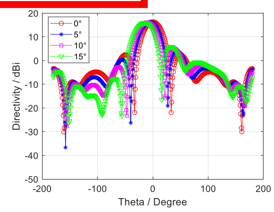
Preparation of large MIMO array



Configuration of the proposed 2x2 antenna subarray



S-parameter curves vs. beam steering angle

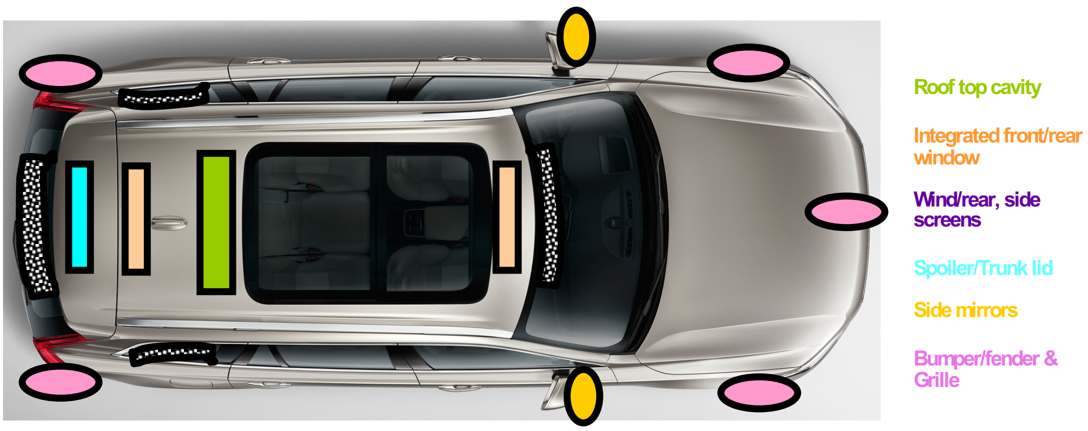


Radiation pattern

CHALMERS Chalmers University of Technology

Future work: 5G antenna concept

focusing on indoor parking system and communication system



CHALMERS Chalmers University of Technology

Thanks

The University Of Sheffield.

Coverage Analysis of Ultra-densely Deployed Indoor Small-Cell Networks

Haonan Hu

Department of Electronic and Electrical Engineering, University of Sheffield, Sheffield, UK

European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Background

2

Education:

- *Oct/2014 – present*: **PhD student** in Communication, Dept. of Electronic and Electrical Engineering, **University of Sheffield**, Sheffield, UK
- *Sep/2010 – June/2013*: **MEng** in Communication and Information System, Dept. of Communication and Information Engineering, **Chongqing** University of Posts and Telecommunications, Chongqing, China
- *Sep/2006 – June/2010*: **BEng** in Communication, Dept. of Information and Communication Engineering, **Beijing** University of Posts and Telecommunications, Beijing, China

European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Secondment

3

- From University of Sheffield to Chongqing University of Posts and Telecommunications (27/03/2017 – 06/05/2017)
- **WP3-Task 3.1**: Derive fundamental performance limits of 3D MIMO small-cell networks in 3D indoor environments



European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Contributions

4

- Incorporating stochastic geometry into the limited-range indoor small-cell network analysis
- LOS and NLOS probability for a 2D indoor environment with walls locating randomly
- Analytical coverage probability is derived and validated by simulation
- Work has been accepted in *IEEE VTC2018-Fall* in Chicago, Illinois, USA.

H. Zheng, J. Zhang, **H. Hu**, and J. Zhang, "The Analysis of Indoor Wireless Communications by a Blocka Model in Ultra-dense Networks"

European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Indoor Coverage Analysis

5

Introduction

Motivation:

- Indoor layout varies significantly in different floors or buildings
- The limitation of walls (orientations, length)

Limitations:

1. Difficult to incorporate reflection
2. Simplified assumptions, such as symmetric indoor space, user locating at center, channel model.

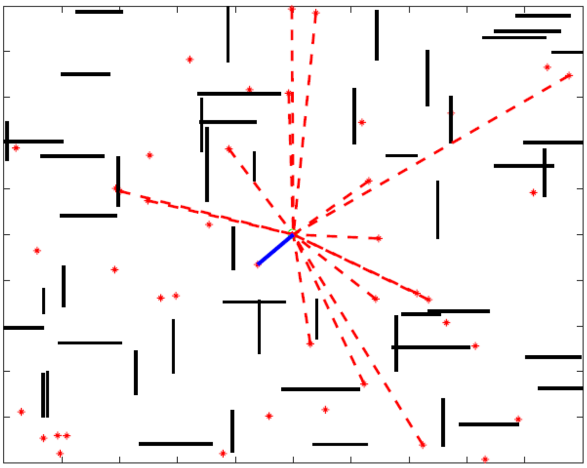
European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Indoor Coverage Analysis

6

System Model



European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Indoor Coverage Analysis

7

SIR for the typical user:

$$\mathrm{SIR}=\frac{h_0 l_{S_0}(r_0)}{\sum_{i\in\Phi/\{0\}} h_i l_{S_i}(r_i)} \qquad \begin{cases} l_{\mathrm{L}}(r)=a_{\mathrm{L}} r^{-\alpha_L} \\ l_{\mathrm{N}}(r)=a_{\mathrm{N}} r^{-\alpha_{\mathrm{N}}} \end{cases}$$

Assumptions for simplicity:

Impenetrable wall blockages for mmWave signals

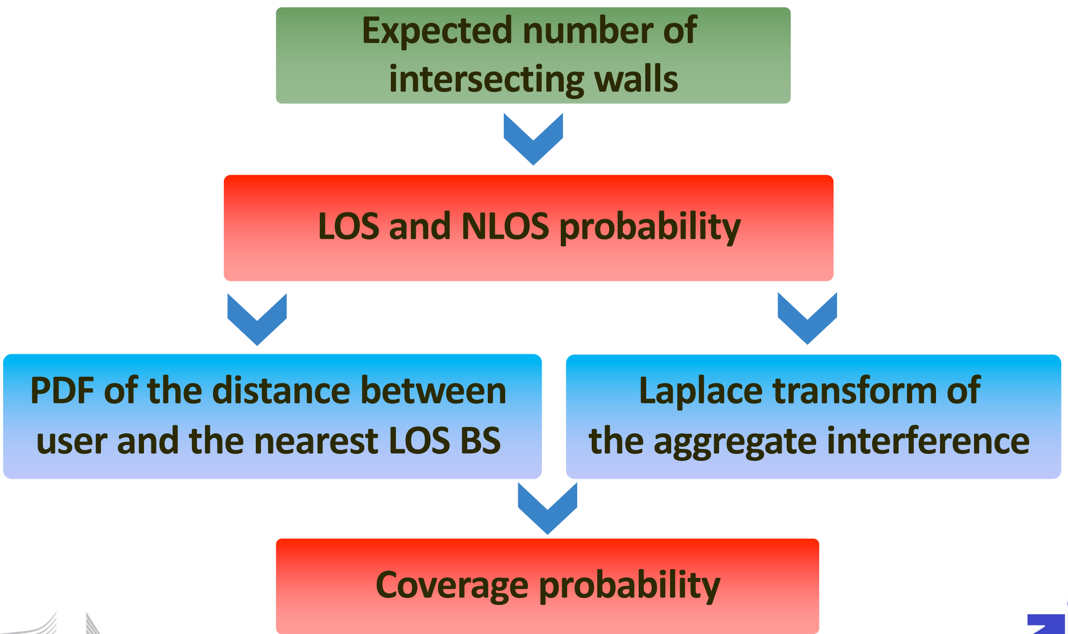
$$\mathrm{SIR}=\frac{h_0 a_{\mathrm{L}} r_0^{-\alpha_{\mathrm{L}}}}{\sum_{i\in\Phi/\{0\}} 1_{S_i=\mathrm{L}} h_i a_{\mathrm{L}} r_0^{-\alpha_{\mathrm{L}}}}$$

The University Of Sheffield.

Indoor Coverage Analysis

8

For a link with known length and angle:



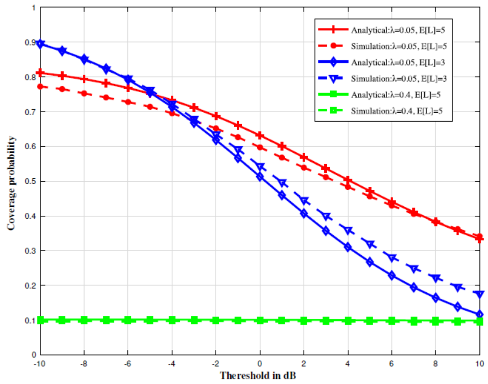
European Commission | Horizon 2020 European Union funding for Research & Innovation

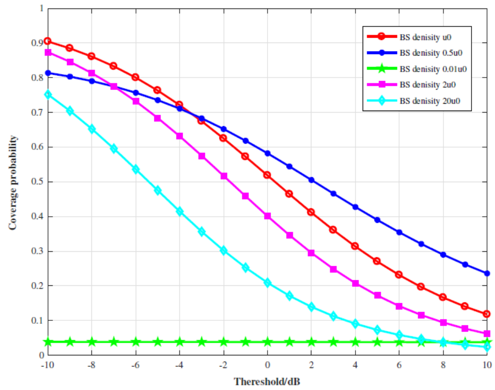
The University Of Sheffield.

Indoor Coverage Analysis

9

Results:





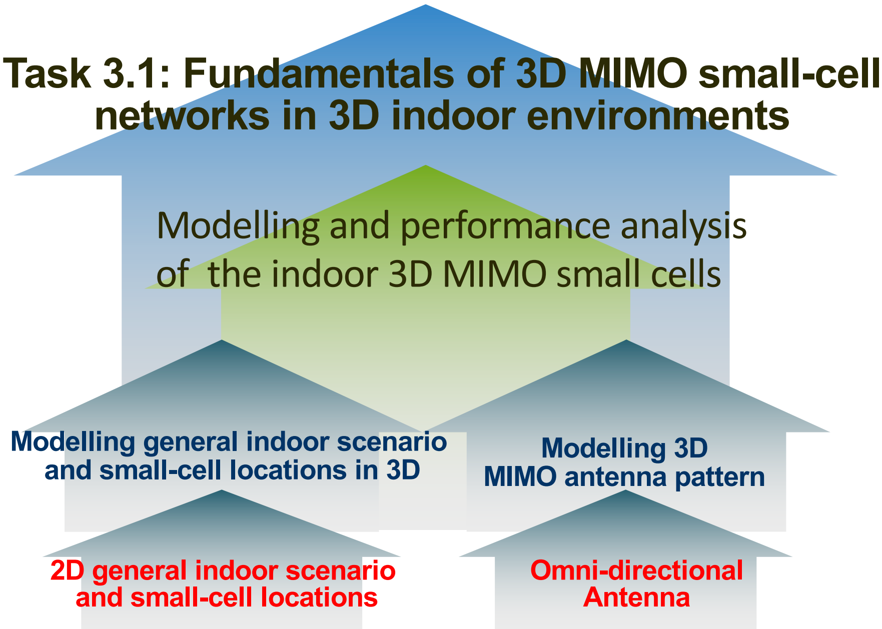
European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Indoor Coverage Analysis

10

Future works to achieve task 3.1:



European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Conclusion

11

- We investigate the performance of indoor ultra-dense small-cell networks base on a wall blockage model.
- The analytical coverage probability is derived for the case of impenetrable wall blockages.
- Require extension to achieve goals in task 3.1

European Commission | Horizon 2020 European Union funding for Research & Innovation

03/07/2018 The University of Sheffield / Department of Eelectronic and Electrical Engineering

The University Of Sheffield.

12

Thank You! &Any Questions?

European Commission | Horizon 2020 European Union funding for Research & Innovation

European Commission | Horizon 2020 European Union funding for Research & Innovation

Massive MIMO Relaying with Irregular Antenna Arrays

Bleron Klaiqi
Dept. of Electronic and Electrical Engineering,
University of Sheffield, UK

The University Of Sheffield.

FELLOW INFO & BACKGROUND

- **Bleron Klaiqi**
  - ER
  - PhD student in Electronic and Electrical Engineering at the University of Sheffield, Sheffield, UK. (02/2013-11/2017)
- **Education**
  - Dipl.-Ing. (Msc) in Electrical Engineering and Information Technology, RWTH Aachen University, Germany. (12/2004)
- **Experience**
  - ER for H2020 Decade project seconded at Iquadrat, Barcelona, Spain. (02/2016-01/2017)
  - Senior Software Engineer for 3G and triple RAT (2G, 3G and 4G) L1 inter-working at Intel Corporation, Nuremberg, Germany. (05/2006-11/2012)

European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

FELLOW INFO & BACKGROUND

- Secondment
  - Seconded from University of Sheffield to Gapwaves, Gothenburg. (02/05/2017-30/11/2017)


European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

CONTRIBUTION TO THE PROJECT

- Contribution to the WP3.
- Investigation of massive MIMO performance for irregular antenna arrays.
- Both simulation and theoretical studies are performed.
- Results to be submitted soon in an IEEE letter.

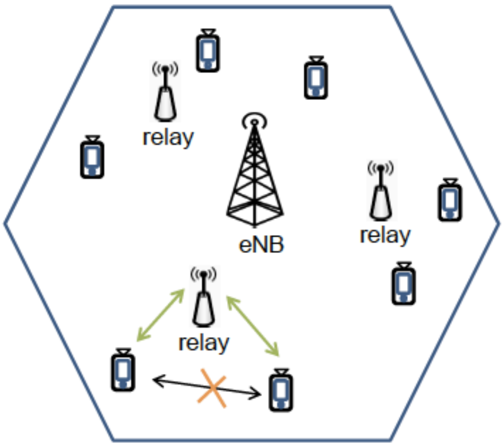
European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Massive MIMO Relaying

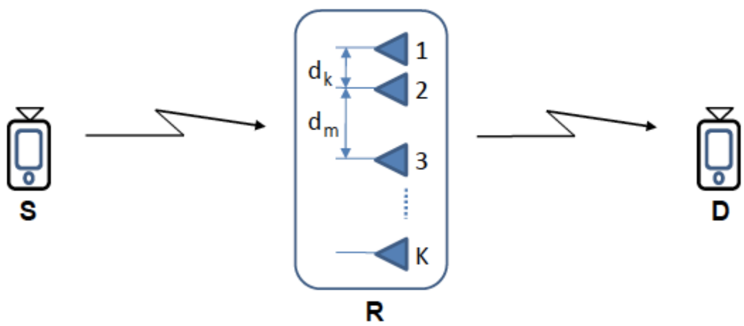
- Channel conditions may not be favourable to support direct D2D communications.

  => use massive MIMO relays to assist the D2D communication.



Massive MIMO Relaying

- Irregular antenna array, i.e., unequal inter-element distances.



- Three main activities (training, antenna selection, data transmission).

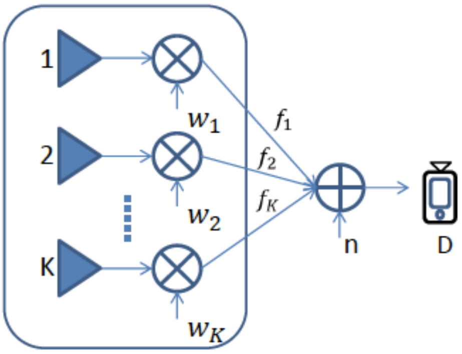
Training (S->R)	Training (D->R)	Antenna Selection	Data Transmission (S->R)	Data Transmission (R->D)

European Commission
Horizon 2020
European Union funding
for Research & Innovation
The University Of Sheffield.

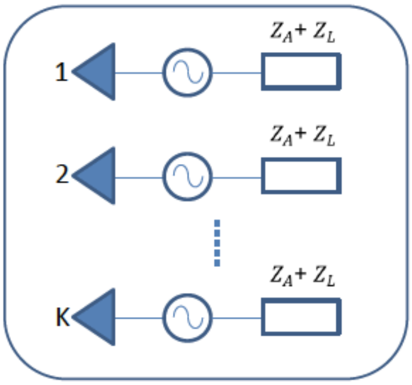
Massive MIMO Relaying

- We consider RX/TX beamforming and antenna coupling.

- Optimal weights ($w_1,\ldots,w_K$) are calculated to minimize transmission power and satisfy target data rate.



- Antenna coupling model with antenna impedance (Z_A) and load impedance (Z_L).



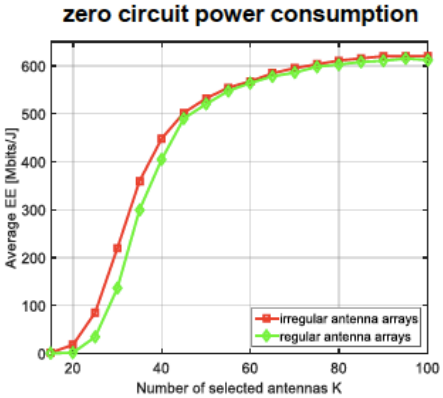
European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

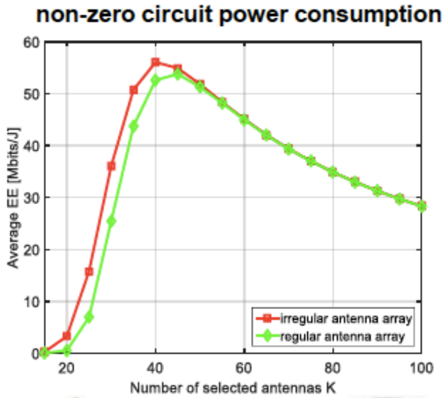
Simulations results

- We investigate average energy efficiency (EE) of massive MIMO relaying under maximum transmission power constraint.
- EE gives number of successfully transmitted bits per joule (J).
- For comparison purposes also regular antenna arrays, i.e., equal inter-element distances are simulated.
- Massive MIMO relay with 100 antennas is deployed.

zero circuit power consumption



non-zero circuit power consumption



European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

TRANSFER OF KNOWLEDGE/EXPERIENCE

Through ToK sessions at Gapwaves premises

- Received knowledge on antenna design.
- Received knowledge on massive MIMO.
- Provided knowledge on multi-hop D2D communications to Gapwaves staff.

European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

EXPECTED IMPACT ON FUTURE CAREER

- Study of massive MIMO complements my knowledge on multi-hop D2D communications.
- Enables incorporation of massive MIMO in my future research for system level performance evaluation.
- Opportunity to start a new collaboration with Gapwaves for joint research project proposals and publications.
- Experience obtained in massive MIMO very useful for my current job in 5G baseband research at Huawei, Kista, Sweden.

European Commission | Horizon 2020 European Union funding for Research & Innovation

The University Of Sheffield.

Ranplan WIRELESS

Contents

European Commission | Horizon 2020 European Union funding for Research & Innovation

Background - Work Description

- WP1: Indoor 3D MIMO channel modelling
  - Lead by HITSE with the active participation of CHALMERS, USFD, and RPN
  - Task 1.1: Indoor 3D ray launching channel simulation incorporating elevation sub-path generation (HITSZ, USFD and RPN)
    - The mechanisms of sub-path generation will be studied by mapping the positions of clusters to the sub-path parameters, through theoretical analysis and FDTD simulation. Specifically, the relationship between the elevation sub-path angular spread (and the distribution and numbers of mid-paths and sub-paths per cluster) and other channel parameters such as path length, positions and roughness of reflectors in indoor environments will be investigated. An indoor 3D MIMO channel simulation platform will be established by integrating the mechanisms of azimuth and elevation sub-path generation into the ray launching based 2D MIMO channel model
- WP3: Network planning and optimization for indoor 3D MIMO small cells
  - Lead by USFD with the active participation of RPN, CQUPT, CHALMERS and HITSZ
  - Task 3.2: Optimization of 3D MIMO configurations for indoor small cell APs
    - Investigating how 3D MIMO configurations (for 3D beamforming or 3D SMX) should be optimized for small-cell APs to mitigate inter-cell interference and to provide very high spectral efficiency in indoor environments. The spectral efficiency achievable from the optimized 3D MIMO configurations will be evaluated.
  - Task 3.3: Optimization of 3D MIMO small-cell network deployment in typical indoor environments
    - Investigates the optimization of 3D MIMO small-cell network deployment in practical indoor environment. First, signal quality mapping for target traffic load will be performed with different 3D MIMO array antennas and AP locations, in order to reveal how the user experience and network performance very with different deployment. Second, small-cell APs and their 3D MIMO array antennas will be integrated with the building structures of certain material properties. Finally, the deployment of 3D MIMO small-cell APs in practical indoor environments will be optimized and assessed through system-level simulation and small-scale real-world deployment.

European Commission | Horizon 2020 European Union funding for Research & Innovation

3

Background – MIMO and 3D MIMO

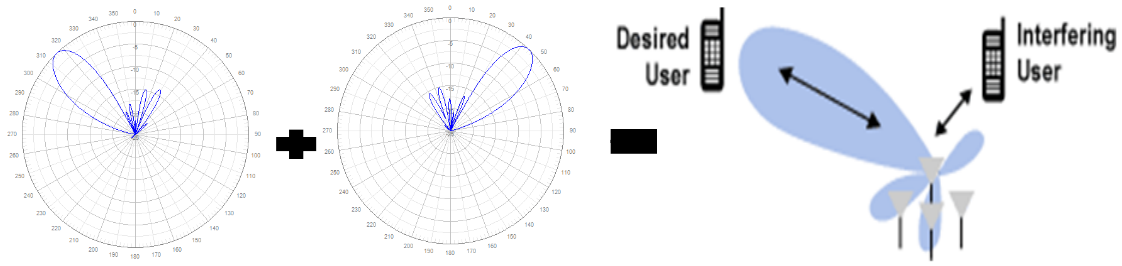
- LTE MIMO has been in 3GPP standards since Release 8 (early 2009)
  - LTE supports many different MIMO modes (for different conditions), allows dynamic switching
  - MIMO systems can send streams to single users (SU-MIMO) or to multiple users (MU-MIMO) within the same time and resource block
  - LTE-Advanced (3GPP Release 10) supports 8 steams of DL MIMO
- LTE-A Pro (Release 13; early 2016) has Full Dimension MIMO (FD-MIMO)
  - 8 Steams; 64-element antenna array; elevation added
  - Sprint asking Nokia for 64x64 FD-MIMO to use on the 2.5GHz LTE network (Lightreading)
- 3D MIMO is a key component of 5G, currently being developed
  - Probably < 6GHz; algorithms steer nulls to other UEs (Beamforming)
  - Channel State Information calculation complexity from UE to base station (TDD is prefer)

European Commission | Horizon 2020 European Union funding for Research & Innovation

4

Background - 2D-MIMO

- 2D (2-dimensional) -Beamforming is a 2D-MIMO techniques
- Beamforming is a downlink multi-antenna technique. The transmitter of a base station weights the data before transmission, forming narrow beams and aiming the energy at the target user
- **The benefits of beamforming are as follows:**
  - Increased SINR in the direction of incoming wave from the UE
  - Increased system capacity and coverage
- Influence on the KPI
  - Cell average throughput
  - Cell edge user throughput

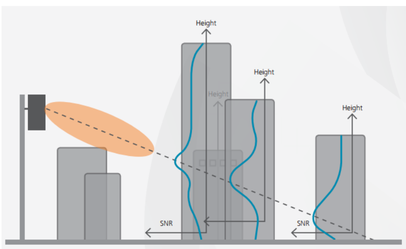


Cross Polarization: -45 Cross Polarization: +45

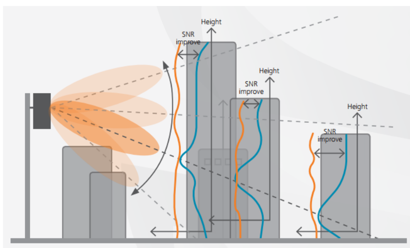
5

Background - 3D-MIMO

- AAS is a 3D-Beamforming techniques
- AAS provides electronic beam control in both the horizontal and vertical domains. This allows many spatial processing techniques to extend into the vertical domain
- Benefits: Expand capacity and coverage



2D-BF: Vertical coverage is limited



3D-BF: Coverage is extended

6

Background – 3D MIMO Benefit

- Classic Multi-User MIMO and 3D MIMO

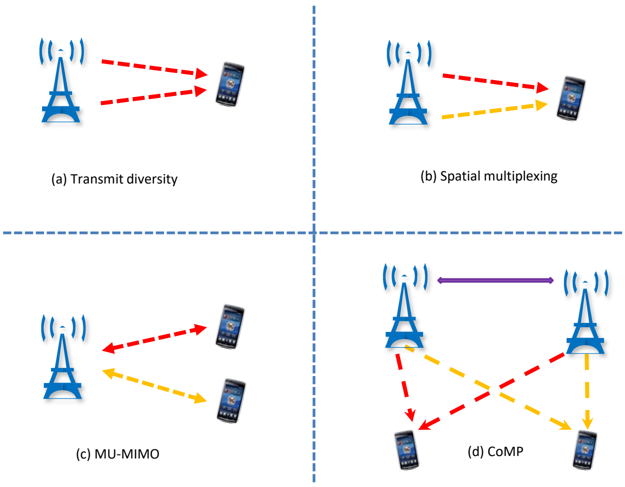
	Classic Multi-user MIMO	3D MIMO
Antenna M, Users K	$M \approx K$	$M \gg K$
Signal Processing	Non-linear is preferred	Linear is near optimal
Duplexing Mode	Designed for FDD and TDD	Design for TDD w. reciprocity
Instantaneous Channel	Known at BS and User	Only be needed at BS
Channel Quality	Affected by frequency-selective and fast fading	Almost no channel quality variations
Variation in User Load	Scheduling needed if M<K	Scheduling seldom needed
Resource Allocation	Rapid due to fading	Only on a slow time scale
Cell-edge Performance	Only good if BS cooperate	Improved by array gain of M
BS Cooperation	Highly beneficial if rapid	Only long-term coordination

European Commission | Horizon 2020 European Union funding for Research & Innovation

7

MIMO Modelling in Ranplan

- MIMO transmission modes supported

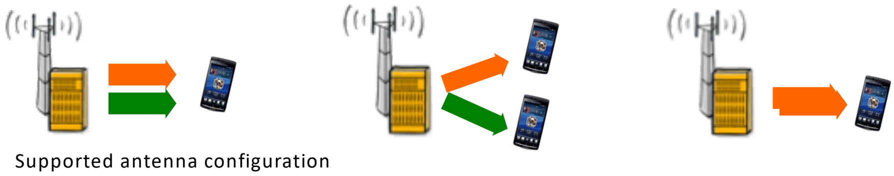


European Commission | Horizon 2020 European Union funding for Research & Innovation

8

Downlink & Uplink MIMO in Ranplan

- **Downlink MIMO**
  - Supports Spatial Multiplexing (Close-loop and open-loop), MU-MIMO, Transmit Diversity, and CoMP

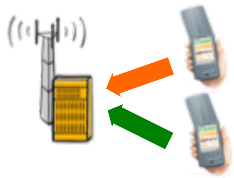


  - Supported antenna configuration

    1x1, 2x2, 4x2, 4x4

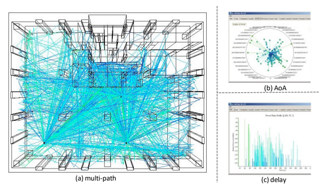
- **Uplink MIMO**
  - Support SIMO, MU-MIMO, and CoMP
  - Supported antenna configuration

    1x1, 1x2, 1x4

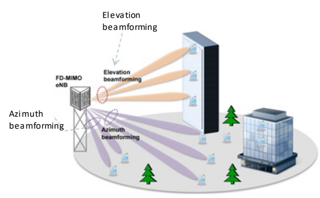


3D MIMO Modelling in Ranplan

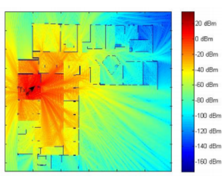
- Multipath: consider multi-factor to generate the multipath
  - Small scale fading: delay, AoA, AOD etc.
  - Polarization: vertical, horizontal, cross



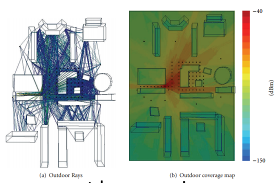
- Beamforming:
  - Electrical down tilting to form vertical beamforming
  - Electrical azimuth to form azimuth beamforming
  - Full dimension direction beams in the network



- Indoor/outdoor
  - Indoor and outdoor multipath propagation
  - Outdoor to indoor or indoor to outdoor multipath propagation



Indoor scenario



outdoor scenario

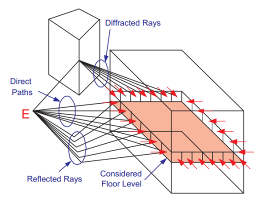
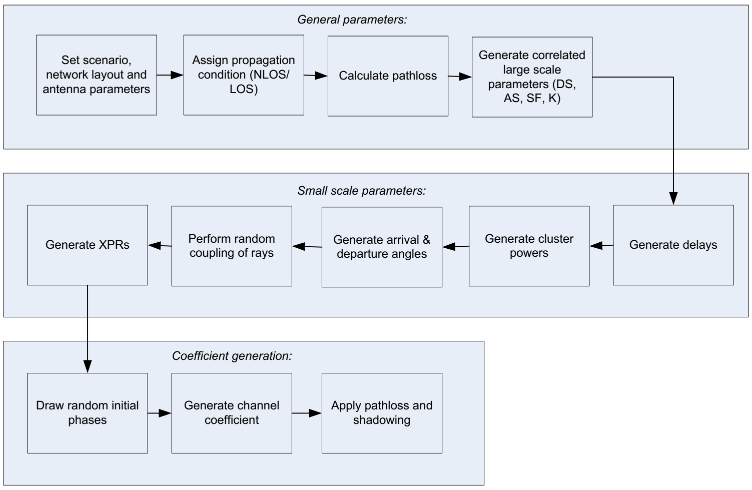


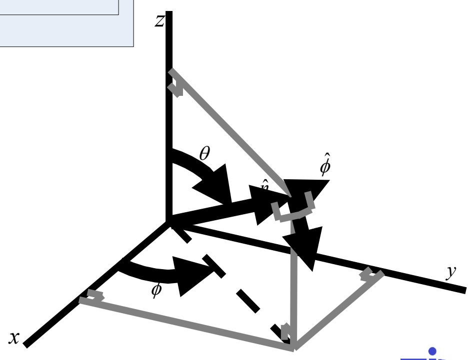
Fig. 2. Schematic representation of the combined approach. First the outdoor part is simulated, then the incoming indoor flows are computed and used for the indoor simulation

outdoor to indoor scenario

Channel Modelling in Ranplan

- General 3D MIMO modelling: Channel coefficient generation





11

Channel Modelling in Ranplan

- Combine the multi-path parameters and phase of each element to obtain the final MIMO channel coefficient matrix

$$H_{u,s,n}^{\text{NLOS}}(t)=\sqrt{\frac{P_n}{M}}\sum_{m=1}^{M}\begin{bmatrix}F_{rx,u,\theta}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)\\ F_{rx,u,\phi}\left(\theta_{n,m,ZOA},\phi_{n,m,AOA}\right)\end{bmatrix}^{T}\begin{bmatrix}\exp\left(j\Phi_{n,m}^{\theta\theta}\right) & \sqrt{\kappa_{n,m}^{-1}}\exp\left(j\Phi_{n,m}^{\theta\phi}\right)\\ \sqrt{\kappa_{n,m}^{-1}}\exp\left(j\Phi_{n,m}^{\phi\theta}\right) & \exp\left(j\Phi_{n,m}^{\phi\phi}\right)\end{bmatrix}\begin{bmatrix}F_{tx,s,\theta}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)\\ F_{tx,s,\phi}\left(\theta_{n,m,ZOD},\phi_{n,m,AOD}\right)\end{bmatrix}\exp\left(\frac{j2\pi\left(\hat{r}_{rx,n,m}^{T}.\bar{d}_{rx,u}\right)}{\lambda_0}\right)\exp\left(\frac{j2\pi\left(\hat{r}_{tx,n,m}^{T}.\bar{d}_{tx,s}\right)}{\lambda_0}\right)\exp\left(j2\pi\frac{\hat{r}_{rx,n,m}^{T}.\bar{v}}{\lambda_0}t\right)$$

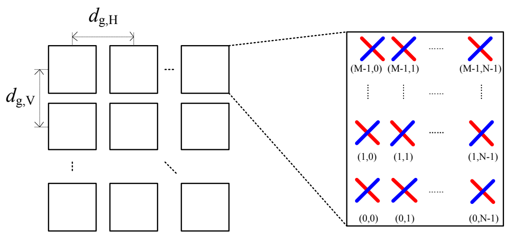
- Parameters

Parameter	Notation
LOS AOD	$\phi_{LOS,AOD}$
LOS AOA	$\phi_{LOS,AOA}$
LOS ZOD	$\theta_{LOS,ZOD}$
LOS ZOA	$\theta_{LOS,ZOA}$
AOA for cluster *n*	$\phi_{n,AOA}$
AOD for cluster *n*	$\phi_{n,AOD}$
AOA for ray *m* in cluster *n*	$\phi_{n,m,AOA}$
AOD for ray *m* in cluster *n*	$\phi_{n,m,AOD}$
ZOA for cluster *n*	$\theta_{n,ZOA}$
ZOD for cluster *n*	$\theta_{n,ZOD}$
ZOA for ray *m* in cluster *n*	$\theta_{n,m,ZOA}$
ZOD for ray *m* in cluster *n*	$\theta_{n,m,ZOD}$
Receive antenna element *u* field pattern in the direction of the spherical basis vector $\hat{\theta}$	$F_{rx,u,\theta}$
Receive antenna element *u* field pattern in the direction of the spherical basis vector $\hat{\phi}$	$F_{rx,u,\phi}$
Transmit antenna element *s* field pattern in the direction of the spherical basis vector $\hat{\theta}$	$F_{tx,s,\theta}$
Transmit antenna element *s* field pattern in the direction of the spherical basis vector $\hat{\phi}$	$F_{rx,s,\phi}$

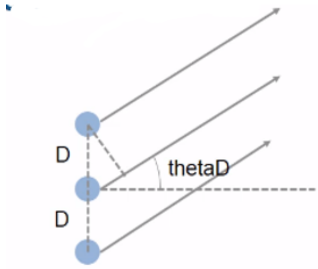
12

Antenna Modelling in Ranplan

- Design challenges
  - Simulation speed of traditional antenna modelling is low
  - Difficult to simulate the massive antenna coupling
  - Optimal beamforming
- Cluster-based modelling
  - Calculate the cluster: delay, angle, and power

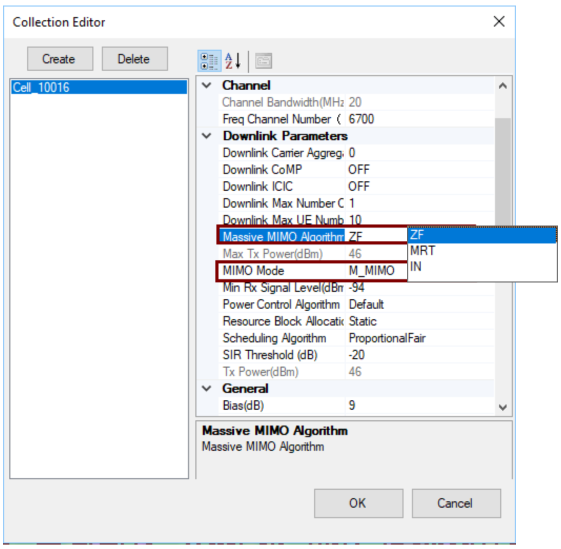


  - Intra-cluster
    - Delay for the antenna K: K*D*sin(thetaD)/C
    - Based on the distribution of delay, angle



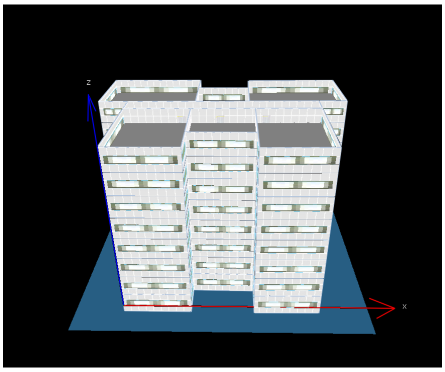
Performance Simulation - Configuration

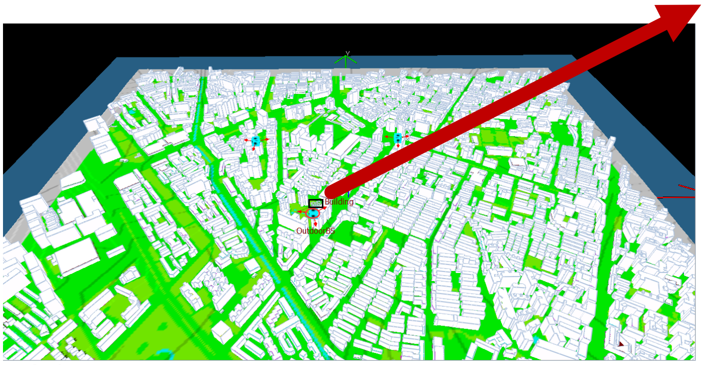
- Mode and algorithm configuration
  - Transmission mode: M_MIMO
  - 3D MIMO algorithm
    - Zero forcing
    - Maximum ratio transmission



Performance Simulation – Outdoor-Indoor Scenario

- Outdoor-Indoor scenario with 8-storey building
  - FDD-LTE Band 22 3500MHz (20MHz Bandwidth)
  - 9 Macro cells configurated with 64 antenna each
  - 1 user per floor (Full Buffer: unlimited data rate), total 8 users
  - 2x2 MIMO CLSM/ 64x2 3D MIMO
    - Rectangular antenna array
    - MIMO schema (CLSM and Multi-User Massive MIMO)
    - Antenna distance in MS terminal is 0.5 wavelength



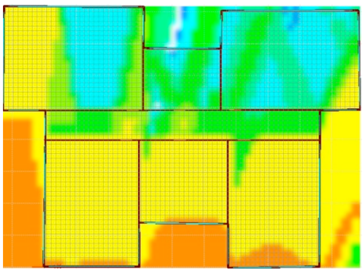


European Commission | Horizon 2020 European Union funding for Research & Innovation

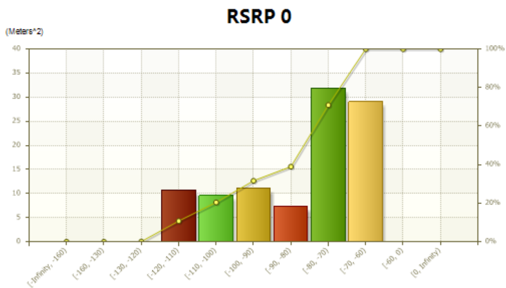
15

3D MIMO Performance – Coverage

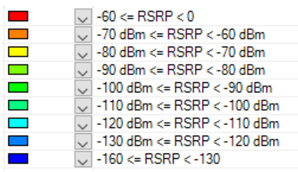
- Outdoor and indoor coverage



Indoor Floor 1



Outdoor

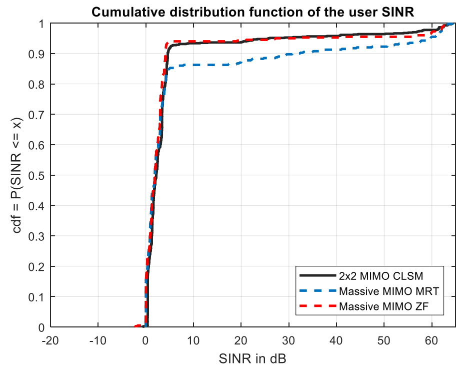


European Commission | Horizon 2020 European Union funding for Research & Innovation

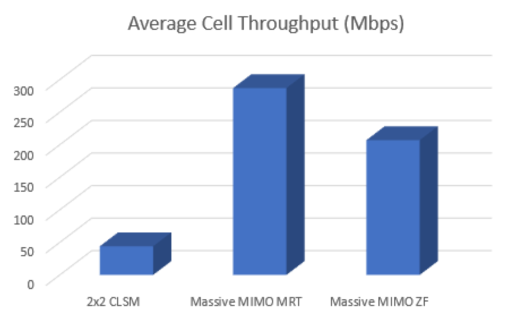
16

3D MIMO Performance – SINR & Throughput

- Outdoor-Indoor scenario
  - 2x2 MIMO scenario
    - 2x2 MIMO with CLSM
  - 3D MIMO scenario
    - Zero forcing precoding algorithm
    - Maximum ratio transmission



Average Cell Thrpughput (Mbps)		
2x2 CLSM	Massive MIMO MRT	Massive MIMO ZF
44	287	207

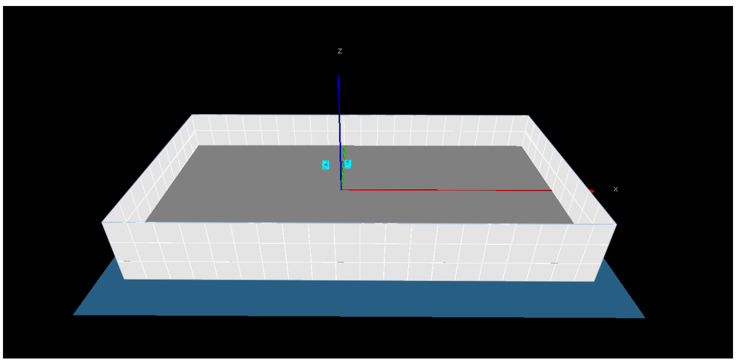


European Commission | Horizon 2020 European Union funding for Research & Innovation

17

Performance Simulation – Indoor Scenario

- Indoor building
  - FDD-LTE Band 7 2600MHz (20MHz Bandwidth)
  - 1 cell configurated 64 Antennas
  - 8 users (Full Buffer: unlimited data rate)
  - 2x2 MIMO / 64x2 Massive MIMO
    - Rectanqular antenna array
    - MIMO schema (CLSM, Massive MIMO)
    - Antenna distance in MS terminal is 0.5 wavelength

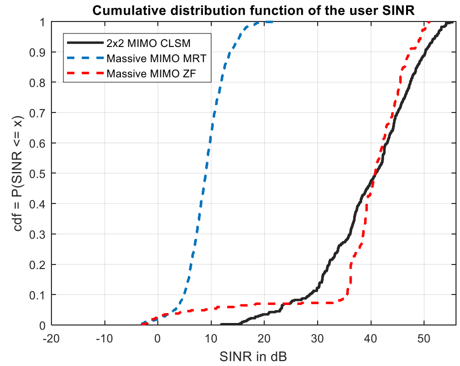


European Commission | Horizon 2020 European Union funding for Research & Innovation

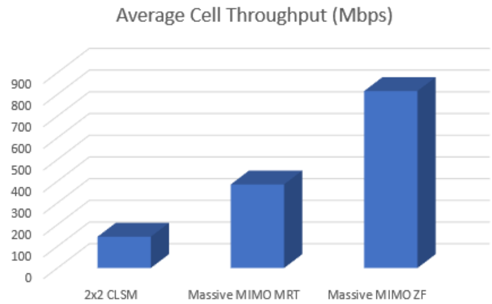
18

3D MIMO Performance – SINR & Throughput

- Indoor scenario
  - 2x2 MIMO scenario
    - 2x2 MIMO with CLSM
  - 3D MIMO scenario
    - Zero forcing precoding algorithm
    - Maximum ratio transmission



	Average Cell Thrpughput (Mbps)	
2x2 CLSM	Massive MIMO MRT	Massive MIMO ZF
144	385	815



European Commission | Horizon 2020 European Union funding for Research & Innovation

19

Conclusions & Future Works

- Ranplan implements the indoor 3D channel modelling based on ray tracing
  - Record the AoA (Angle of Arrival) and AoD (Angle of Departure) of each ray in Azimuth and Elevation angle spread direction
  - Integrating the mechanisms of azimuth and elevation sub-path generation into 3D MIMO channel
- Ranplan researches the 3D MIMO optimisation tool
  - Implement 3D MIMO antenna configuration
  - Evaluate the 3D MIMO capacity gains by 3D beamforming and 3D SMX configuration algorithms
  - Evaluate the capacity performance based on different scenarios, especially in FWA scenario, optimize the indoor network deployment
- Future works
  - Verify and calibrate the 3D MIMO channel model based on measurement
  - Research the coverage and capacity-based optimisation configuration tool to jointly optimize the location and number of cells and 3D MIMO configuration

European Commission | Horizon 2020 European Union funding for Research & Innovation

20


Thank you!
PLANNING FOR A CONNECTED WORLD
Better Together – Indoor and Outdoor Radio Planning
www.ranplanwireless.com
21

Concluding Remarks

The is3DMIMO project workshop (year 1) has been successful in providing the attendees with the ongoing work of the European Union Horizon 2020 MSCA-RISE project is3DMIMO. Based on the oral presentations given by researchers on the research & innovation work carried out within the is3DMIMO project in year 1 and through the fruitful discussions during the workshop, the project partners have been able to synchronize their research work on their corresponding work package(s) and task(s) for the project. The workshop concludes that the research work so far has been on track following the workplan in the Grant Agreement. Building on the discussions and comments from the attendees, the project partners are prepared to push the research & innovation progress up to a new level in year 2 of the project.