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WORLD-CHANGING INNOVATION

MASSIVE MIMO: THE KEY TO UNLOCKING 5G USER EXPERIENCES

CW TEC 2019 - 5G, Satellites & Magic MIMO

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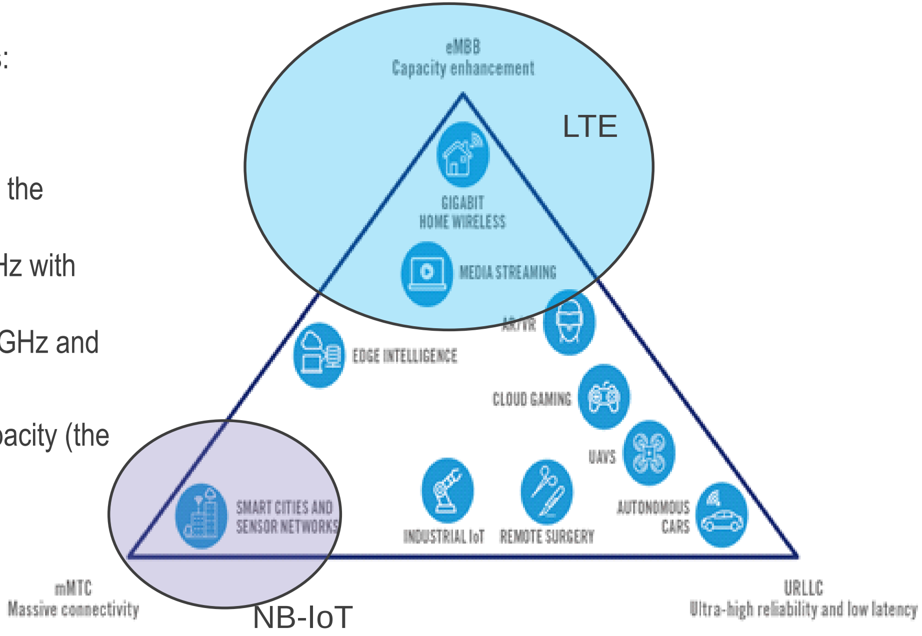
Emiliano Mezzarobba – Senior RF System Consultant
Role: Technical Authority

- Key relevant experience
- 9+ years in the radio over fibre industry
- 8+ years in RF systems and antenna design consultancy
- 3 years in satellite product requirement specification and development
- Overview:
  - Emiliano Mezzarobba is a Consultant in the System RF Group. He joined Cambridge Consultants in August 2014 as Senior Consultant
  - He graduated in 2002 at Trieste University (Italy) and then worked for Fracarro Radioindustrie and BPT where he was leading innovative developments with Radio over fibre technology for CATV and FTTx products. Some of the products developed in those years are still sold in high volume by both companies.
  - He moved to the UK in 2007, where he had the opportunity to join Zinwave, a spin-off company of Cambridge University, becoming the Hardware Team Leader to develop the next generation product of their unique (patented) broadband fibre optic DAS system.
  - In 2011 he started his career as consultant, working as system RF engineer leading projects and becoming experienced in satellite communications, SDR radio and antenna design (granting several patents on products he worked on)
  - Since joining Cambridge Consultants, he has worked on a wide range of projects. Examples include: system RF for SDR radio designs, first NB-IoT dual band module, massive MIMO antennas and digital beam-forming, mmWave automotive radars, digital pre-distortion, custom antenna design for wearables and phased arrays

What is 5G NR?

5G is generally described as a new telecommunication system with the objective to improve the user experience and enable new use-cases beyond consumer mobile broadband

- Increasing flexibility of the system
- User experience is believed to be improved through two main techniques:
  - increase the delivered throughput (> 1Gbps)
  - reduce the latency (< 1ms)
- At the moment the standard is splitting in two main categories referred to the frequency bands used to deliver the service
  - Sub 6GHz NR (bands N1-N90) although predominantly below 4.5GHz with various options for FDD and TDD systems
  - mmW systems (bands N257-N261), defined in the region of 26 to 28GHz and 39GHz
- There is also an expectation from a network point of view to increase capacity (the total amount of throughput delivered across the cell)
- The system is also aimed to increase
  - Reliability
  - Connectivity (number of users)



How 5G is going to deliver the enhanced user experience?

- Increase the delivered throughput
  - Increase SINR
  - Increase the available bandwidth for each user
  - Increase number of virtual channels and spatial reuse
  - Reduce cell size

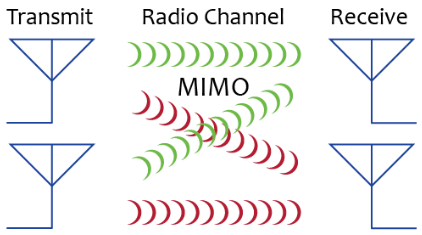
- Reduce latency
  - Numerology (compressing symbol time in size)
  - Lower BLER (block error rate) target
  - Reduce HARQ re-transmission
  - Wide component channel (reduced number of symbol)
  - TDD frame structure and slot format

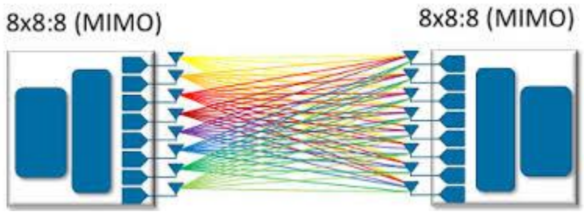
- Increased capacity by means of new spectrum allocation

- Plus other 10000 aspects….

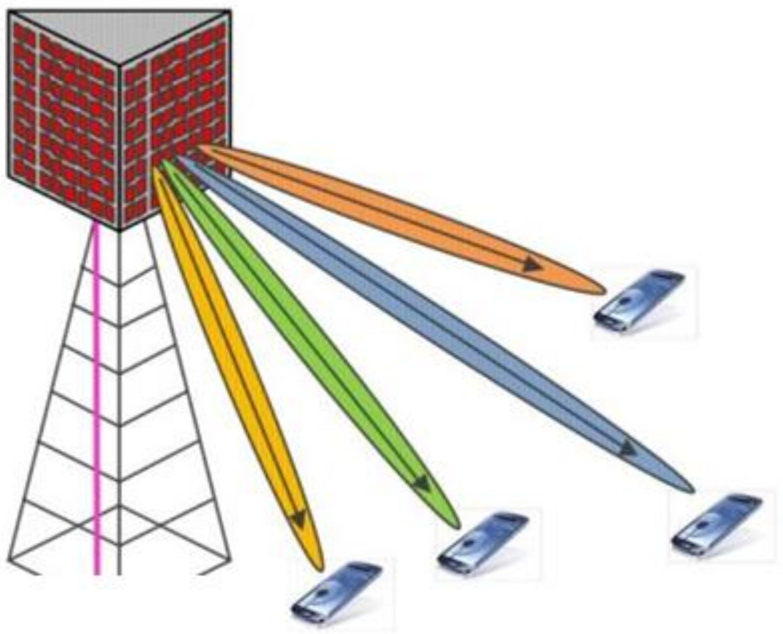
The role of massive MIMO

- What is massive MIMO and beam-forming?





Multi Input Multi Output creates spatial multiplexing is achieved through complex algorithms and channel coding that reduce the correlation between the different channels (multi-path), increasing effectively the available bandwidth per user. Shannon's law is still valid: each channel if made completely independent obey Shannon's law.



Beamforming in massive MIMO is how in 4.5G and 5G the system will generate a more efficient and guaranteed spatial multiplexing. In multi-user massive MIMO each user will be reached and "followed" by a specific beam generated by the gNB (base station), aiming to maximise SINR reusing the spectrum as efficiently as possible minimising interference between users

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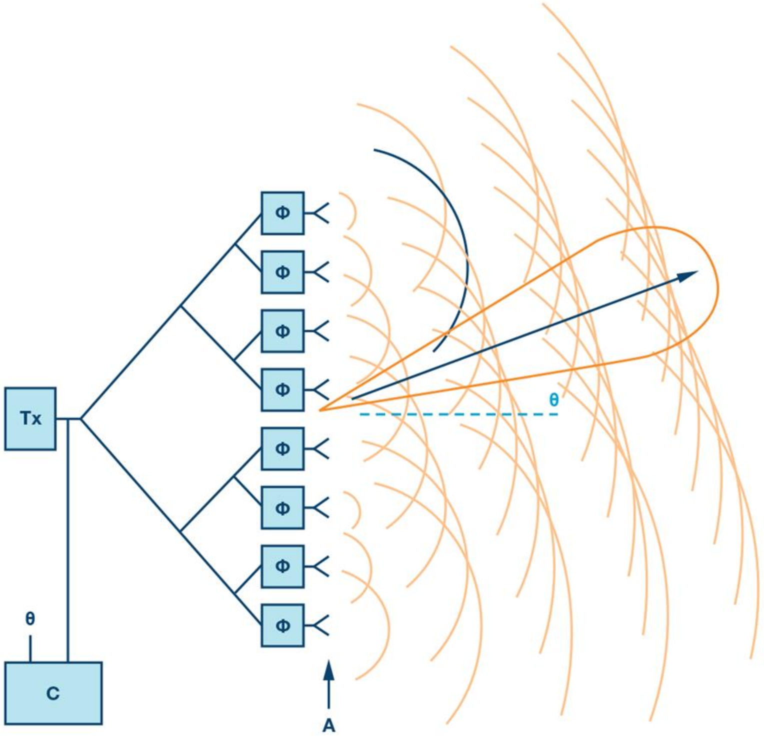
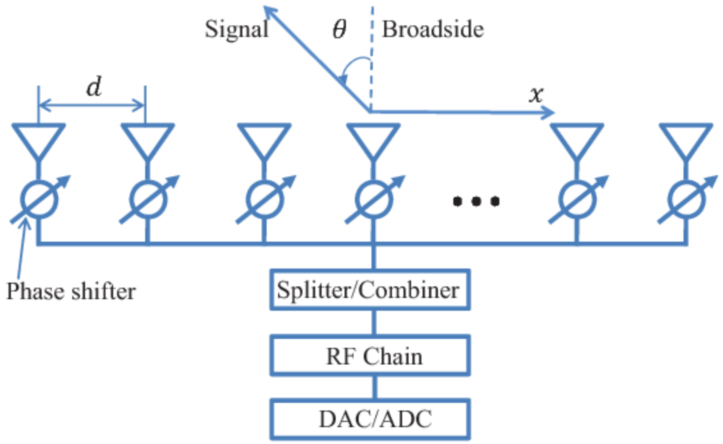
What is beamforming?

- Beam-forming is a technique which is used to aggregate signals from multiple antenna with the correct phase so that the signals can interfere constructively in a certain direction and destructively in all the others
- The result is a virtual antenna with a significant directional gain in a specific direction

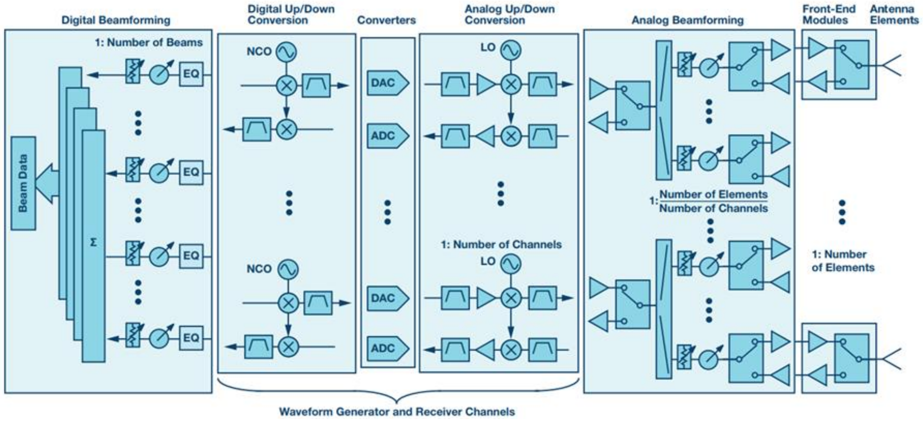


Analog versus digital beamforming

- For the last 40 years beam-forming has been in used in military applications (especially radars) and was mostly obtained through analog changes of the amplitude and phase of the signal feeding each antenna. Analog beam-forming allows the generation of only one beam at the same time

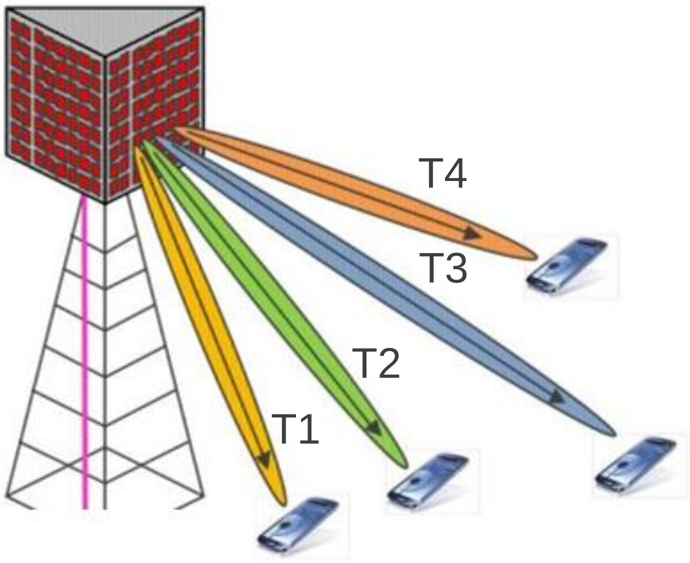


- Digital beam-forming is a technique that emerged in the last 10 years thanks to integration of radio chipsets and cost effectiveness of the DSP/FPGA solution. The number of beams available from a digital beam-former is still limited by the number of elements contributing to the antenna array and, practically, is generally in the order of 20-30% of the number of elements



Analog beam-forming in 5G NR

- Analog beam-forming is applicable to sub-6GHz and mmW systems
- Because of cost and technical difficulties, though, mmW antenna systems will be in the first generations limited to the use of analog beamforming
- This will have an impact on the applicability of MULTI USER massive MIMO. During each time slot only and only one UE (user) can be addressed by a dedicated beam and therefore the allocation of different users in different location on the same resource block will not be possible.

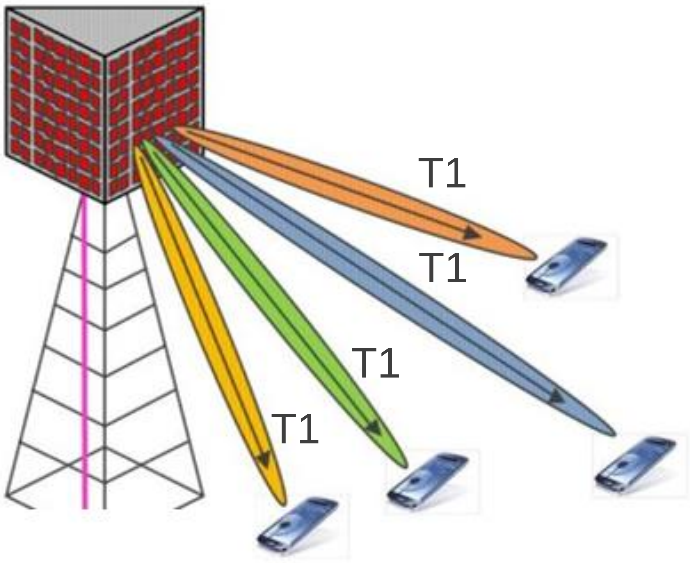


in the same time slot resource block the beam can only be directed to a limited group of users

mmW analog beam-forming

Digital beam-forming in 5G NR

- Digital beam-forming enables the generation of multi-beam at the same time
- MULTI USER MIMO can be more aggressive and the spatial diversity generated by the different beams allows users connected to different beams to use the same channel
- Cost and technical issues have been mostly overcome in the last 3 years allowing sub-6GHz system to heavily make use of this technology in the 5G NR standard



mmW analog beam-forming

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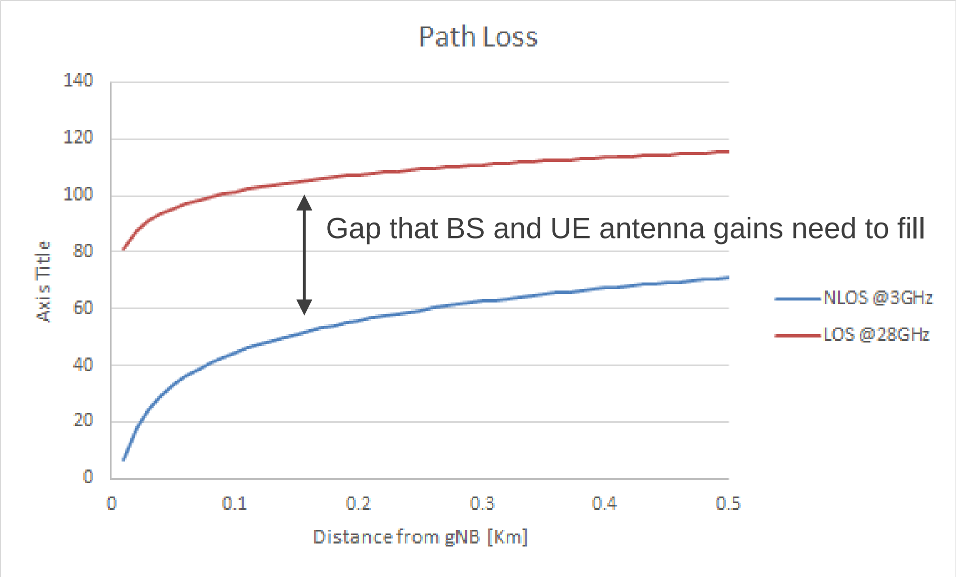
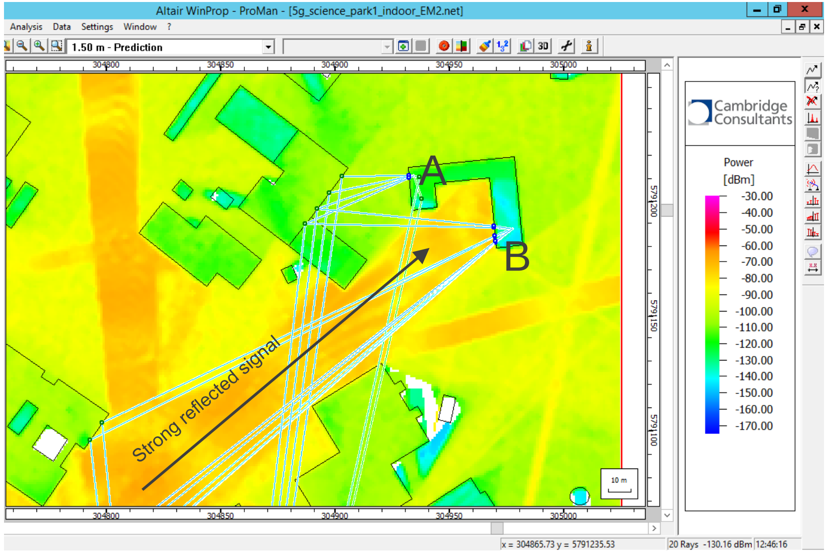
The role of mmW

- mmW frequency bands allow higher bandwidths, offering a significant increase in throughput
- Using opportune beam-forming the channel at mmW can be assumed almost LoS (line of sight) and fading models can be simplified
- The signal will suffer additional propagation losses at these frequencies (compared to sub-6GHz) which massive MIMO and digital beam-forming are key to recover



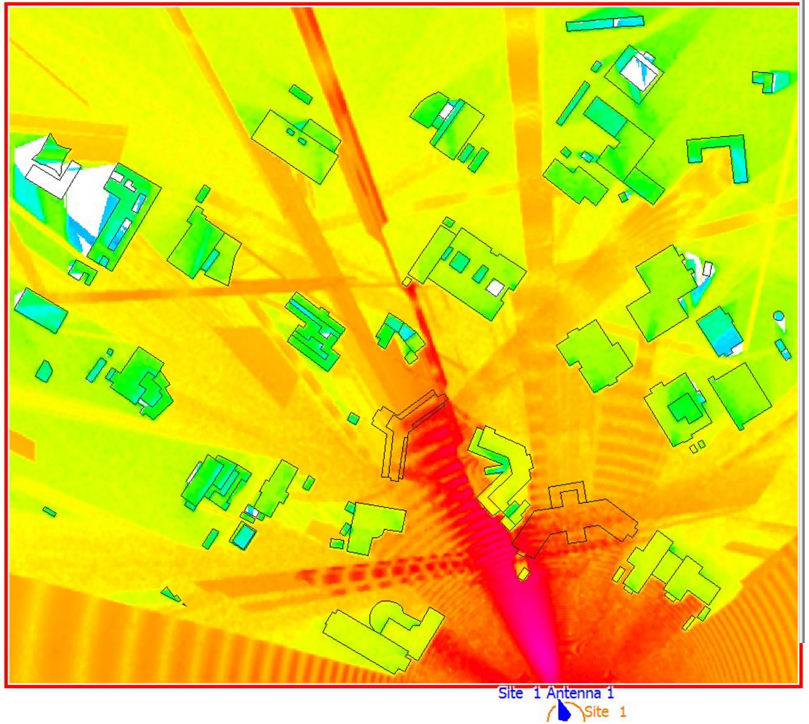
Indoor coverage at mmW – game changing in designing the network

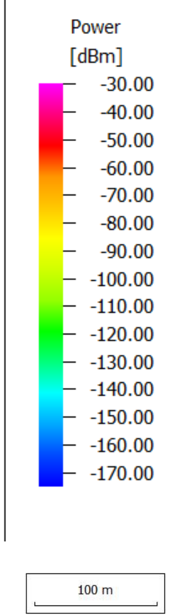
- In this example we are tracing the ray-tracing information for two indoor locations
- The highlighted rays are the main contributor paths to the available signal in the selected locations
- The two indoor locations have completely different coverage despite the outdoor location is “illuminated” by strong signal reflected by a nearby building
- Indoor coverage will be incredibly difficult and will require completely different coverage and planning strategies
- **mmW will be used as hotspots for additional capacity**



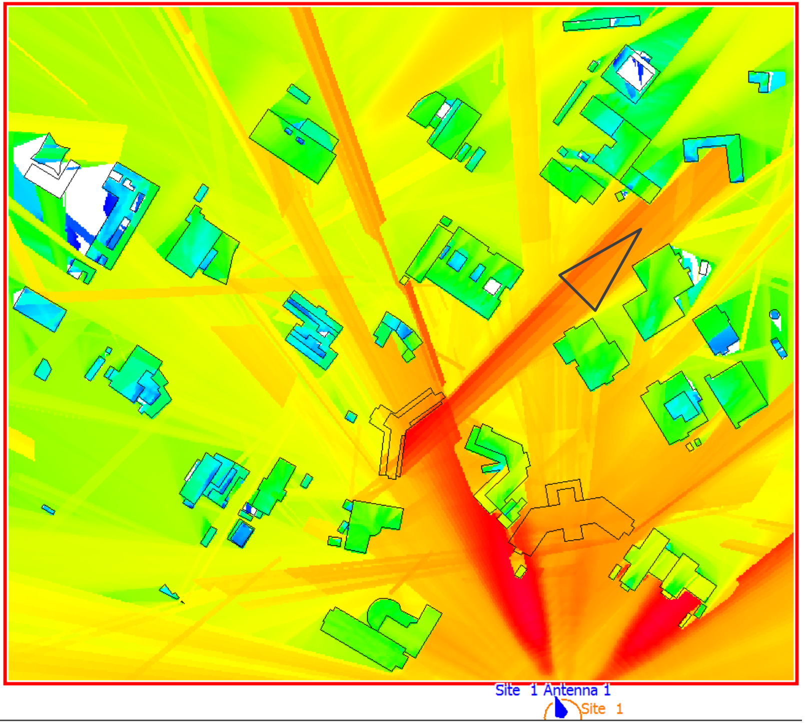
Effect of directive antenna on coverage

Results using an omnidirectional antenna with unity gain at the UE side





Results using a directive antenna with 12dBi gain with the orientation in figure allows to exploit in certain areas NLOS reflections of the main signal



mmW Uplink asymmetry problem

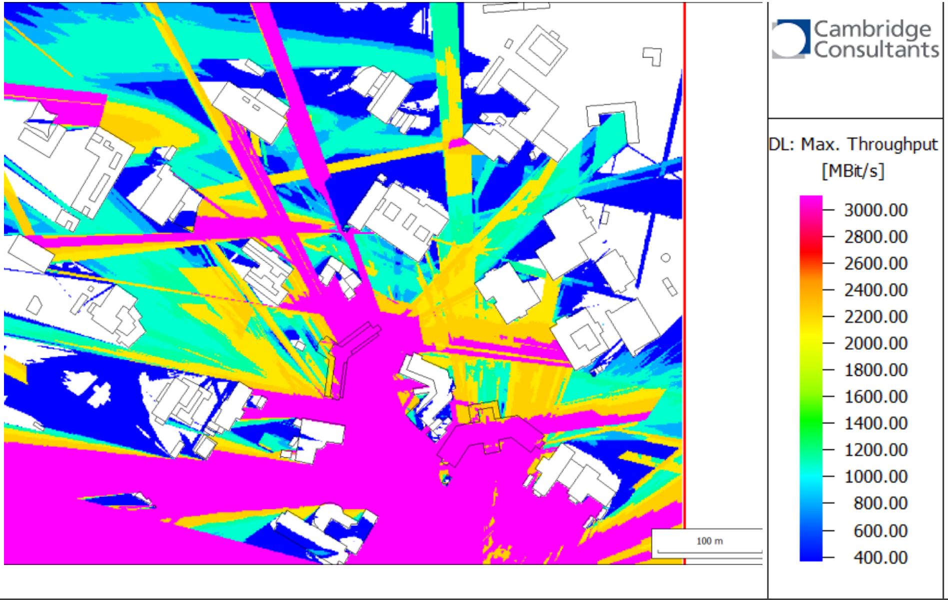
- The directionality of the antennas (TX and RX) can only be useful up to a certain point, in fact what will normally happen is that uplink performance will be limited by the maximum EIRP allowed by the regulatory standard

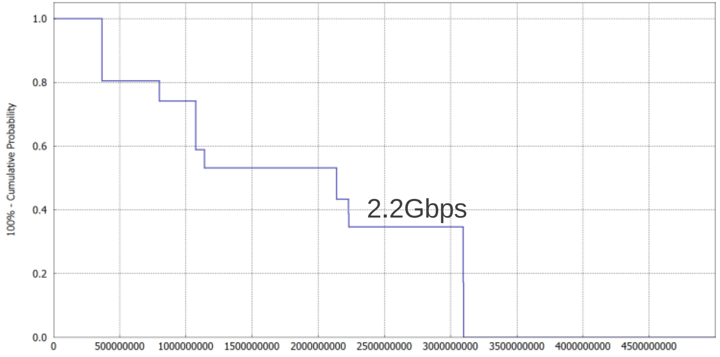
- This has been already recognised as one of the biggest problems of the future mmW 5G systems

- Cambridge Consultants is investigating in these problems and how supplementary uplink can play a significant role in the game, leveraging the sub-6GHz network uplink to make use of the higher throughput available at mmW in downlink

Network performance analysis

- The picture below shows the maximum throughput available calculated with WinProp using Numerology 3 (400MHz channel) forcing the network to use only downlink SINR for the computation and assuming 100% uplink coverage through supplementary uplink





Cumulative Probability
Downlink Maximum Throughput [bit/s]

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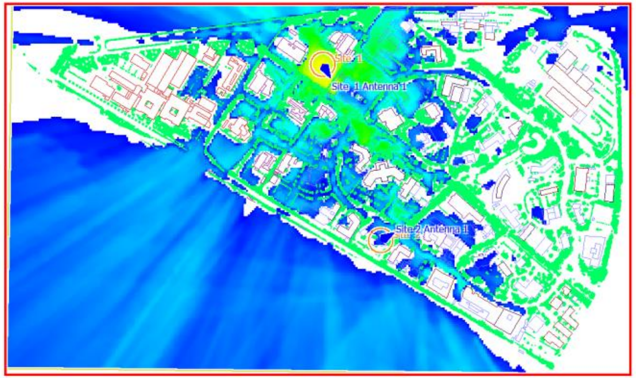
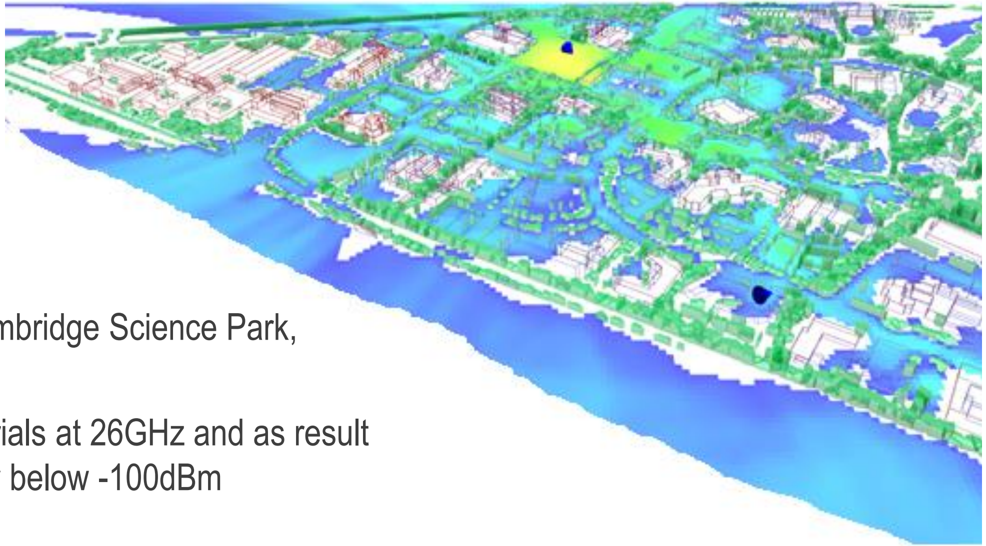
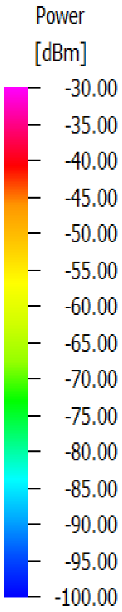
Interference between 2 coexisting gNB not coordinated



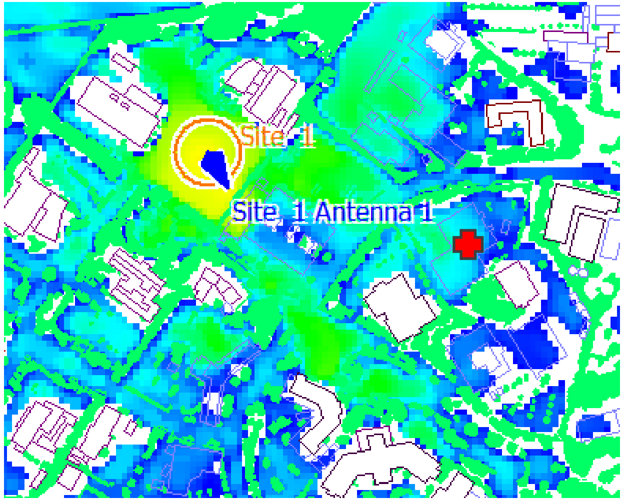
53dBm EIRP beam-forming gNB results



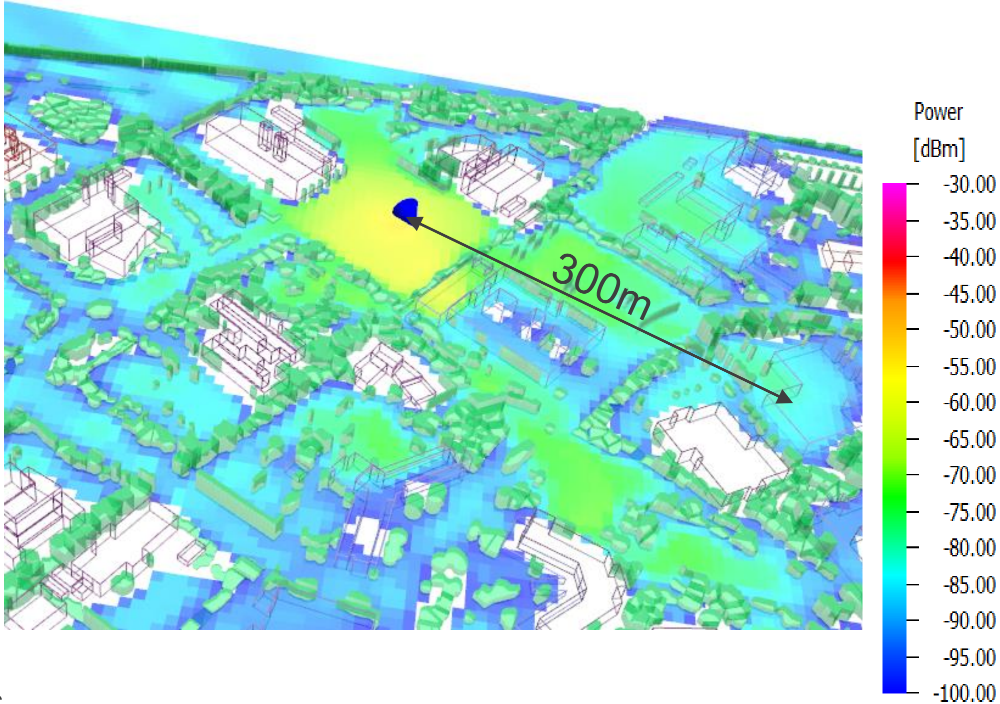


- This model includes vegetation details of the Cambridge Science Park, adding more realism to the simulation results
- The model includes very high loss building materials at 26GHz and as result inside the building the received power falls easily below -100dBm

Detail of indoor propagation



-84.8dBm



- 53dBm EIRP beam-forming gNB results
- The selected building is made of low loss glass

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