5G Collaboration between Academia and Industry

Professor Rahim Tafazolli
Director, CCSR, 5GIC
University of Surrey
R.Tafazolli@surrey.ac.uk

Centre for Communication Systems Research (CCSR) Strategy

Industry Relevant Research

Whilst pushing technology barriers

CCSR' S Strengths

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- Well known Research Centre in Communications internationally, particularly in Europe
- Good networking with industry and academia
- Good awareness of strategic and hot research areas -To some extent we are the drivers

Industry Collaborators

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Alcatel·Lucent, BBC, BT, 3, Nokia Siemens Networks, NEC, EADS astrium, HUAWEI, FUJITSU, Turner, vodafone, SAMSUNG ELECTRONICS, TOSHIBA, orange, THALES, MOBILE VCE, RIM, Telefonica, TELECOM ITALIA, ERICSSON, NTT DoCoMo, SAGEM, cea, InterDigital, HITACHI Inspire the Next, hp invent, SAP, SIEMENS

CCSR at the Centre of Worldwide Research

Europe

- Many top universities & RI, incl; Luxemburg, Bologna, Alexander institute

Asia

- China (4G future programme with 4 Univ) and Science Bridge in Mobile Comms
- Korea (ETRI and 2 Universities)
- Japan (NICT– exchange programme)

USA

- Partnership with Universities of California San Diego / Irvine, Wright State

India

- 7 IIT's – UK/India: Next Generation Networks

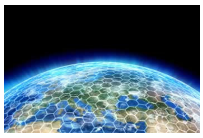
CCSR

Driving UK and Europe's ICT programmes

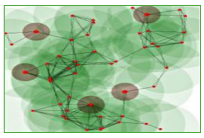
- EU Technology platforms: Net!Works (chair), ISI
- Advisor to EC on Framework programmes and H2020
- Standards: IEEE P.1900.6 (chair and Founder), ETSI (co-Chair) Security Systems
- Board Member of UK Future Internet Strategy Group (TSB)
- Leader of IoT Strategic Research roadmapping for the UK (TSB+ RCUK)

Communication and Information Systems

- **Mobile Cellular**
  - 3G, Beyond 3G, 4G, 5G
- **Satellite**
  - Broadband Fixed
  - Broadband Mobile – BB on the move
  - Broadcast – passenger vehicles
- **Machine to Machine**
  - ZigBee, LTE
- **Vehicle to Vehicle Communications**
  - 802.11p, LTE
- **Future Internet (incl. IoT)**





Research Areas

- **Air-interface**
- **Radio Access System Optimisation**
- **Cognitive Radio**
- **Cyber Security**
- **Cognitive Networks and Future Internet**
- **Semantic Web & Big Data**

CCSR Research Strategy 2020

Future Research Strategy

- Areas
  - Internet of Things (IoT)
  - Broadband Mobile Communications
- Maximise Impact, Research Methodology
  - Cognitive networking
  - More experimental Research
  - Work closely with Industry

New Systems

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- Cellular
- Satellite
- Machine to Machine
- Vehicle to Vehicle
- Future Internet (incl. IoT)

Optimisation

ICT for

SMART
- Health
- Environment information
- Energy & Grid
- Transportation

Experimental Research Integration & Automation

SMART CAMPUS
Largest sensors/actuators experiment testbed

HIGHER EDUCATION FUNDING COUNCIL FOR ENGLAND hefce

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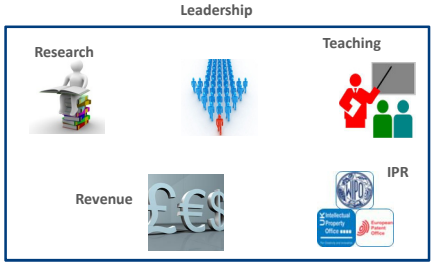
Surrey International Centre for Future Generation Mobile Broadband Internet and Communications Research: 5G Centre

AIRCOM INTERNATIONAL · HUAWEI · SONY · SAMSUNG · ROHDE&SCHWARZ · Telefónica · O2 · FUJITSU

BT · BBC · EE · Ofcom · vodafone · AEROFLEX

5GIC's Mission

- To become world leading centre for multi-disciplinary communications research
- To be model for collaborations with academic institutions, industry and the community
- To deliver innovative communications solutions in order to generate social and economic value
- To influence future standards and regulation



THE ECOSYSTEM

- Service providers
- Infrastructure & device manufacturers
- Test equipment vendors
- Standardisation bodies
- Application & content providers
- Industry forums and alliances
- Regulators and policy makers
- Academia and research centres
- SMEs & other solution providers

Benefits for Members

- Access to world-class academics and researchers
- Access to state of the art technology evaluation facility dedicated to 5G technology
- Use of a facility to fund research on a bilateral basis by commissioning projects in line with their business strategy
- Ability to effectively and timely influence the 5G technology standardisation through high quality yet cost effective research results from the 5GIC
- Work in a complete ecosystem and build consensus on 5G technologies and standardisation
- Access to IPR
- Publications in high-quality journal and conference

5GIC Ecosystem

Benefits for the University

Leadership
- To create a world leading centre for multi-disciplinary communications research

Research
- To establish high quality publications on theories and practical performance of 5G advanced technologies.

Teaching
- To improve teaching quality by training the next generation of multi-disciplinary communication and system engineers for industry and academia in the UK

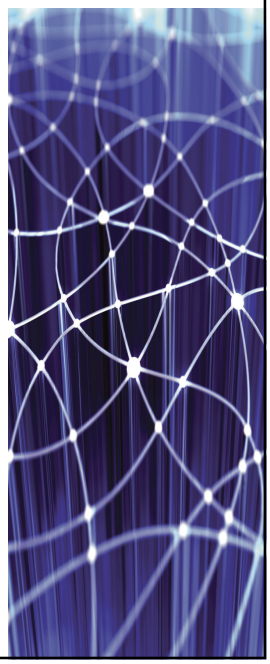
Collaboration
- To create a close and sustainable industry/academia partnership which will influence, direct and inform the development of the emerging 5G standards

IPR
- To generate essential IPR

Economic Growth
- To deliver innovative solutions for the broadband mobile internet in order to generate social and economic value and create significant downstream benefits for economic growth

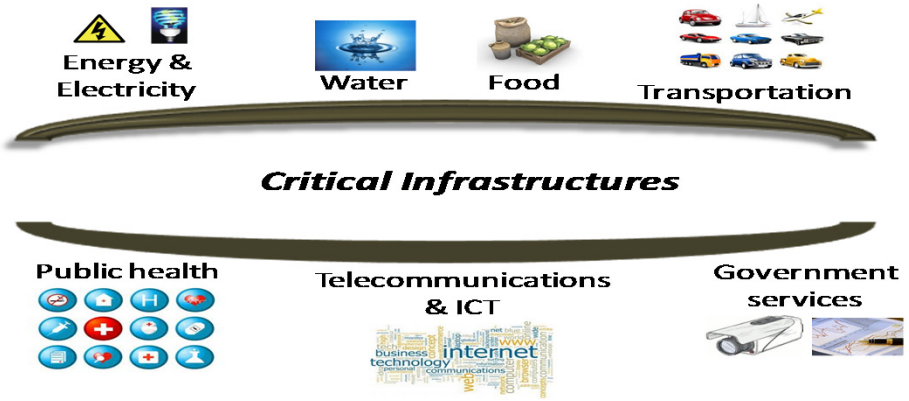
Future is about connectivity

- **Communications & Control**
- **Towards Digital Economy and Society**
  - **Modernisation of aging industries**
    - Transportation
    - Energy
    - Manufacturing
    - Health
    - …
  - **Smart Homes, Cities and Countries**



Communication Networks

becoming Super National Critical Infrastructure



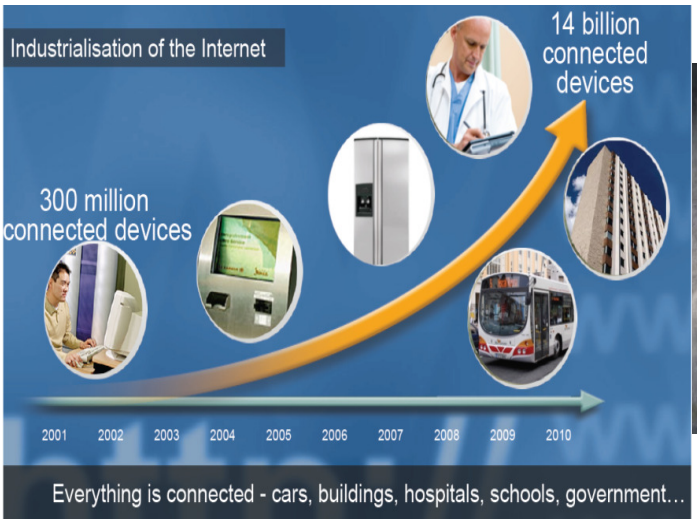
- By connecting the other National Critical Infrastructures

Penetration of various technologies, 2011

Population-weighted rates	Developing Economies (109)	Advanced Economies (35)	All Economies (144)	Customers
Mobile cellular telephone subscriptions per 100 pop.	81.3	110.7	85.7	>5B
Active mobile broadband subscriptions per 100 pop.	8.8	64.8	17.0	
Percentage of individuals using the Internet	25.0	77.3	32.8	~2B

Source: ITU's *World Telecommunication/ICT Indicators Database* 2012 (December 2012 edition).

Control and Modernisation of other industries



- **Still 99% of THINGS are not connected**

UK industry benefits of big data, £ million, 2011–17 (2011 prices)

Industry	2011	2012–17
Manufacturing	5,965	45,252
Retail	3,406	32,478
Other activities	3,446	27,929
Professional services	3,039	27,649
Central government	2,517	20,405
Healthcare	1,450	14,384
Telecommunications	1,465	13,740
Transport and logistics	1,360	12,417
Retail banking	708	6,408
Energy and utilities	660	5,430
Investment banking	554	5,275
Insurance	517	4,595
UK economy (total)	25,087	215,964

Source: CBER, 2012.

Trends and Drivers all compared with 2010

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	by 2015	by 2020	By 2030
No of Mobile Phones	7Bn	50 Bn Connected Devices	500 Bn Connected Devices
Mobile traffic	•26 fold (CISCO) •Mobile to Mobile traffic; 295 Petabytes per month • Video 2/3 of Traffic •One Second of video uploads on Net takes 2 years to watch	X 1000	X 1,000,000
Annual Expenditure (Mobile Services Only)	$1.7 Tn	$3 Tn	

Internet Services Trend

- Internet is getting more complex with rich multi-media content
- Web pages getting more complex
- Video and HD
  - Average file size on the web = 10 MBytes
  - Video accounts for ~99% of all bytes transferred

Mobile/Wireless Services Trend

- 6Bn mobile subscriptions
- 200M smartphones sold every **quarter**
- 120M apps downloaded every **day**
- 4Bn YouTube views every **day**
- 3Bn social media **profiles globally**
- 1Bn active Facebook users, 600M mobile
- 200Bn photos in Facebook
- 500M Twitter accounts
- 200,000 tweets every **minute**

Source: NSN-2013

TOTAL spectrum Requirement (MHz)					
Demand Scenario (UK)	2012	2014	2016	2018	2020
(Profile "A") - Working pop. Inner London					
TOTAL Demand (Gb/s/km^2)	2.10	6.89	14.88	31.55	67.72
ISD = 1000m ; cell rad. = 333m	98-215	323-633	700-1520	1480-2900	3175-6225
ISD = 500m; cell rad. = 167m	26-56	88-180	190-395	400-840	860-1800
ISD = 200m; cell rad. = 100m	24-48	32-66	70-144	146-305	313-653
(Profile "D") - UK Peak					
TOTAL Demand (Gb/s/km^2)	0.47	1.54	3.33	7.06	4.68
ISD = 1000m ; cell rad. = 333m	22-48	118-158	156-306	330-720	710-1546
ISD = 500m; cell rad. = 167m	6-12.2	20-41	42-88	90-188	192-403
ISD = 200m; cell rad. = 100m	2-4.5	7-15.2	15-32	32-68	70-146
(Profile "F") - UK Mean					
TOTAL Demand (Gb/s/km^2)	0.04	0.14	0.31	0.65	1.40
ISD = 1000m ; cell rad. = 333m	2-4.4	6.7-14.5	14.4-31.4	31-67	65-143
ISD = 500m; cell rad. = 167m	0.5-1	1.6-3.3	4-8.2	13-17.3	17.8-37
ISD = 200m; cell rad. = 100m	0.2-0.4	0.6-1.4	1.4-3	3-6.3	6.5-13.5

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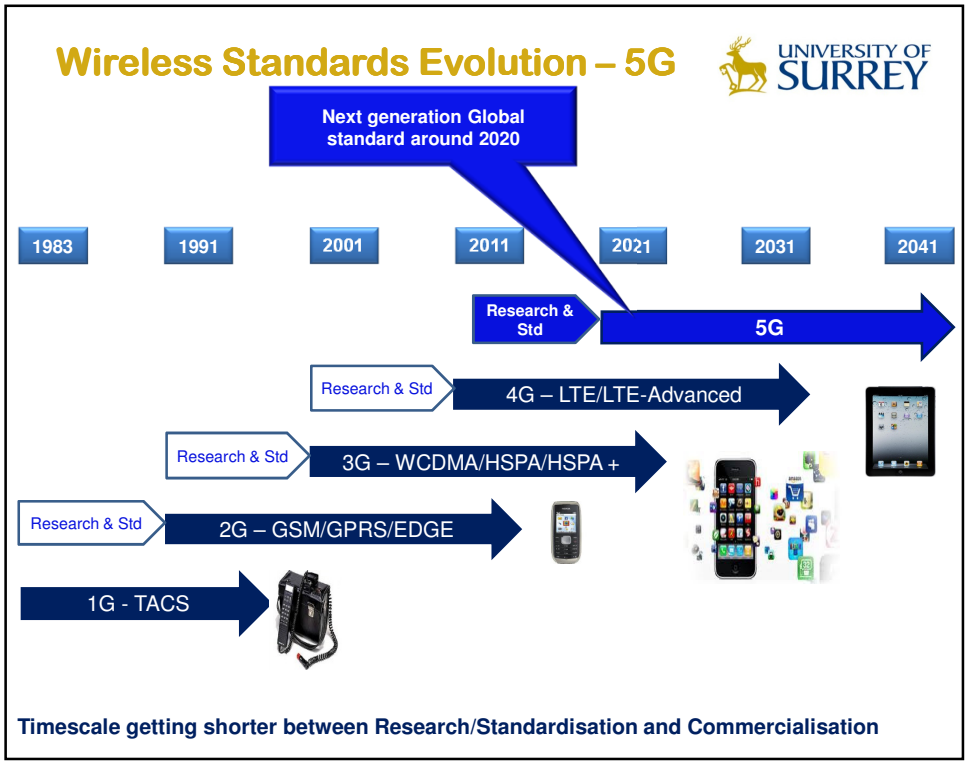
- SU-MIMO 2 x 2
- SU-MIMO 4 x 2
- SU-MIMO 4 x 4
- SU-MIMO 8 x 2
- MU-MIMO 4 x 2
- MU-MIMO 8 x 2
- CS/CB-CoMP 4 x 2
- CS/CB-CoMP 8 x 2
- JP-CoMP 4 x 2



5G in one sentence

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"Always Sufficient Rate" to give users the *perception* of Infinite Capacity"

5GIC approach

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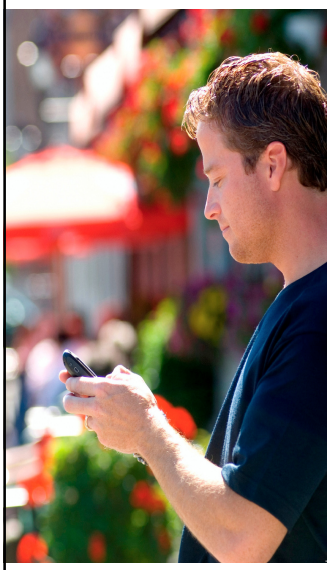
- **Research starts from end user QoE (H2H, H2D, D2D)**
  - Unlike 2G….4G , designed for end device
  - Data rate is not the differentiation between 5G and previous generations
  - Area spectral & energy efficiencies, Latency (radio and end to end) ..
  - Spectrum packing
- **No difference between licenced and licenced-exempt bands**
  - Broadcast, Cellular, WiFi technologies
    - Differences in Freq Bands
      - …….while services offered the same or converging..
        - » Data, Video, Audio

5GIC Research Approaches



Two complementary

- **Content, User and Network Context**
  - Dynamic user profiling
  - Data Handling
    - » Intelligent Content (Storage, Search, Delivery) Networking
- **Efficient use of radio spectrum**
  - Area Spectral Efficiency
  - Energy Efficiencies
  - Spectrum Uniformity
    - » licensed (and exempt) bands

Key Features of 5G

- Capture and use the User context, Content context and Network context
- QoE and resources efficiency based on user profile
- Utilisation of telecom and IoT Big Data
- In-network processing (storage, transmission) for content
- Dense small cell
- Device to device
- Spectrum Sensing
- Utilize the licensed and unlicensed band
- New frequency bands: including mm-Wave
- Split data and control radio network architecture
- Multi cell cooperation
- Massive MIMO
- Full duplex radio

Why Higher Speed

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- 3 reasons
  - Low latency: Full utilisation of advanced techniques potentials
  - QoE: Fast network responses
  - See next…

Fixed & Mobile data rate evolution

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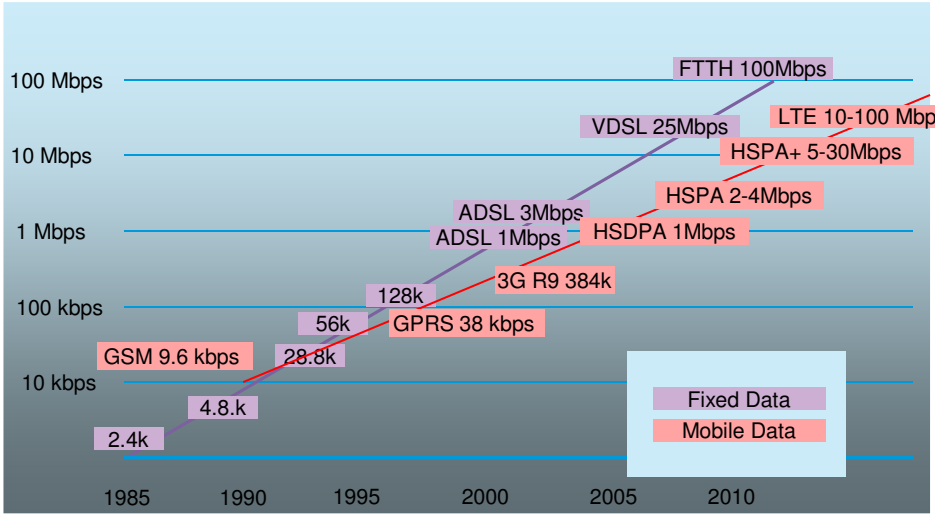

Coverage and Capacity

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- One size does not fit all!
- Low+ Medium+ High Dense cells
  - Capacity limited
  - Coverage limited

Why New Air-Interface?

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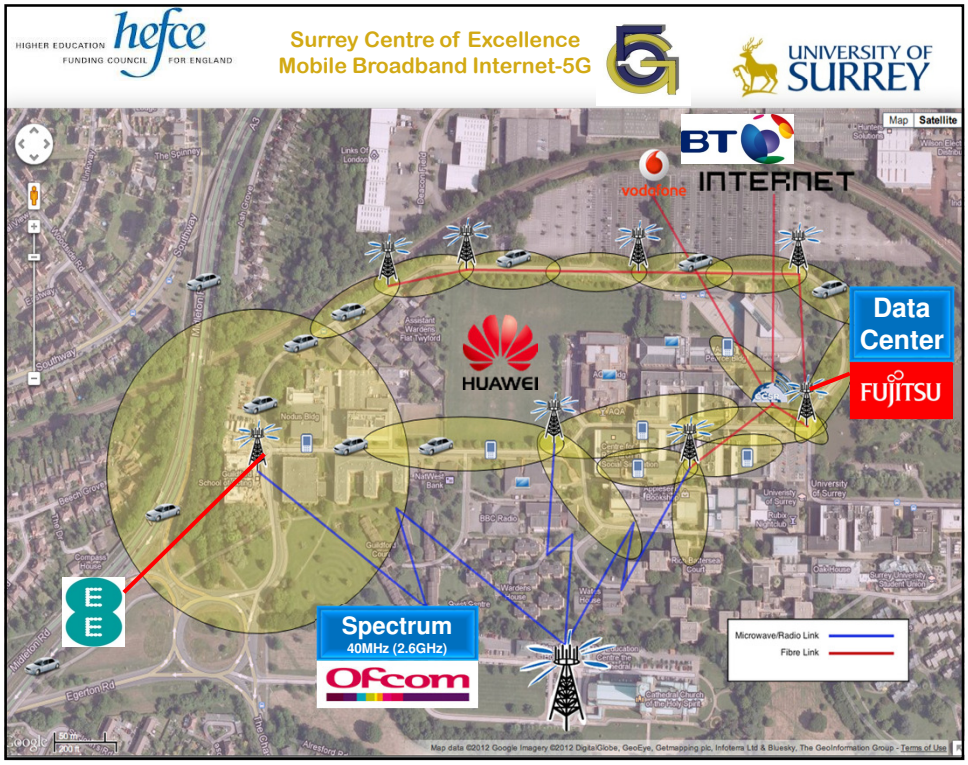
- Low to medium density cells
  - 4G (LTE-A,B,C) large cells
- High Density Cells
  - Objectives is NOT link spectral efficiency
  - Very low control signalling overhead for management, relaxes the stringent time-frequency control inherent in OFDMA
  - Flexible implementation of carrier aggregation across highly fragmented spectrum including license-exempt band
  - Highly energy efficient
  - Allow full-duplex operation
  - Sub-millisecond Air-Interface latency
  - Support fast and reliable spectrum sensing for opportunistic spectrum sharing with and without database support
  - Support distributed MAC between network and mobile device
  - Support of device to device communications
  - Scalable for Machine type communications
  - ….



5GIC High Level Technical Activity Roadmap

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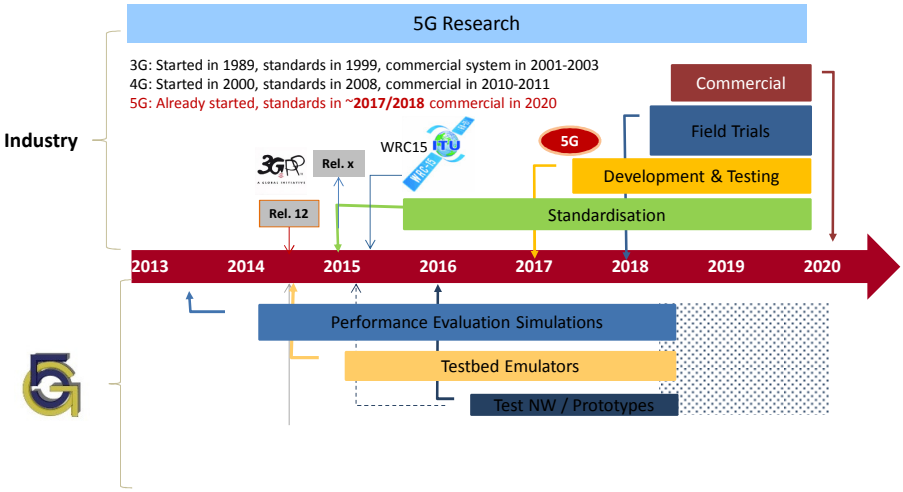


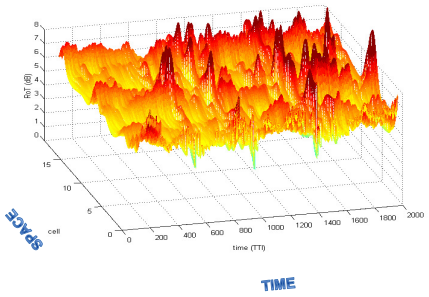
36

5G system approach - Summary

- 5G includes: All other National Critical infrastructures including mobile broadband
- New business models
- Old approach to 2G, 3G and 4G not sustainable
- Focus : Perceived infinite capacity
  - Latency
  - Energy Efficiency
  - Scalability
  - Reliability and Robustness
  - Distribute control between Network and Devices
  - Uniformity between licensed and license-exempt bands (including Broadcast)
  - Dense cell technologies
  - Explore and understand new frequency bands

5G Targets

- Maximum, Average or Percentile as cell rates not relevant



- Targets:
  - Area Spectral Efficiency…
  - Energy Efficiency….
  - Latencies: E2E and Over The Air…
  - QoE….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