Vision on 5G for 2020

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January 2014

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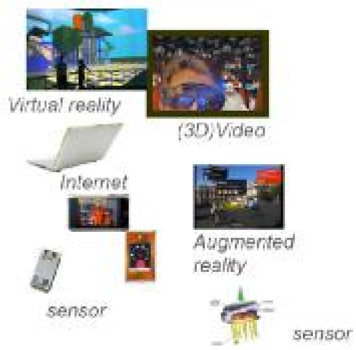
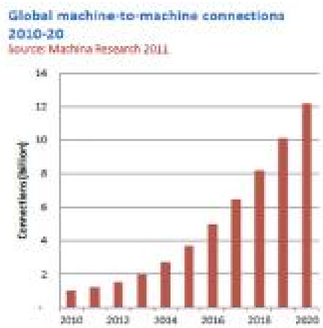
What is 5G?

- **Currently no set of industry requirements or strong demands for 5G**
- **Key drivers to guide 5G:**
  - Emerging new mobile services to end-users
    - HD, 3D video, advanced web applications, gaming, social networking, virtual reality, augmented reality, self-driven cars, or other currently un-imagined new services
  - Handling larger traffic (x1000)
  - Adapting to static, nomadic and vehicular environments including cars, buses, trains, subways, planes, etc.
  - New available radio bands located well above 3 GHz
  - Massive increase (10-50 billion) in the number of attached M2M devices and internet of things
  - Cloud-based interworking among cellular mobile, broadcast and shorter range wireless access technologies





New Services, M2M Devices and Internet of Things will drive 5G.

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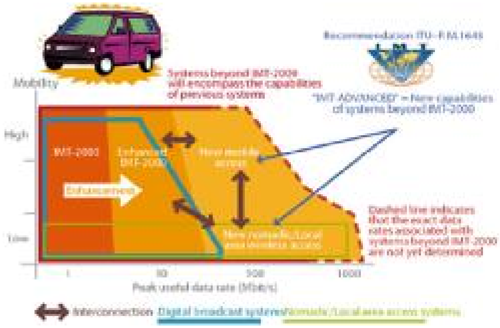
How 5G will be formulated?

- "5G" has not yet been defined by any recognized standards body
  - Industry view that 5G will be the next generation wireless technology deployed in the post 2020 timeframe
- Historically the ITU-R (International Telecommunications Union – Radiocommunication Sector) has led the industry in the definition of next generation wireless technologies through the IMT (International Mobile Telecommunications) program (IMT-2000 and IMT-Advanced)
  - Discussion of standardization "Beyond IMT-Advanced" has been underway in the ITU since 2010
  - ITU does not officially use the nomenclature "4G" or "5G", leaving this to industry marketing
  - Historically there has been an evolution of wireless technology every 10 years; a possible timing for ITU related vision could be ~ 2013-2015 and requirements ~2016-2018



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When?

Period	3G mobile	4G Mobile	5G Mobile	ITU-R Recommendations
2000-05	Deployment and ongoing evolution (3GPP Rel4-7)	Research (OFDM, MIMO)		IMT-2000
2005-10	Mainstream adoption and continuity evolution (3GPP Rel8-9)	Initial standards (3GPP Rel8-9)		IMT-2000 updates (inclusion of HSPA, LTE and WiMAX)
2010-15	Maturity	Deployment and ongoing evolution (3GPP Rel10-12)	Research	IMT-2000 updates IMT-Advance
2015-20	Declining usage?	Mainstream adoption and continuity evolution (3GPP Rel13-??)	Initial standards around 2020 (3GPP Rel16?)	IMT-Advance updates IMT-2020
2020-25		Maturity	Deployment and ongoing evolution	

2011:early work new principles → 2014: selection → 2017: standards

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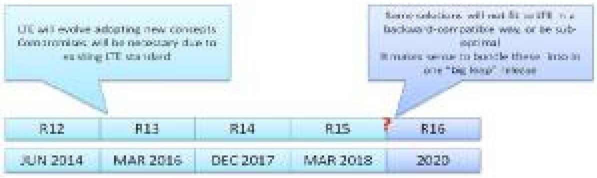
Compatible to Upcoming Future LTE-Advanced

- **LTE-Advanced (Rel. 10 & Beyond) will continue to evolve to provide additional capacity, to improve end-user experience and to support new services in Releases 12-15**
- **A non-exhaustive list of *LTE-Advanced Evolution* enhancements already foreseen in 3GPP R. 12 & 13:**
  - MIMO (3D MIMO) and CoMP enhancements
  - Carrier aggregation enhancements
  - Small cells enhancements
  - Energy savings enhancements
  - Public Safety Features
  - Machine Type Communications
  - Enhancement for local IP access & SIPTO
  - Improvement for user plane congestion management
- **In evolving LTE-Advanced, some compromises will inevitably be made to support some new concepts and services while retaining backward compatibility**
- **New requirements will eventually be unsupportable in LTE**



5G would accommodate a backward-compatible way within the LTE air interface which would result in some loss of performance compared to the potential optimum.

Broadband and MTC traffic

Broadband traffic

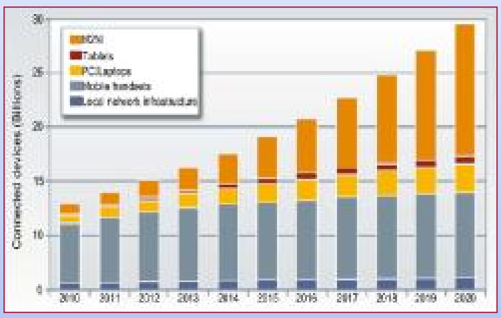
Traffic per month:

Sanity check: This is 1 GB per month for every person on earth

Sustained growth of broadband traffic

Machine type traffic

Number of connected devices:



Number of M2M devices grows faster than number of mobiles

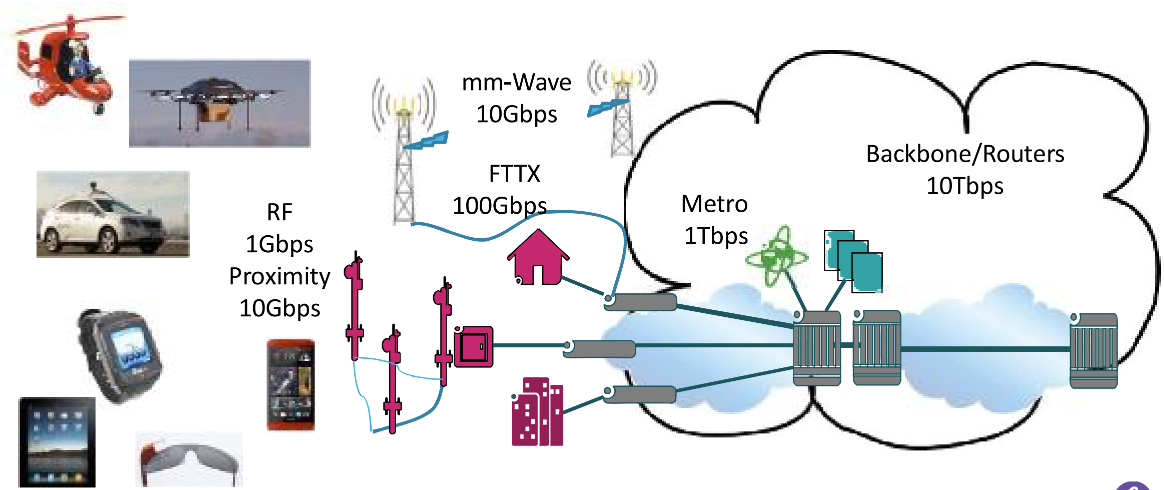
Source : GSMA
http://www.2cm.com.tw/technologyshow_content.asp?sn=1307240004

Early Vision of 5G Infrastructure for 2020

- Capacity of Wireless Traffic: 1,000x than 4G
  - Terminals: 10 Gbps
  - Micro Cells: 100 Gbps
- Connectivity: P2P, D2D, M2M, IoT
  - Million-Billion Connections
  - 100x faster: low latency end-end in millisecond
- Network:
  - Cloud-based, heterogeneous
  - Enhanced Security
  - Software-Defined Network (SDN)
- Terminals:
  - Backward compatibility with 2G, 3G, 4G
  - Dynamic Spectral Management
  - Multi-User Spatial Diversity with multiple antennas
  - Proximal Connection with mm-Wave, Optical, etc. to FTTX broadband access point
  - Seamless user connection via concurrent air interfaces

Early Vision of Network Evolution @ 2020

Typical Interface	Terminal	Access	Metro	Edge
2010	<0.1G	<1G	1/10G	10G
2020	1G/10G	100G	1T	10T



5G Technology Enablers

- **Wireless research activity has already begun to coalesce around a small number of technologies for consideration as part of 5G**
  - New 5G air interfaces
  - Advanced antenna design
  - Use of mm-wave frequencies
  - Massive machine-to-machine communication
  - New cloud-based network architectures

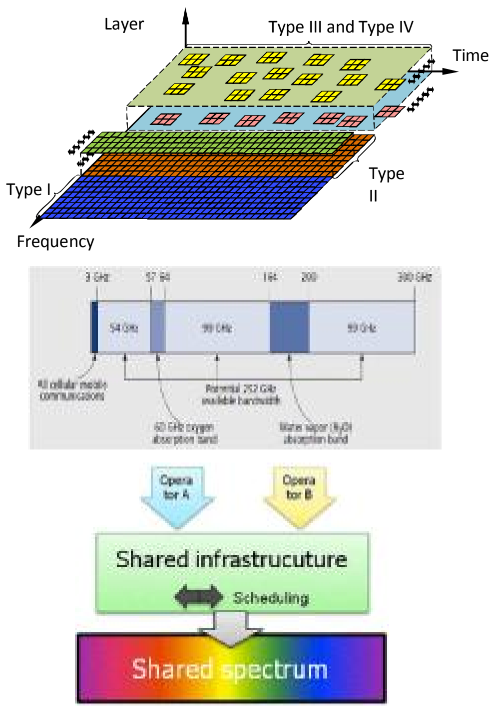
- **Technology trends impacting next generation wireless include:**
  - Silicon technology enables MIMO, advanced signal processing and mm-wave radios
  - Power savings techniques
  - Significant processing and storage capabilities available in network nodes and phones
  - Networks are being virtualized (NFV) and can be tailored to the service
  - Different services can be delivered in different topologies
  - Self- organization, Dynamic optimization and machine learning techniques are maturing

Areas of Investigations

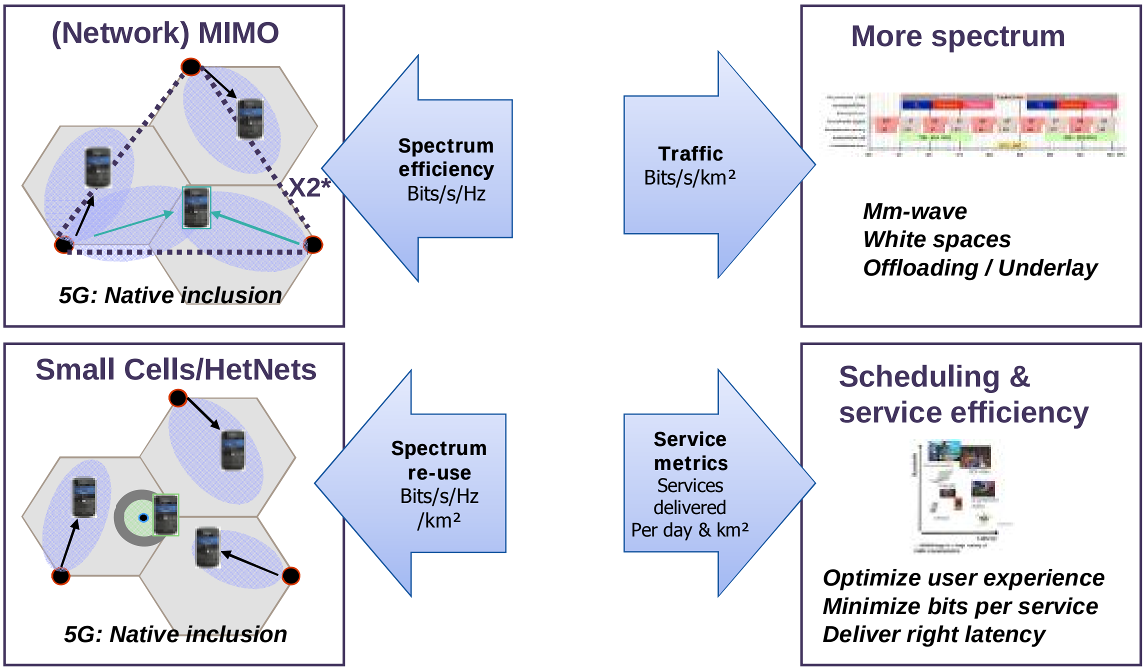
Capacity
- Air Interface(s) Wide Area
- Multipoint, Multi Antenna System Design
- Spectrum & Infrastructure Sharing

Connectivity
- Smartnodes
- Massive Machine Type Traffic
- Mm-Waves for small cells

Networking and Applications
- 5G Networking & cloud-based architecture
- Service Framework
- Energy efficiency & Ultra reliability



How to enhance capacity?



PHY Layer Targets for 5G Air Interface

Scalability / flexibility

- Option for low-latency services
- Support of spectrum re-farming, sharing, white spaces
- Support of broadband and small packets services (M2M, messaging)

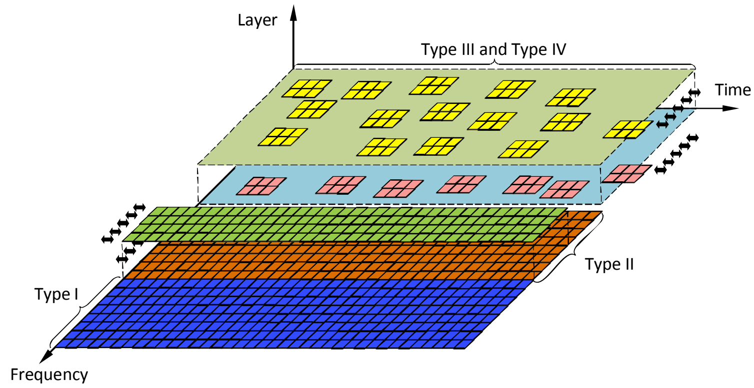
Efficiency

- Native support of Co-operative multipoint techniques
- Native support of heterogeneous networks
- Energy efficiency: support of blanking
- Computational efficiency (silicon, energy)

Radio Frame – Unified Frame Structure

Target:

Efficiently combine various types of service and performance classes within a radio frame (from small packet service to high rate ‘bit-pipe’)

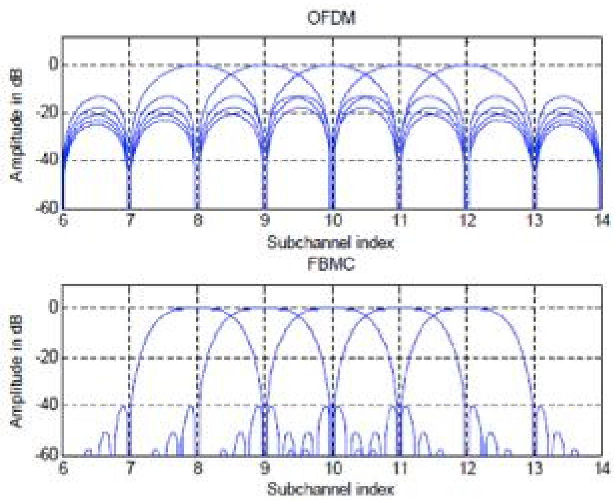


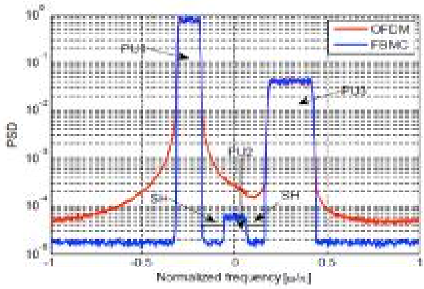
Traffic Type	Synchroisation?	Access Type	Properties
I	closed-loop	scheduled	classical high volume data services
II	open-loop	scheduled	HetNet and/or cell edge multi-layered high data traffic
III	open-loop	sporadic, contention-based	few bits, supporting low latency, *e.g. smartphone apps*
IV	open-loop/none*	contention-based	energy-efficient, high latency, few bits

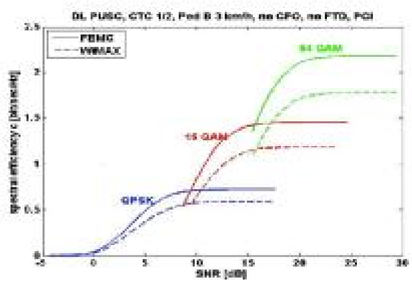
***: none for maximal energy savings at Tx, open-loop for reduced complexity at Rx**

New Waveforms:

FBMC vs OFDM





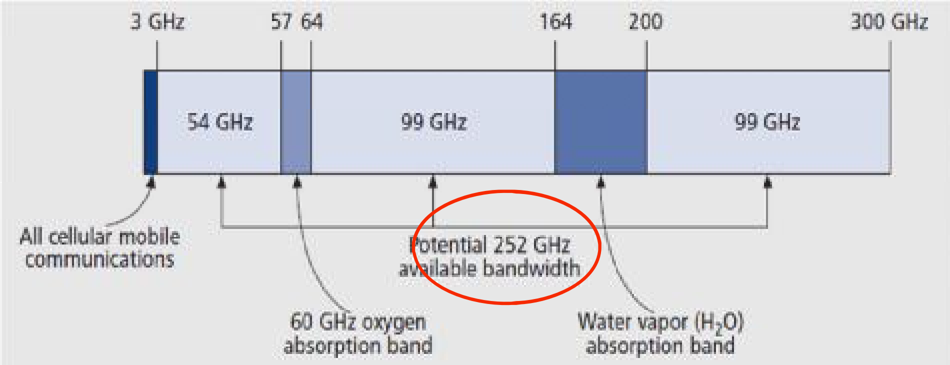


FBMC (Filter Bank Multiple Carrier):

- no significant spectral portion outside the range of the subchannels
- smaller frequency guards (leading to higher spectral efficiency ~20%)
- improved spectrum sensing possible (for Cognitive Radio in white space)

Antenna arrays for MMW

- The spectrum below 3 GHz is over-crowded: what's next?
  - Are very high-data rates (>>1Gbit/s) possible in the 1-3Ghz range (assuming small cells, dynamic spectrum sharing, CoMP…)?
  - Expanding MIMO applications
- mm wavelength communications are a possible way forward



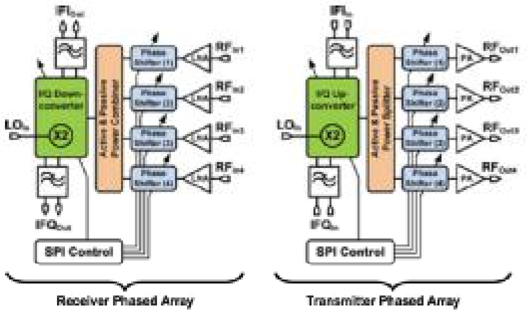
Antenna arrays for MMW

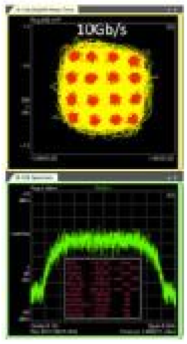
- MMW communications are a candidate 5G technology
- commercial solutions available
  - for backhaul,
  - 802.11ad for P2P access (short links, niche applications)
- Future mm-wave (segments)
  - Low cost (Metro) Backhaul
  - Urban access
  - Indoor access

- Challenges
  - Propagation
  - Deployment
  - Beamforming design (digital vs RF vs hybrid)
  - Waveforms
  - Hardware design
  - System Architecture (e.g. Phantom cell)

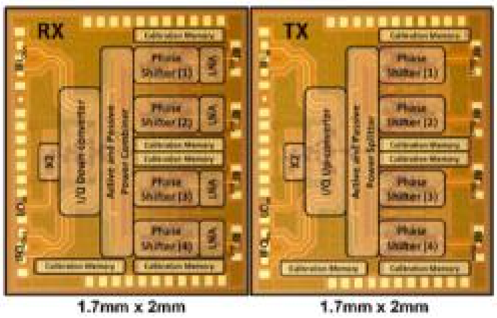
10 Gbps Wireless Array ASIC at 90 GHz @ Bell Labs

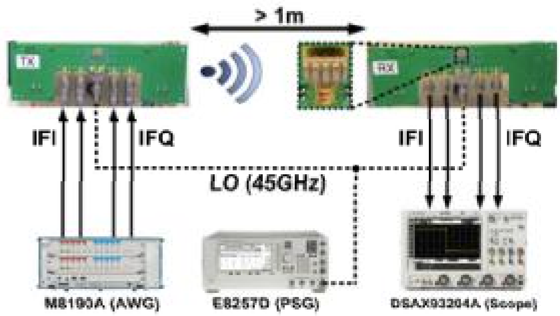
(Targeted for P-P Wireless Backhaul & Proximal Links)





- Carrier: 90 GHz
- 1.5 GHz ISM band
- BW = 2 GHz
- 10Gbps @16QAM
- 4 x 4 MIMO Ready





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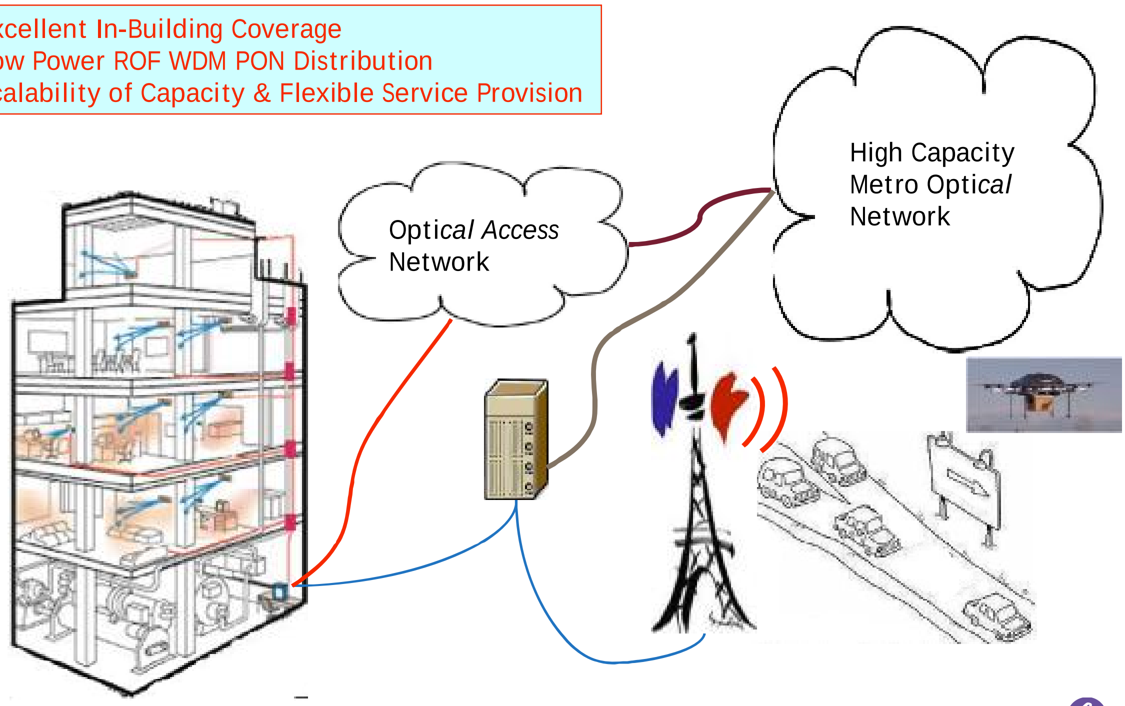
Energy-Efficient Scalable Urban 5G ROF-PON Backhaul Access

Excellent In-Building Coverage
Low Power ROF WDM PON Distribution
Scalability of Capacity & Flexible Service Provision



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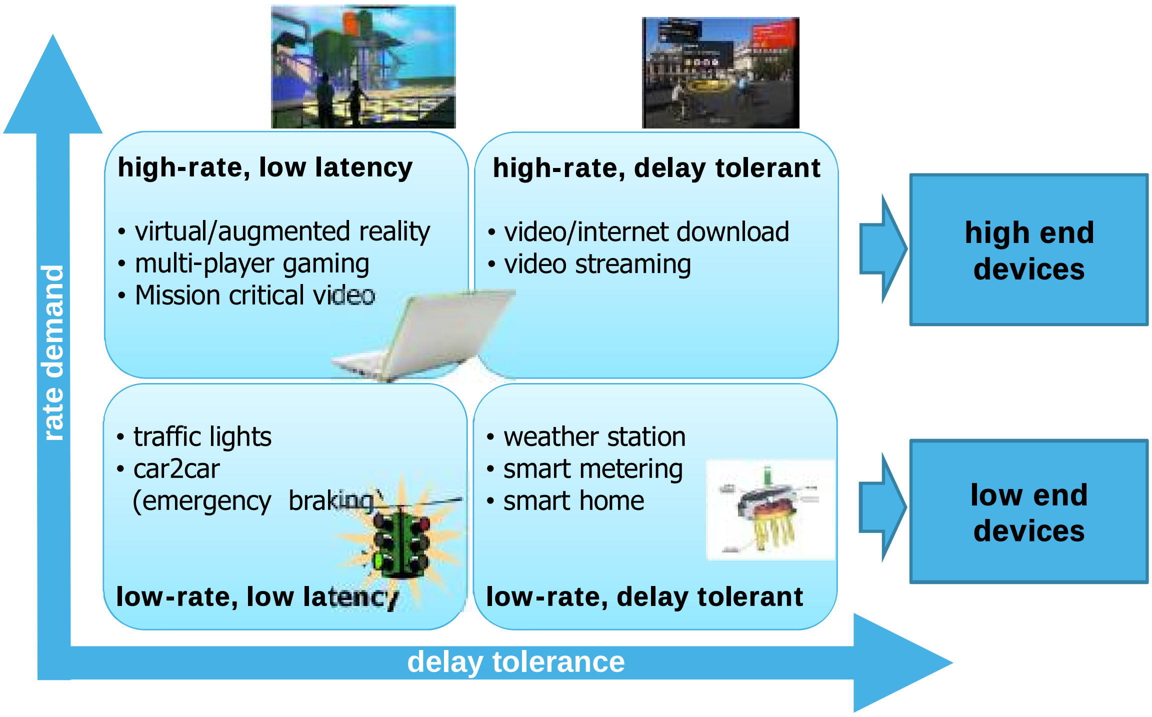
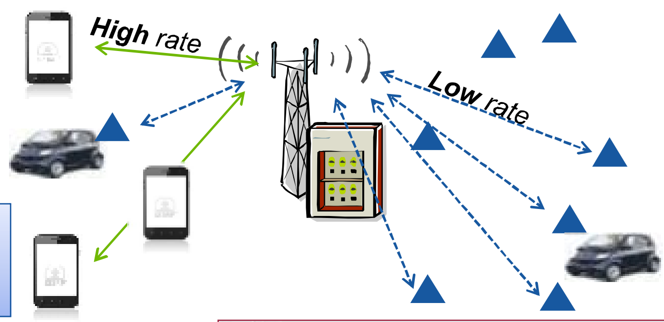
5G Service Matrix

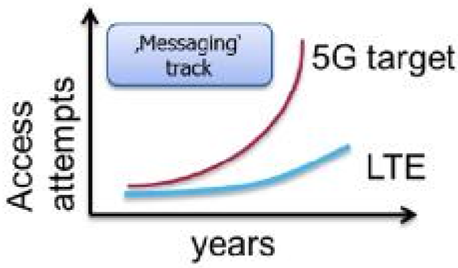


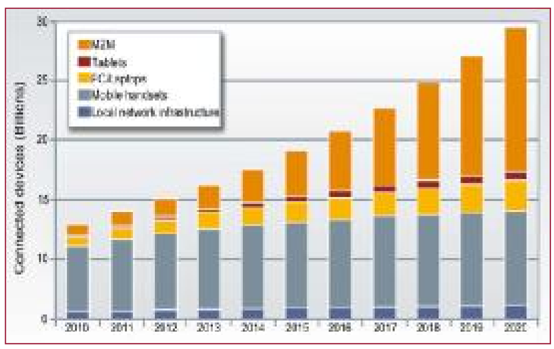
Mixed Broadband and MTC traffic

LTE will evolve for more broadband capacity

.. But many nodes and high signaling traffic will be difficult







Source : GSMA
http://www.2cm.com.tw/technologyshow_content.asp?sn=1307240004

PHY & MAC Layer for Cheap M2M and IoT Devices

PHY Layer for Low Power and Low Cost

Challenge
- Reduced bandwidth
- Low PAPR
- Low complex signal processing
- Coding for very short and low power frames
- Simple TX (UL)/ simple RX(DL)
- Long battery lifetime

Solutions
✓ Single carrier-like (very narrowband)

✓ Spreading code (time domain);

✓ Very complex iterative UL receiver – deals with asynchronicity, MU interference and low power

✓Sleep mode, efficient control Tx signaling

MAC Layer for Correlated and Coordinated Devices

Requirements
- ❑ Random and redundant deployment (many times)
- ❑ Signals might be correlated in space and time

Solutions
✓ Interface between Machine Manager and cellular network

✓ Exploitation of time and spatial correlation

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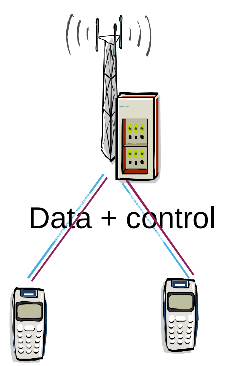
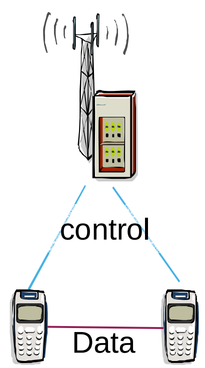
When does D2D Pay-off?

Traditional D2D



Network-assisted D2D



How many communication partners are in D2D range?

Traditional cellular
- state of the art complexity
- serves all within cell coverage area
- congested signaling
- power drain of mobile devices

D2D
- Spatial reuse
- needs Management of D2D links
- needs extra mobility management
- serves all within device coverage area

Tradeoff (control overhead)←→(spatial reuse)

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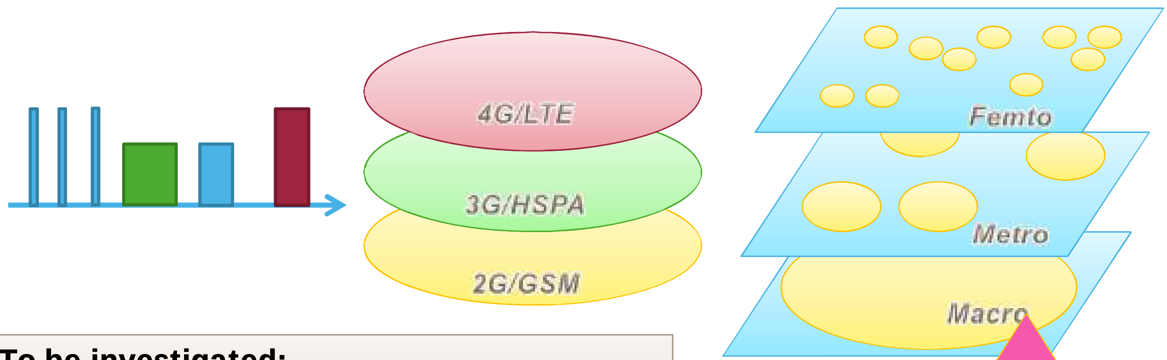
Application Scenarios for D2D

Application scenario	D2D / WA usage ratio	special requirements on solution	WA function used for	Remarks
Smartphone offloading	1%	Broadband traffic	Service at distance	Usage is seldom
Offloading in venue or crowd scenario	3-30%	High spatial re-use	Service at distance	Potential to be evaluated !
Local gaming and content sharing	0-30%	Low application latency	Service at distance	WLAN, Bluetooth are alternatives
Local advertisement	- %	-	Connectivity	WLAN, Bluetooth are alternatives
Automotive Car to car	> %	security .. Low-latency neighbor discovery <u>no</u> multi-hop	Control (channel) Coverage and connectivity	Difficult for D2D to meet availability requirements
Emergency	Seldom, but 100% in case of infra failure	Local and multi-hop communication prioritization of users	Service in normal (non emergency) condition	Cost, Capacity and Spectral efficiency are of lower importance

Simplify The Complexity of Radio Layer

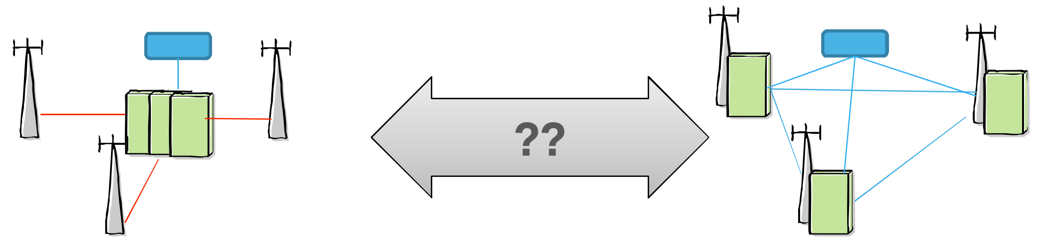
Current 3 dimensions of heterogeneity :

Multi-band **Multi-standard** **Multi-layer**



<u>To be investigated:</u>
- Cell concepts
- Architecture
- Functions to be provided across the het. layers
  - (self) configuration
  - Interference management
  - Mobility management

Architecture : Centralized or Distributed RAN?



Advantages :
- Straightforward introduction of cooperative technologies → full performance gains
- Simpler maintenance & upgrade

Neutral :
- Energy saving by pooling

Disadvantages:
- High data rates and low latency needed on the (digital radio) backhaul
- Complexity of the central node

Advantages :
- Lower data rate on the interconnections (lower backhaul cost)
- More time for signal processing

Neutral :
- Energy saving by power management

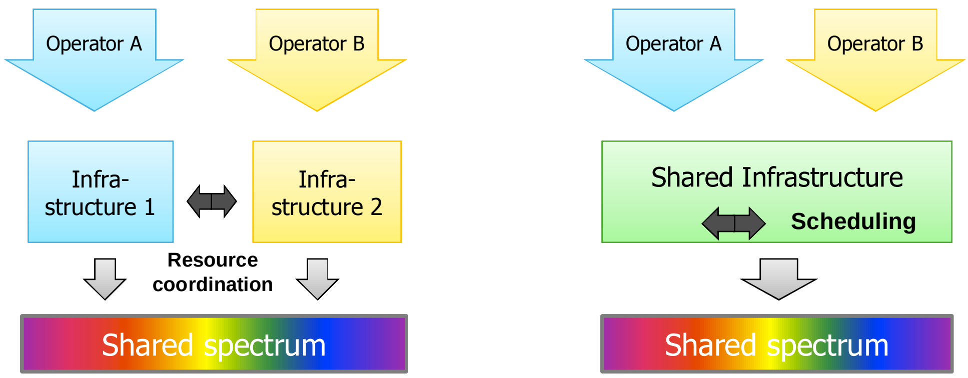
Disadvantages:
- Advanced schemes like co-scheduling, CoMP may suffer from latency → lower COMP gains
- No hardware pooling

Need a scalable solution in the cloud environment.

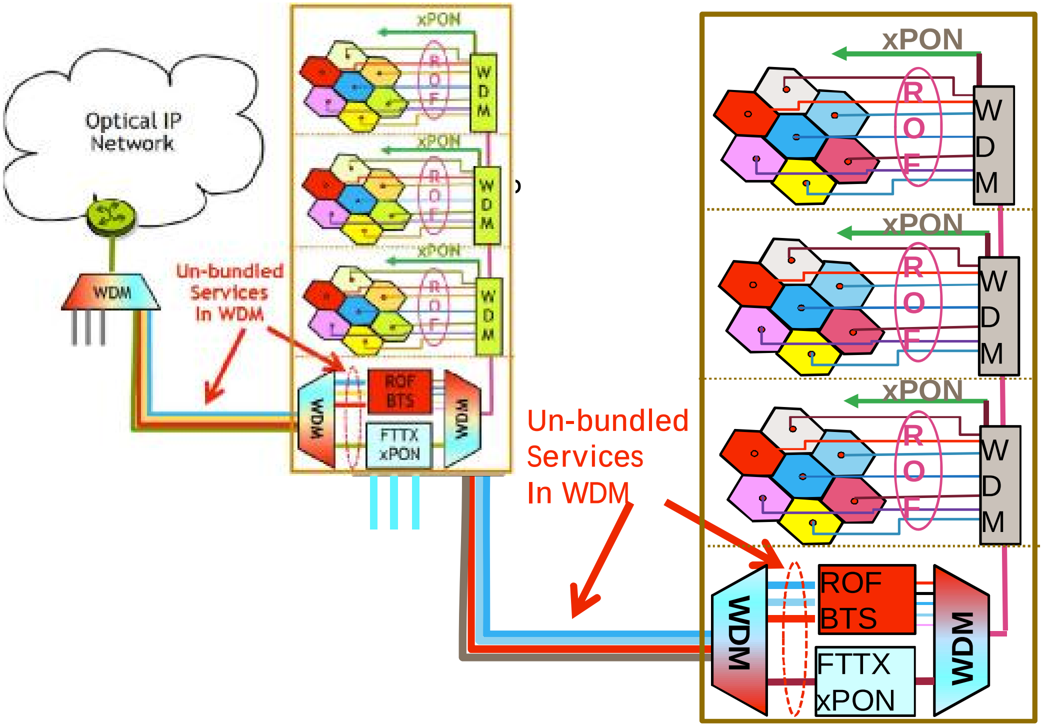
Spectrum Sharing Example

Cost sharing for spectrum

Cost sharing for spectrum and infrastructure/sites



Scalable Low Energy WDM PON Network for In-Building 5G Wireless Backhaul



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ALU University and Industry Fora & Consortia: Europe Case

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Seventh Framework Programme (FP7)

- About
  - 'Framework programmes' (FPs) have been the main financial tools through which the European Union supports research and development activities covering almost all scientific disciplines. FPs are proposed by the European Commission and adopted by Council and the European Parliament following a co-decision procedure.
- Project
  - 5th Generation Non-Orthogonal Waveforms (5GNOW) for Asynchronous Signaling
    - 5GNOW questions the design targets of LTE and LTE-Advanced. 5GNOW will develop new PHY and MAC layer concepts being better suited to meet the upcoming needs with respect to service variety and heterogeneous transmission setups.
- Participants
  - Fraunhofer Heinrich-Hertz-Institut, Germany, **Alcatel-Lucent, Deutschland AG, Germany**, Commissariat a l'Energie Atomique et aux Energies Alternatives, France, IS-Wireless, Poland, National Instrucments, Hungary, and Technische Universitat Dresden, Germany
- Website
  - http://www.5gnow.eu/node/5

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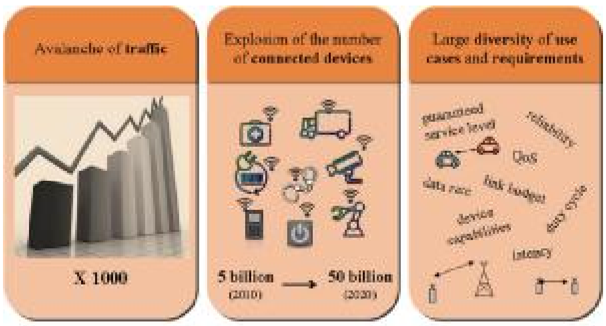
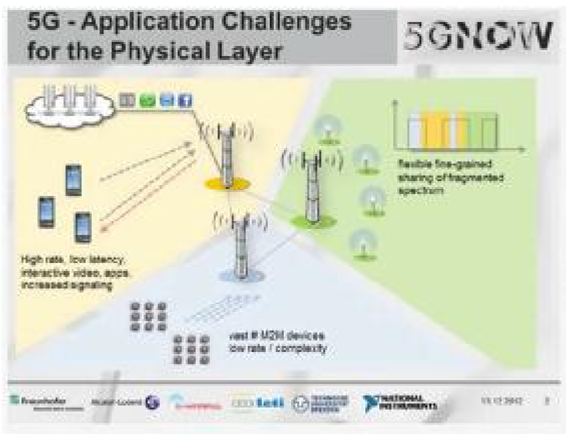
Related Public Projects @ Bell Labs

- **METIS 2020:**
  system definition
  https://www.metis2020.com/
- **5GNow:**
  PHY layer research
  http://www.5gnow.eu/





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Mobile and wireless communications Enablers for the Twenty-twenty Information Society (METIS)

- About
  - EU program with the main objective of the project is lay the foundation of **5G**, the next generation mobile and wireless communications system. Received €16M grant from EU to identify network technologies beyond LTE-Advanced
- Project
  - METIS will provide fundamentally new solutions which fit the needs beyond 2020. Research will be conducted on network topologies, radio links, multi-node, and spectrum usage techniques. Horizontal topics will be used to integrate the research results into a system concept that provides the necessary flexibility, versatility and scalability at a low cost.
- Participants
  - Ericsson, Aalborg University, Aalto-University, **Alcatel-Lucent**, BMW, Chalmers, Deutsche Telekom, DoCoMo (Europe), NTT DoCoMo, Elektrobit, France Telecom, Frauhofer, Huawei, Institut Mines-Telecom, Kungliga Tekniska Hoegskolan, National and Kapodistrian University of Athens, Nokia, Nokia Siemens, Oulun Yliopisto, Poznan University of Technology, RWTAACHEN University, Telecom Italia, Telefonica, Universitaet Bremen, Universistat Kaiserslautern, Uniersidad Politecncica de Valencia.
- Website
  - https://www.metis2020.com/

Centre for Communications System Research (CCSR)

- About
  - £35MUK Research Partnership Investment Fund (UKRPIF) and with University of Surrey consortium
- Project
  - Develop a specialized 5G Innovation Centre to stimulate significant expansion in UK telecommunication research, development, innovation and the provision of broadband mobile internet services, with significant downstream benefits for economic growth.
  - Research areas include Air Interface, Cognitive Networks and Future Internet, Cognitive Radios, Radio Access System Optimization, Security and Knowledge and Data Enginerring
- Participants
  - University of Surrey, Huawei, Samsung, Telefonica Europe, Fujitsu Laboratories Europe, Rohde & Schwarz, and Aircom International
- Website
  - http://www.surrey.ac.uk/ccsr/

Summary

Bell Labs are leading next generation communications to implement 5G network with > 100x increase in capacity with seamless user application interface through a converged cloud-based infrastructure.

Bell Labs is interested in working with local industry, universities and institutes to fully develop the next generation communication technologies.

Acknowledgement:
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Dr. Tod Sizer, Program Leader of Wireless Research
Dr. Peter Vetter, Program Leader of Access Resaerch

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