The road to 5G

Le (brumeux) chemin vers la 5G

Loutfi Nuaymi

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5G today …

Reusing freely and with full respect…

The Diamond Sūtra:

“What is called 5G is not the 5G, that is why we call it the 5G”

(Original: replace « 5G » by « the tree »)

Plan

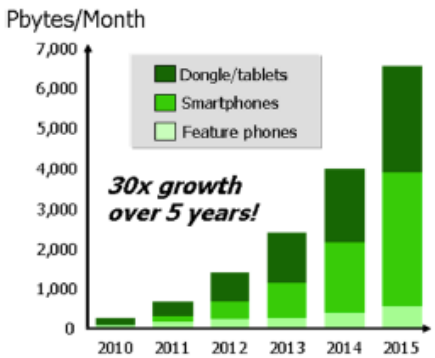
- 1- Context, Generations
- 2- Normalization and standards
- 3- Research Efforts
- 4- METIS RAN Approach
- 5- Technologies
- 6- Simulation, Use Cases

1- Context

- **Mobile Data traffic increase** : x2 every year or two years according to different sources → **x1000 in around 15 years** (but who will verify in 15 years?)
- Greater traffic data asymmetry: Ratio of downlink to uplink traffic will rise as the proportion of video traffic in the mobile network grows.

Example of reference: Cisco traffic forecast update, "Cisco visual networking index: global mobile data," 2011.

Source Fig.: Rit12, Projet Greentouch



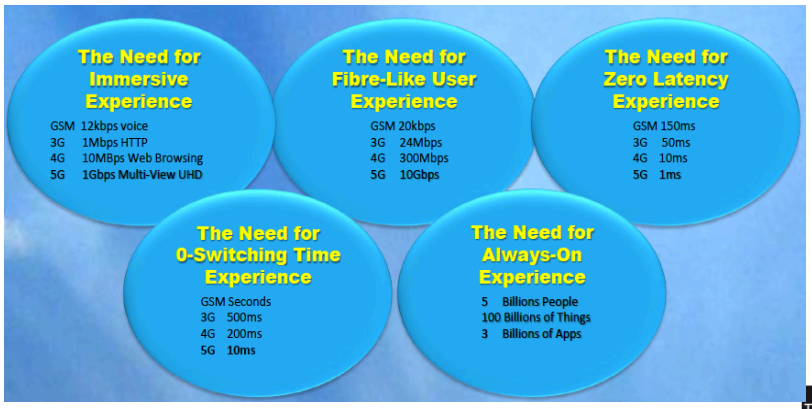
1- Context: generations of cellular systems

- **1985, 1G:** analog. AMPS etc.
  First wireless telephony: before WW1, 1905, 80 years
- **1992, 2G**: digital, TDMA/CDMA etc.
  Shannon Theory, 1948, to 1992. 44 years. Bell Labs dscoveries (Ring, Young)
- **2002, 3G:** multimedia, WCDMA etc.
  De-Rosa-Rogoff defined the direct sequence spread spectrum method in 1950, 52 years. In addition: Lamar
- **2012, 4G:** upgraded form of 3G, rich multimedia, MIMO+OFDM, etc.
  1970, MIMO, A.R. Kaye and D.A. George;
  1970: OFDM, Robert W. Chang. → 42 years

1- Context: Why 5G?

- 5G design challenges

Source Fig.:D. Soldani, « On the Advanced 5G Network Infrastructure for the Future Internet », ICC 2013, Budapest, June 2013

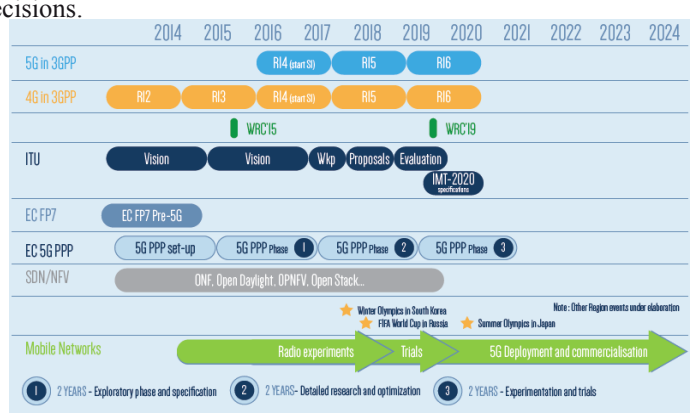


1- Context: 5G users

- Today we can identify 3 categories of 5G users (TB discussed):
  - **Humans**
  - **Massive Machines** (sensors, smart environment,…) – will it be 5G (LTE-LC, LTE-M) or LPWA (LoRa, …)?
  - **Ultra Reliable Machines** (health, reliable transportation, …)

2- Normalization, Standards

- Nothing for the moment! Expected to start in 2016 (may 2015 info), Rel. 14
- Important (and expected) effect of WRC, World Radiocommunication Conference, decisions.
- **Timeline:**



- Fig. Source: GPPP White Pap, Feb. 2015

- However, many ongoing and proposed study items for Rel-12 are already closely related to 5G candidate technologies

3- Research Efforts: METIS Goals

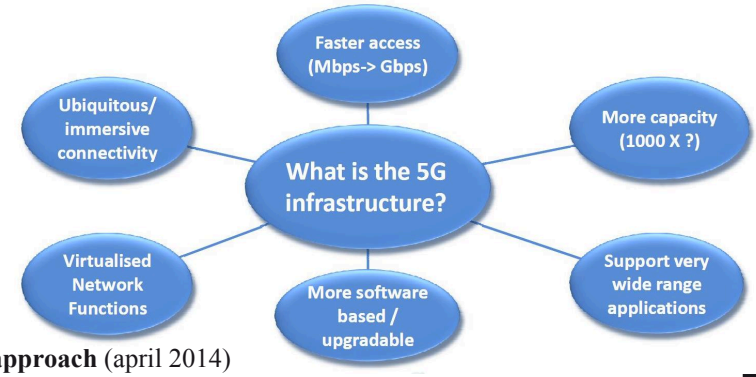
METIS displayed goals (very close to 5GPPP), very close to 5GPPP High-Level KPIs

- 1000x data volume
- 10 – 100x user data rate
- 10 – 100x number of devices
- 10x longer battery life
- 5x reduced E2E latency
- Energy efficiency and cost

3- Research Efforts 5GPPP

- **Dec 2013:** The Public Private Partnership (PPP) on the Advanced 5G networks for the Future Internet (5G), **5GPPP** is signed by ALU, NSN and European Community. Follow : http://5g-ppp.eu/

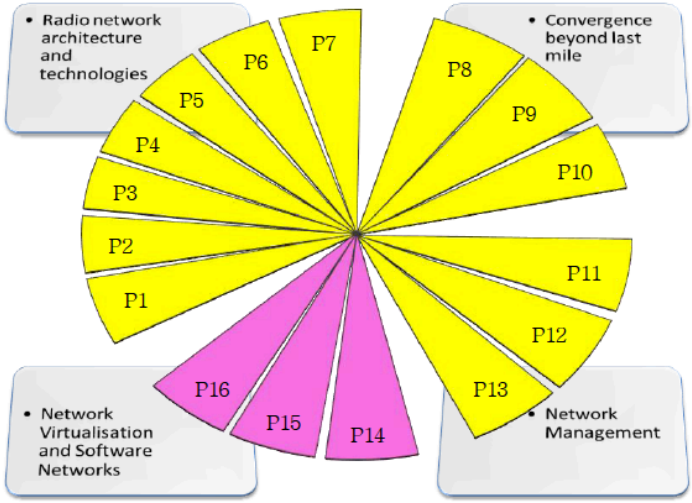
  Members → http://5g-ppp.eu/structure-2/



5GPPP approach (april 2014)

3- Research Efforts 5GPPP

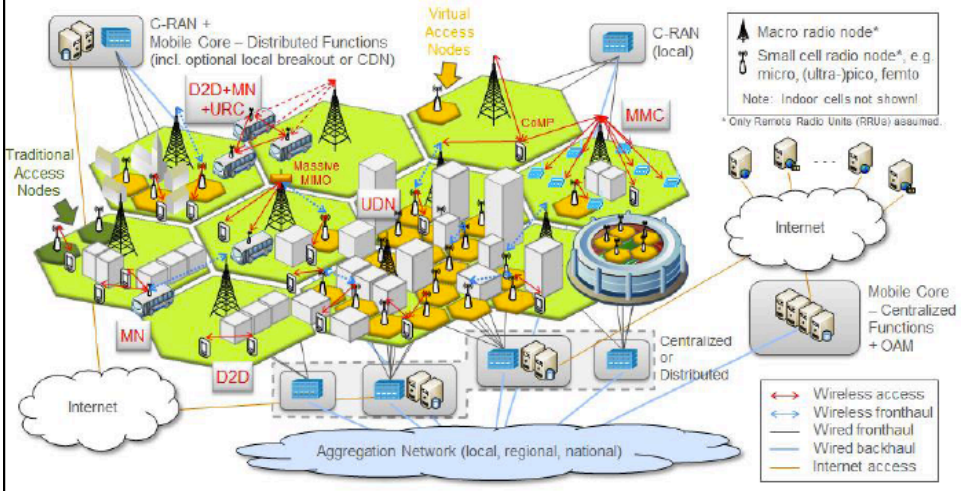
- **5GPPP Projects**
- Slides Source: BOURSE D, "The Energy Efficiency Challenge in the EC H2020 5G Infrastructure PPP", Next GWIN 2014, Oct. 2014



4- METIS RAN Approach

- **METIS proposed Architecture (April 14) : Dynamic RAN**
- The RAN includes SDN, NFV and SON

Fig. source: H. Tullberg, METIS, April 14



4- METIS RAN Approach: Dynamic RAN

Five scenarios have been specified in METIS:

- **"Amazingly fast"** : Very high data rates for future mobile broadband users to experience instantaneous connectivity without delays.
- **"Great service in a crowd":** Reasonable mobile broadband experiences in crowded areas such as stadiums, concerts, and shopping malls.
- **"Best experience follows you":** end users on the move (e.g., in cars or trains), high levels of service experience.
- **"Super real-time and reliable connections":** New applications and use cases with very strict requirements on latency and reliability.
- **"Ubiquitous things communicating":** efficient handling of a very large number of devices (including, e.g., machine type devices and sensors) with widely varying requirements. Massive Machine Deployment

A. Osseiran et al, "Scenarios for 5G Mobile and Wireless Communications: The Vision of the METIS Project," IEEE Com. Mag., May 14

METIS Project Deliverable D1.1, "Scenarios, Requirements and KPIs for 5G Mobile and Wireless System," Del. D1.1, May 2013, https://www.metis2020.com/docu- ments/deliverables/

5- Technologies

- **What about the technologies?**

5- Technologies

- **Where is the research we can do?**

5- Technologies: (1) High frequencies

(« Go to the forbidden territories »)

- Use of **High Frequency** (mm Wave) : Although far from being fully understood, the use of high frequencies have already been standardized for WLAN (IEEE 802.11ad) and also deployed for niche applications such as small-cell backhaul.
- Problem: Bad (or no) penetration of building walls (limit: 5, 10 GHz?)
  - RAPPAPORT T, « Millimeter Wave Wireless Communications for 5G Cellular: It will work! », Keynote Presentation, PIMRC 2014, Sept 2014

5- Technologies: (2) new paradigm

- Move from **BS-centric (or Cell-Centric)** to **Device-centric architecture**.
- Network virtualization and Cloud Radio Access Network (**CRAN**), mainly promoted by China Mobile (but also many other), for a better energy efficiency and reduced costs

5- Technologies

- **Caching (CDN techniques) in the wireless (wired) network:** Where to cache? What to cache? How to cache?

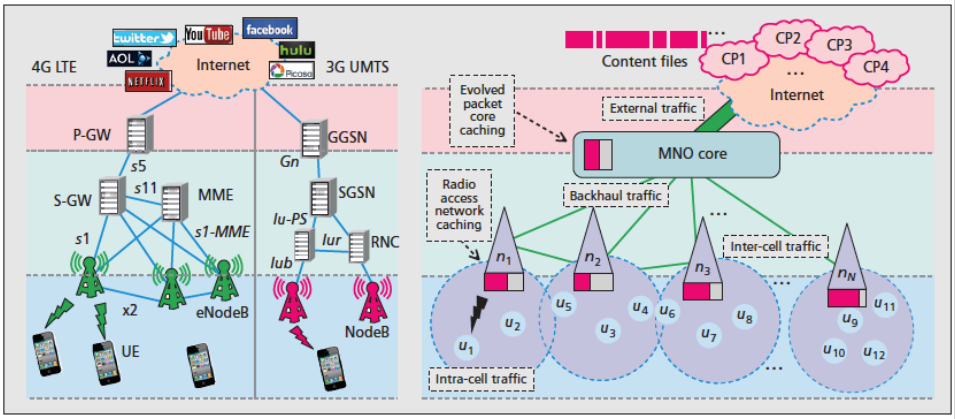


Figure Source : X. Wang, *et al*, "Cache in the Air: Exploiting Content Caching and Delivery Techniques for 5G Systems," IEEE Com. Mag., Feb. 2014

5- Technologies

Caching (CDN techniques) in the wireless (wired) network:

- **Where to cache:** Core Network, RAN (difficult with present LTE versions) or D2D?
- **What to cache:** Studies show that only a small amount of Internet content is accessed by a large amount of mobile users: latest Eurovision Video; XX emails when XX spends a long time in a cell, …
- **How to cache:** Caching policy taking into account: storage sizes, popularity, locations, etc. Cooperation between core network and RAN
- CDNs can incorporate different caching techniques, applying the **information-centric (ICN)** or **content-centric networking (CCN)** Internet and architecture. **The possible objectives of CCN** could be:

- Minimization of inter-ISP traffic (outbound Traffic)
- Minimization of intra-ISP traffic (traffic within the EPC and RAN)
- Minimization of content access delay of all users

5- Technologies: (3) work on signal (PHY)!

- **Massive MIMO**, also referred to as "**Large-Scale MIMO"** or **"Large-Scale Antenna Systems, LSAS**")
- Massive MIMO is a form of multiuser MIMO where the number of antennas at the base station is much greater than the number of devices: M ≫ K ≫ 1 (think 100 × 10. Theory of T. Marzetta, often-cited paper (in 2010): T. Marzetta, "Noncooperative cellular wireless with unlimited numbers of base station antennas" IEEE Trans. Wireless Commun., vol. 9, Nov. 2010.

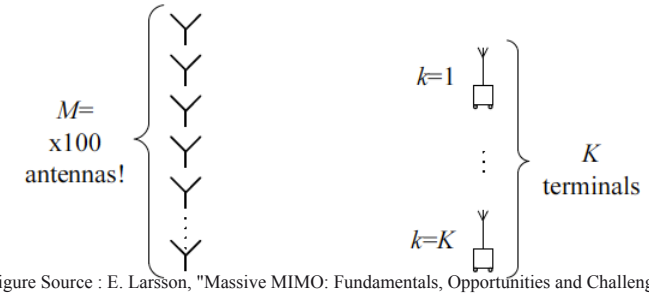


Figure Source : E. Larsson, "Massive MIMO: Fundamentals, Opportunities and Challenges," ICC 2013, June 2013

5- Technologies

Signal Transmission, modulation and PHY layer

- **Energy efficient physical** (PHY) layer design for 5G, see for example METIS project)
- **Full-Duplex** Radio (needs sophisticated interference cancellation techniques)
- Other advanced Coding and Modulation Proposals
- **Waveform and Multiple Access? See following slides**

5- Technologies

Waveforme Choice, Keep OFDM for 5G?

(source: J. Andrews, et al, What will 5G be?, JSAC, May 2014)

- **Advantages of OFDM :**
  - A natural way to cope with frequency selectivity.
  - Computationally efficient implementation via FFT/IFFT blocks and simple frequency-domain equalizers.
  - An excellent pairing for MIMO (see OFDM basics).
  - From a multiple access vantage point, OFDM invites dynamic fine-grained resource allocation schemes in the digital domain. The term OFDMA is employed to denote orthogonal multiple access at a subcarrier level (resource blocks)
- Given its near-universal adoption, industry has by now a great deal of experience with its implementation, and tricky aspects of OFDM such as frequency offset correction and synchronization have been essentially conquered. OFDM remains a frontrunner for 5G.

5- Technologies

Waveforme Choice, other than OFDM?

- **Modified OFDM** (SC-FDMA variant already used in LTE Uplink) and other new waveforms:
- **Filter Bank-based Multi-Carrier (FBMC)**, see (among other) french CNAM works;
- Spectrally-Efficient Frequency Division Multiplexing (**SEFDM**) where up to 40% bandwidth saving (relative to OFDM) may be achieved at the expense of receiver complexity, see University College London works.
- **NOMA** (Non-Orthogonal Multiple Access),
- **GFDM**, Generalized Frequency Division Multiplexing (voir Andrews)

5- Technologies: (4) Moore'Law still our friend !

- **Smarter devices:** thanks to Moore's Law !
  … implementing more and more efficient algorithms and techniques

- **New signalling algorithms increasing the traffic efficiency :** Modes adapted to specific services (ex: Instant Messaging) have been proposed in recent 3GPP Releases (Rel. 11, Rel. 12).
  Efficiency is estimated through the **DSR, Data to Signalling/control Ratio**
  → See: Gupta et al, "Energy Impact of Emerging Mobile Internet Applications on LTE Networks: Issues and Solutions," IEEE Com. Mag., Feb. 2013

5- Technologies: (5) M2M (or MTC) issues

- **Native, standard and enhanced support for M2M communication:** this support of M2M in 5G requires radical changes at both the node and architecture levels.
  Major research work remains to be done to provide innovative and efficient solutions enabling M2M inside 5G systems.

- For Massive or Ultra Reliable Machines?

5- Technologies: (6) Other

And also other Technologies:

- **Green cognitive radio** for efficient spectrum use
- **Smart grids** for 5G
- And of course … **small cells** (hierarchical ou hybrid networks), where a lot has yet to be done
- **Backhaul issues:** energy, capacity, cost

6- Simulation, Use Cases

(This is only the Section basis)

- Useful **material, Simulation software and data** is available on the METIS web site:
  https://www.metis2020.com/documents/simulations/

References

- **METIS** website: https://www.metis2020.com
- **5GPPP** website: http://5g-ppp.eu/
- Radio Access and Spectrum, FP7 - Future Networks Cluster White Paper, "5G radio network architecture," March 2014