Dr.-Ing. Riccardo Bassoli
Deutsche Telekom Chair of Communication Networks

Network Coding for Efficient Vertical Handovers
The Scientific Method in Engineering

Contact: riccardo.bassoli@tu-dresden.de
Website: www.riccardobassoli.com

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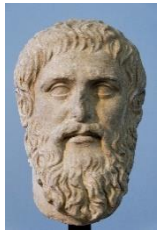
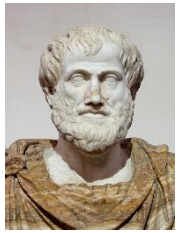
Main Terminology

Main terms around the topic

- Science
- Engineering
- Method
- Standardisation
- Wireless cellular networks
- Vertical handovers
- Network coding

Science and Engineering

Science

5th – 4th Century B.C.

Science (gr. *ἐπιστήμη* [*epistēmē*], ger. *Wissenschaft*) broadly identifies with **knowledge**. Especially, with the knowledge that also includes a ‘guarantee’, that is a **proof** (demonstration) of its validity.

This was distinguished by Plato from common and popular belief or **opinion** (gr. *δόξα* (*doxa*)).

With initially Plato and mainly with Aristotle, the internal dualism between **natural** (empirical) sciences and **mathematical** (abstract or formal) sciences.


17th Century

Starting during the **Renaissance**, and achieving the apex with **Galileo Galilei** and the *Novum Organum* of **Francis Bacon**, **experience** becomes the logic fundament of new speculation.

This represented the decline of Aristotelian metaphysics and idea of science.

The aim of Science is only **description**.

It implies the distinction between science and philosophy with **modern empiricism,** through the systematic use of **Inductive reasoning**.

Science



John Locke, David Hume, and George Berkeley stated the strict separation between **a priori** (philosophy) and **a posteriori** (science) knowledge.

18th Century

Immanuel Kant explained and solved the irreparable strict separation between *a priori* and *a posteriori* knowledge.

a posteriori in natural sciences is not merely empiric but is a **synthesis** with *a priori*, which is funded by the absolute laws of intuition and intellect. This allowed for passing the limit of the immediate empiric experience.

However, **knowledge** (science) comes from the experimental data, so knowing what is beyond experience is impossible.

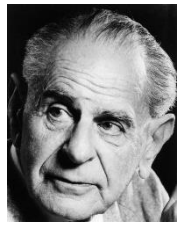
For example, since then, problems such as demonstrating God's existence has been considered out of science's scope.

Science

19th Century

Fallibility of any human knowledge (science) arose among scientists and philosophers.

Charles John Huffam Dickens in *David Copperfield [Chapter 1]* “I need say nothing here, on the first head, because nothing can show better than my history whether that prediction was verified or falsified by the result.”



20th Century

Karl Raimund Popper stated complete uncertainty and fallibility of science. Decline of Science as a complete system of necessary truths.

Science (knowledge) is valid only if it is **self-corrective**. Science can only **conjecture** and prove that statements are *false* so to replace it with the new one, not yet proven to be false.

Full break with previous paradigm of Science as *ἐπιστήμη* (***epistēmē***), as knowledge completely certain and provable. Scientific approach:

1. By chance, we encounter a problem
2. We try to solve it, by proposing a new theory
3. We learn from mistakes and from critical discussions on the proposed theory

Engineering and Technology

Technology or **technique** or **technics** (gr. *τέχνη* [*tékhnē*], ger. *Technik*) is the set of knowledge, procedures and instruments used to make a manual or intellectual action.

The term *τέχνη* [*tékhnē*] was a term related with arts and professions, indicating the knowledge of means suitable to perform any activity. The root of the term can lead to the Indogermanic *tekp*, which identifies the **work of the carpenter**.

Both the Greek *τέχνη* [*tékhnē*] and the Latin *textor* have in common the Latin *texo*, which refers to the **construction of a house**.

The term **engineer** first appeared in the medieval Latin (encignerius, inzignerius) and ancient French (engigneor). It derives from the Latin *ingenium*, which indicates a machine, especially a war machine.

Friedrich Dessauer (1881 – 1963) described engineering as the passage from **homo investigator** (observation and understanding of Nature) to **homo inventor** (design) and finally to **homo faber** (create and rielaborate).

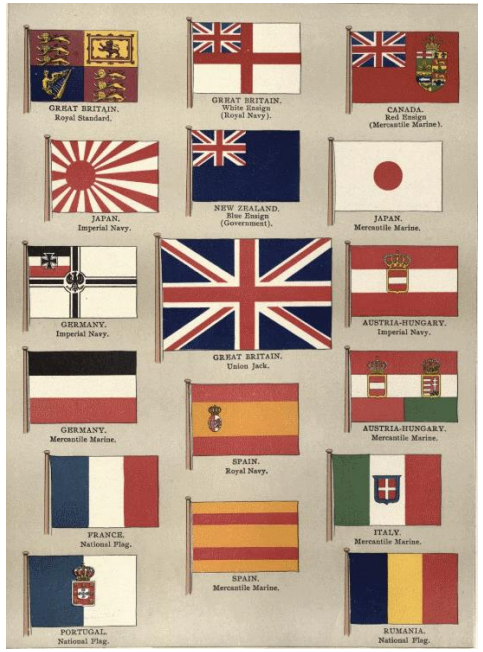
Modern Engineering
Standardisation and Business Exploitation

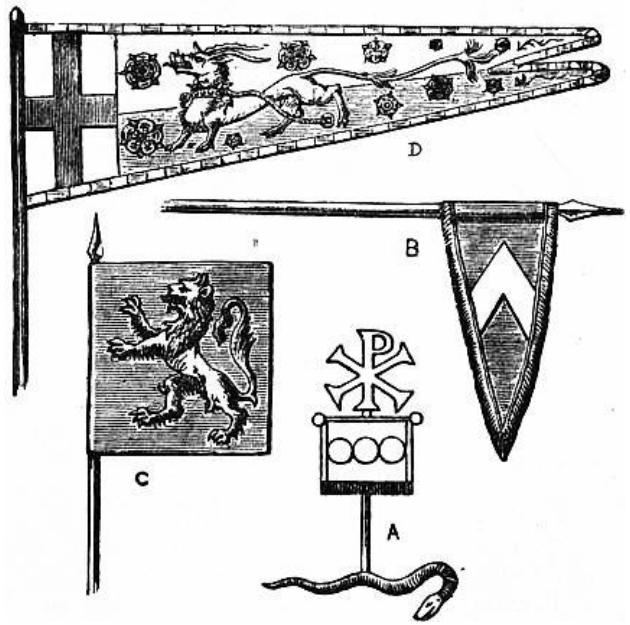
Etymology and Meaning of Standard

“A flag, sculptured figure, or other conspicuous object, raised on a pole to indicate the rallying-point of an army (or fleet), or of one of its component portions; the distinctive ensign of a king, great noble, or commander, or of a nation or city.” (1154)

It comes from Old French *estandard* (=*stable, fixed* because in the middle age it was fixed in the ground).

"standard, n. and adj." OED Online. Oxford University Press, September 2019. Web. 21 October 2019.





Etymology and Meaning of Standard

“The **authorized exemplar of a unit** of measure or weight; e.g. a measuring rod of unit length; a vessel of unit capacity, or a mass of metal of unit weight, preserved in the custody of public officers as a permanent evidence of the legally prescribed magnitude of the unit.” (1429)

"standard, n. and adj." OED Online. Oxford University Press, September 2019. Web. 21 October 2019.

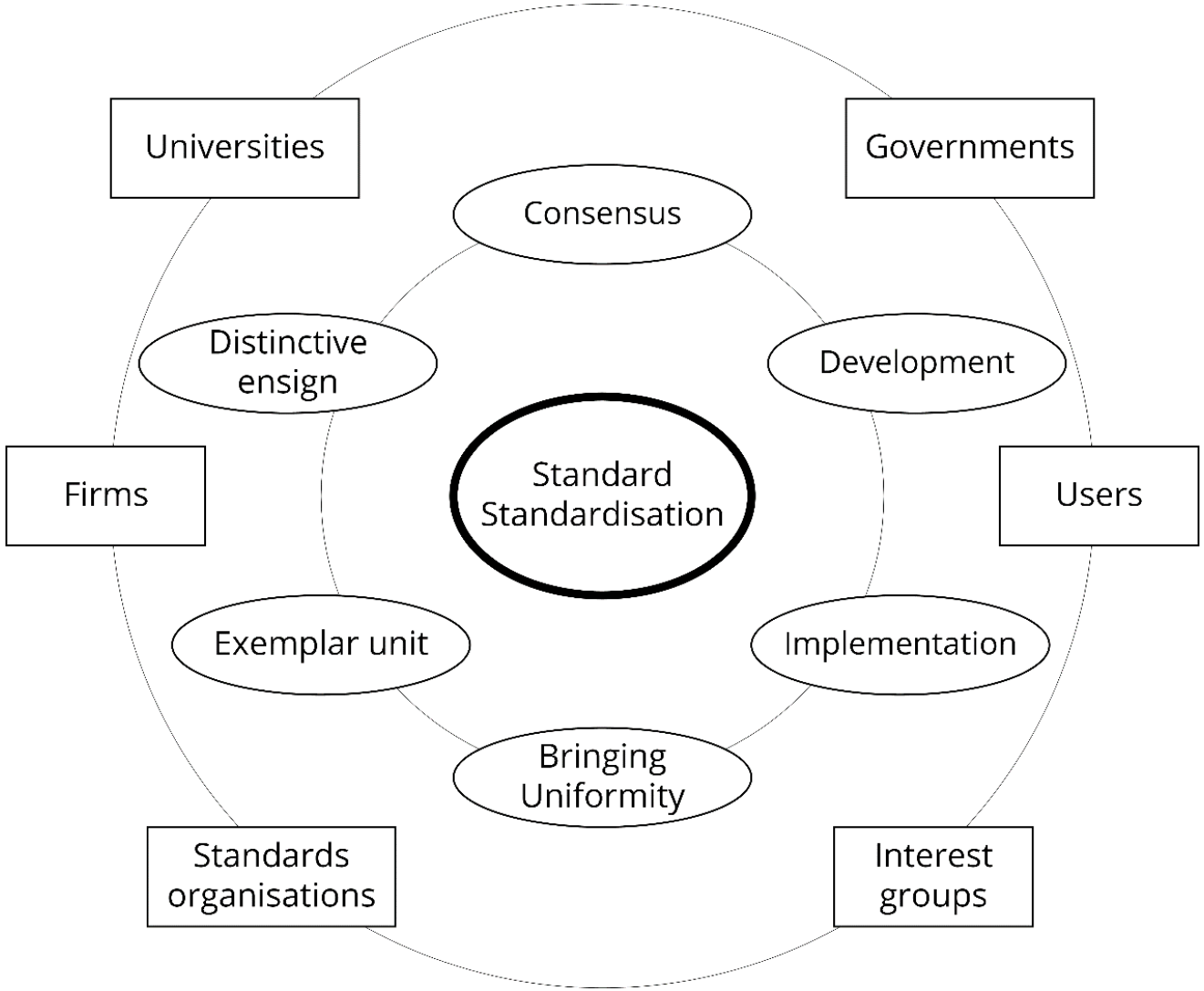
To standardise: “To bring to a standard or **uniform size**, **strength**, **form of construction**, **proportion of ingredients**, or the like.” (1873)

"standardize, v." *OED Online*. Oxford University Press, September 2019. Web. 21 October 2019.

Standardisation “is the process of **implementing and developing technical standards** based on the **consensus of different parties** that include **firms**, **users**, **interest groups**, **standards organizations** and **governments**.

Wikipedia contributors. "Standardization." *Wikipedia, The Free Encyclopedia*. Wikipedia, The Free Encyclopedia, 25 Sep. 2019. Web. 21 Oct. 2019.

Standardisation: Characteristics and Entities



Effects of Standardisation – Technology

- The effect of standardisation on technology and innovation is mixed.
  - Standardisation can be a platform of knowledge transfer and translated into policy measures
  - Increased adoption of a new technology as a result of standardisation is important because rival and incompatible approaches competing in the marketplace can slow or even kill the growth of the technology (a state known as market fragmentation).
  - The shift to a modular architecture as a result of standardisation brings increased flexibility, rapid introduction of new products, and the ability to more closely meet individual customer's needs.
- The negative effects of standardisation on technology have to do with its tendency to restrict new technology and innovation:
  - Standards shift competition from features to price because the features are defined by the standard. The degree to which this is true depends on the specificity of the standard.
  - Standardisation in an area also rules out alternative technologies as options while encouraging the ones following the specific standard.

Effects of Standardisation – Firms

- Competition among companies is mainly shifted from overall systems to their internal individual components.
- Before standardisation, company's design and production has more freedom but products suffer incompatibility. After standardisation each company focuses on providing an individual component compatible with competitors' ones.
- Standardisation makes design and production shifting to a modular approach, supplying other companies with subsystems or components.

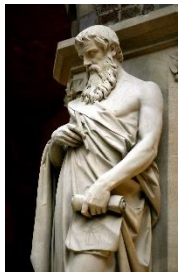
Effects of Standardisation – Consumers

- **Standards increase compatibility and interoperability** between products, allowing information to be shared within a larger network and attracting more consumers to use the new technology.
- **Standards reduce uncertainty** because consumers have more guarantees on products they are going to buy.
- Consumers can also benefit from **being able to mix and to match components** of a system to align with their specific preferences.
- **Standardisation produces lack of variety**. There is no guarantee that the chosen standard will meet all consumers' needs or even that the standard is the best available option. Thus consumers must adapt to the conditions made available by the products.
- If a standard is agreed upon before products are available in the market, then **consumers are deprived of the penetration pricing** that often results when rivals are competing to rapidly increase market share in an attempt to increase the likelihood that their product will become the standard.
- A consumer can choose a product based upon **a standard that fails** to become dominant. In this case, the consumer will have spent resources on a product that is ultimately less useful.

Example of Lifetimes of Research Areas

Abstract Sciences

Geometry



Euclid of Alexandria

Around 300 B.C.

About 2000 years

Giovanni Girolamo Saccheri

1667 – 1733

Christian Felix Klein

1849 – 1925

Carl Friedrich Gauss

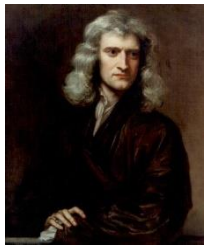
1777 – 1855

Euclidean Geometry

Non-Euclidean and Projective Geometries, group-theoretic geometry via transformations

Natural Sciences

Physics



Isaac Newton

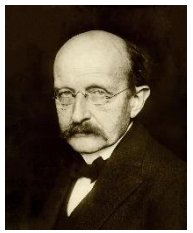
1642 – 1727

Classical mechanics

About 300 years

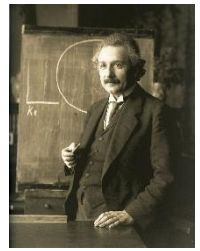
Erwin Schrödinger

1887 – 1961



Max Planck

1858 – 1947



Albert Einstein

1879 –1955

Quantum mechanics

Engineering

Wireless communications

Wireless telegraphy (1896)

Guglielmo Marconi

1874 – 1937

50 years

Bell System (1946)

The **Mobile Telephone Service** (**MTS**) was a pre-cellular VHF radio system that linked to the Public Switched Telephone Network (PSTN). MTS was the radiotelephone equivalent of land dial phone service.

33 years

Nippon Telegraph and Telephone (1979)

The first commercial automated **wireless cellular network** (1G) analog was launched in Japan.

Mobile phones from 1994 to 2004

Standardisation in Telecommunications

4G and Vertical Handovers

International Standardisation Bodies in Telecommunications

Major international standardisation bodies in telecommunications and networking are

- International Standards Organization or International Organization for Standardization (**ISO**) (https://www.iso.org/)
- Institute of Electrical and Electronics Engineers (**IEEE**) (https://www.ieee.org/)
- 3rd Generation Partnership Project (**3GPP**) (https://www.3gpp.org/)
- European Telecommunications Standards Institute (**ETSI**) (https://www.etsi.org/)
- ITU Telecommunication Standardization Sector (**ITU-T**) (https://www.itu.int/en/ITU-T/)
- Internet Engineering Task Force (**IETF**) (https://www.ietf.org/)
- Internet Research Task Force (**IRTF**) (https://irtf.org/)

Institute of Electrical and Electronic Engineering – IEEE

- The **Institute of Electrical and Electronics Engineers** was formed in 1963 from the unification between the American Institute of Electrical Engineers and the Institute of Radio Engineers.
- It is a professional association for electronic engineering and electrical engineering (and associated disciplines) with its corporate office in New York City and its operations center in Piscataway, New Jersey.
- As of 2018, it is the world's largest association of technical professionals with more than 423 000 members in over 160 countries around the world.
- IEEE is composed of societies related to different research areas such as:
  - IEEE Communications society
  - IEEE Computer society
  - IEEE Aerospace and electronic systems society
  - (https://www.ieee.org/membership-catalog/societies.html?N=4294925302)

Wikipedia contributors. "Institute of Electrical and Electronics Engineers." *Wikipedia, The Free Encyclopedia*. Wikipedia, The Free Encyclopedia, 9 Oct. 2019. Web. 23 Oct. 2019.

Institute of Electrical and Electronic Engineering – IEEE

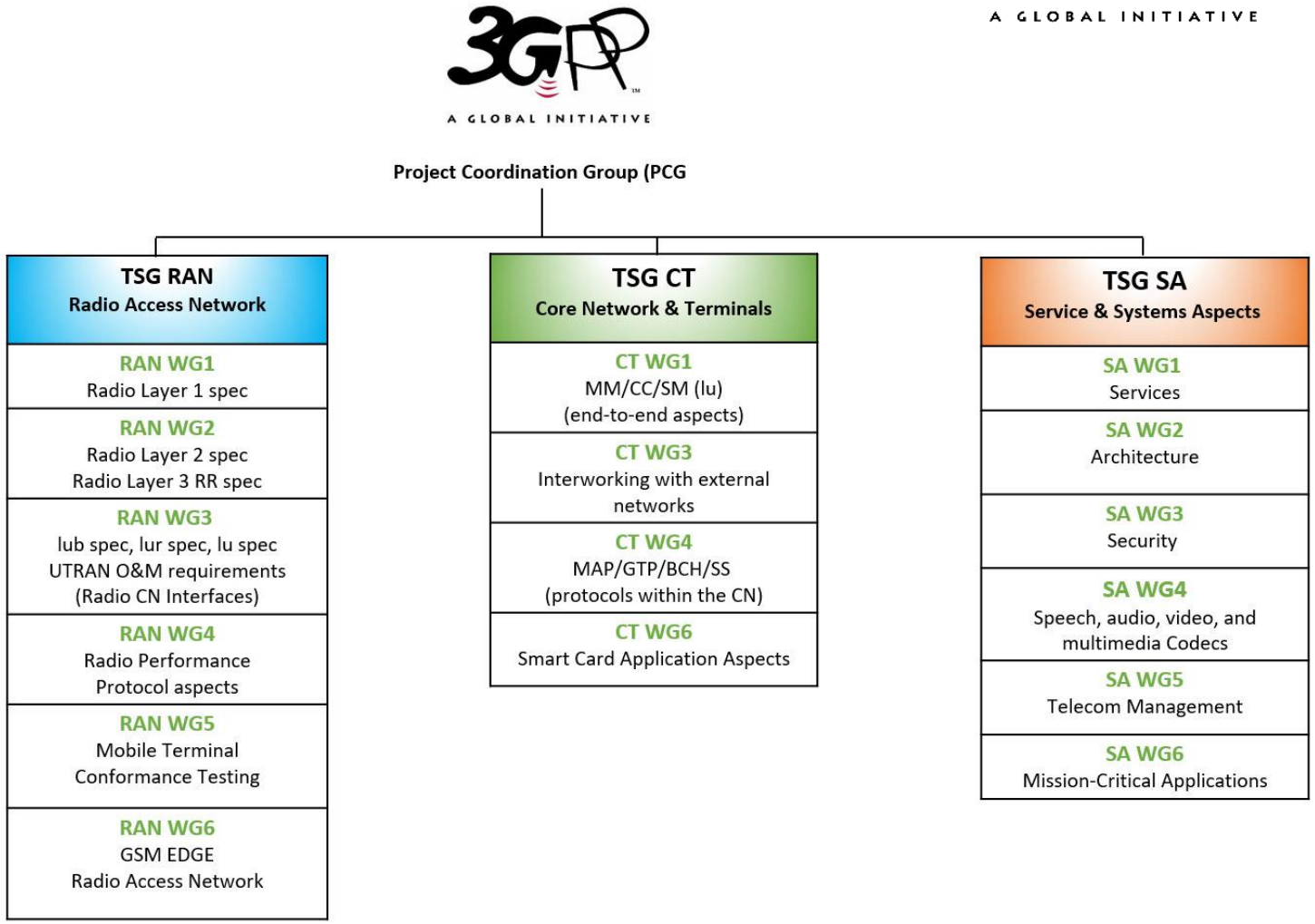
- **IEEE 802.11** standards for Wireless Area Local Networks (WLAN) specifying the set of media access control (MAC) and physical layer (PHY) protocols.
- Non-profit Wi-Fi Alliance was created in 1999 to test equipment compliance with IEEE 802.11 standard by also establishing and enforcing standards for interoperability and backward compatibility, and to promote WLAN technology.
- As of 2010, the **Wi-Fi Alliance consisted of more than 375 companies** from around the world. Manufacturers with membership in the Wi-Fi Alliance, whose products pass the certification process, gain the right to mark those products with the Wi-Fi logo.
- **IEEE 802.3** is a collection of IEEE standards produced defining the PHY and MAC of **wired Ethernet**. This is generally a local area network technology with some wide area network (WAN) applications. Physical connections are made between nodes and/or infrastructure devices by various types of copper or fiber cable.

3rd Generation Partnership Project – 3GPP

- The **3rd Generation Partnership Project** (**3GPP**) is a standards organisation, which develops protocols for mobile telephony. The project was established in December 1998 with the goal of developing a specification for a 3G mobile phone system.
- 3GPP is consortium with seven regional telecommunication associations as primary members (**organisational partners**) and a variety of other organisations as associate members (**market representation partners**).
- **Organisational partners** are:
  - Association of Radio Industries and Businesses (Japan)
  - Telecommunication Technology Committee (Japan)
  - Alliance for Telecommunications Industry Solutions (US)
  - China Communications Standards Association (China)
  - European Telecommunications Standards Institute (Europe)
  - Telecommunications Standards Development Society (India)
  - Telecommunications Technology Association (South Korea)

3rd Generation Partnership Project – 3GPP

- The 3GPP organises its work into **three different streams**:

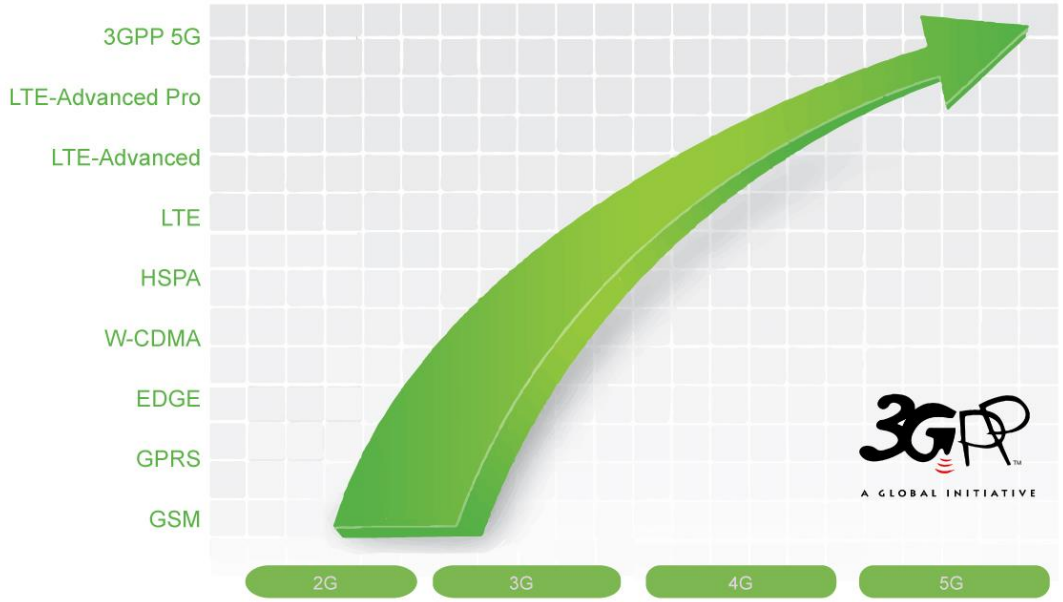


https://www.3gpp.org/about-3gpp/about-3gpp

3rd Generation Partnership Project – 3GPP

3GPP is responsible for development and maintenance of:

- GSM and related 2G and 2.5G standards (GPRS and EDGE)
- UMTS and related 3G standards (also including HSPA)
- LTE and related 4G standards
- 5G NR and related 5G standards
- An evolved IP Multimedia Subsystem (IMS) developed in an access independent manner

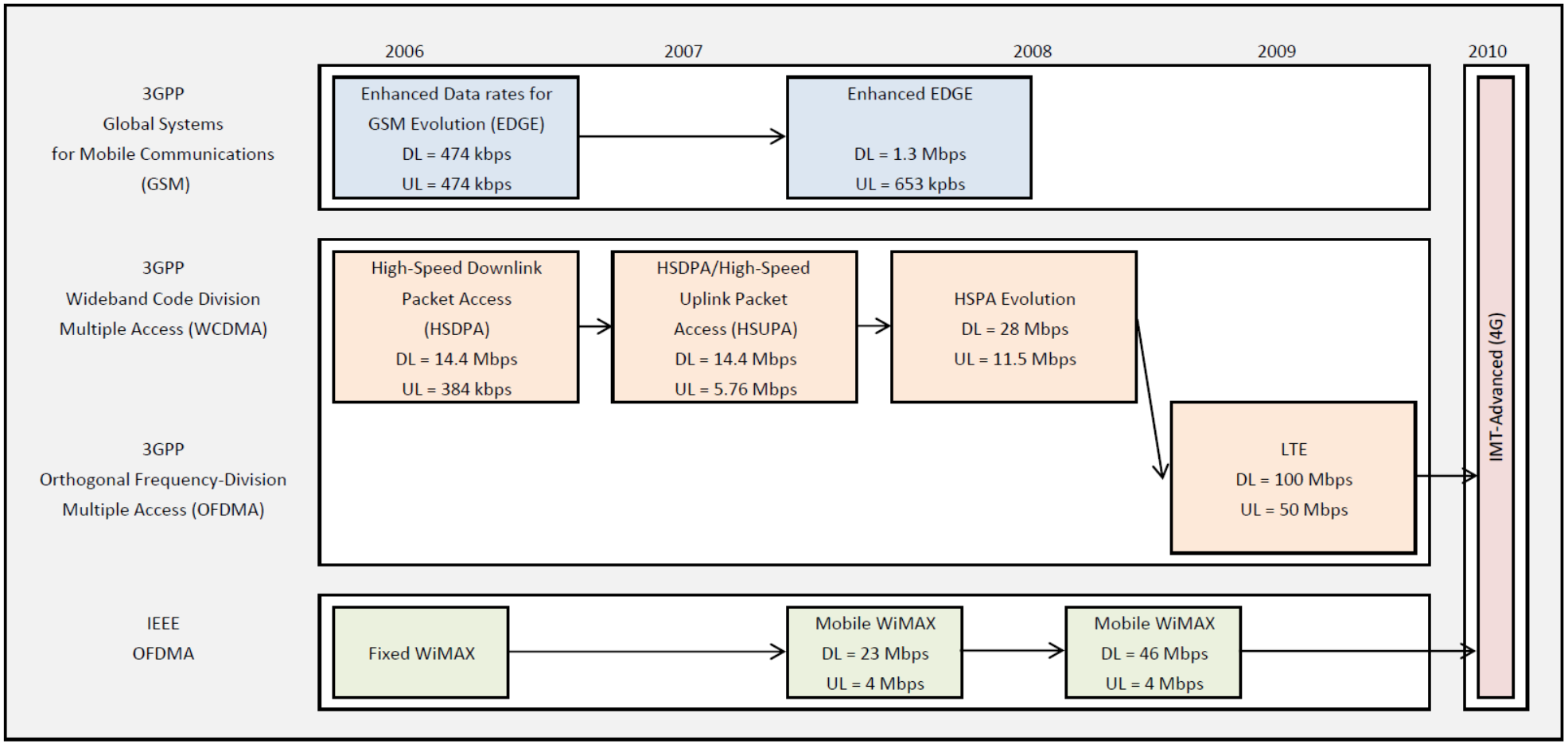


https://www.3gpp.org/about-3gpp/about-3gpp

IEEE vs 3GPP – Wireless Wide Area Networks and Vertical Handovers

IEEE vs 3GPP – Wireless Wide Area Networks

The political-economic ‘fight’ to become 4G…



Dieter Eberle, “LTE vs. WiMAX 4th Generation telecommunication networks”, online available.

IEEE vs 3GPP – Wireless Wide Area Networks

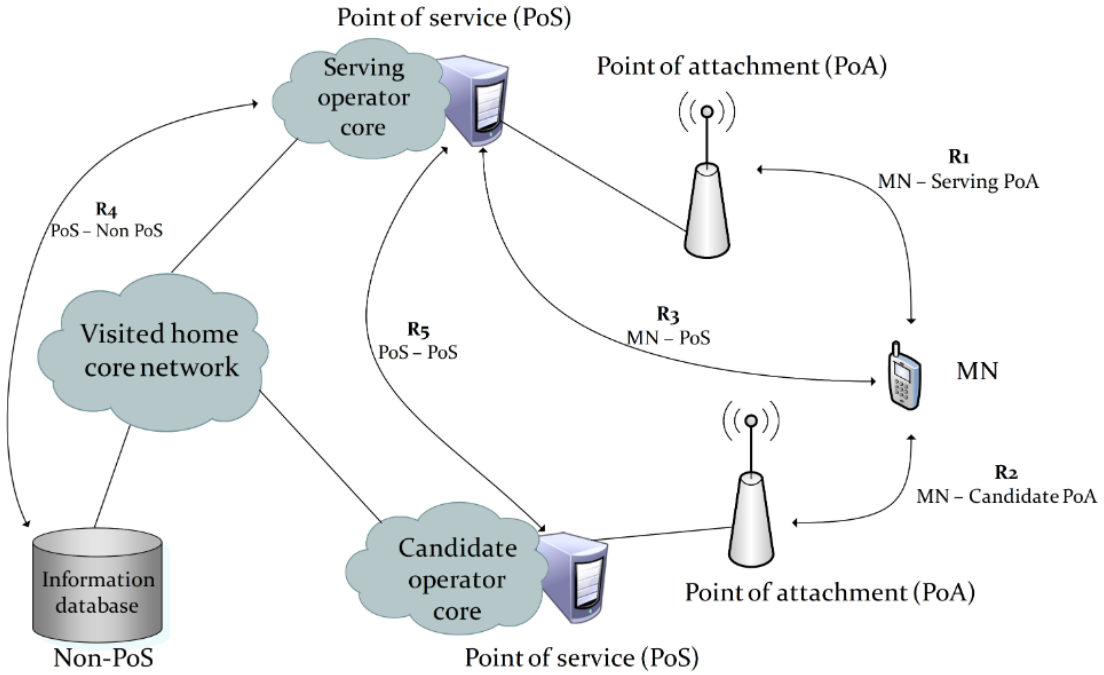
Just an example…

HTC Evo 4G WiMAX (2010)

HTC Evo 4G LTE (2012)

IEEE vs 3GPP – Vertical Handovers

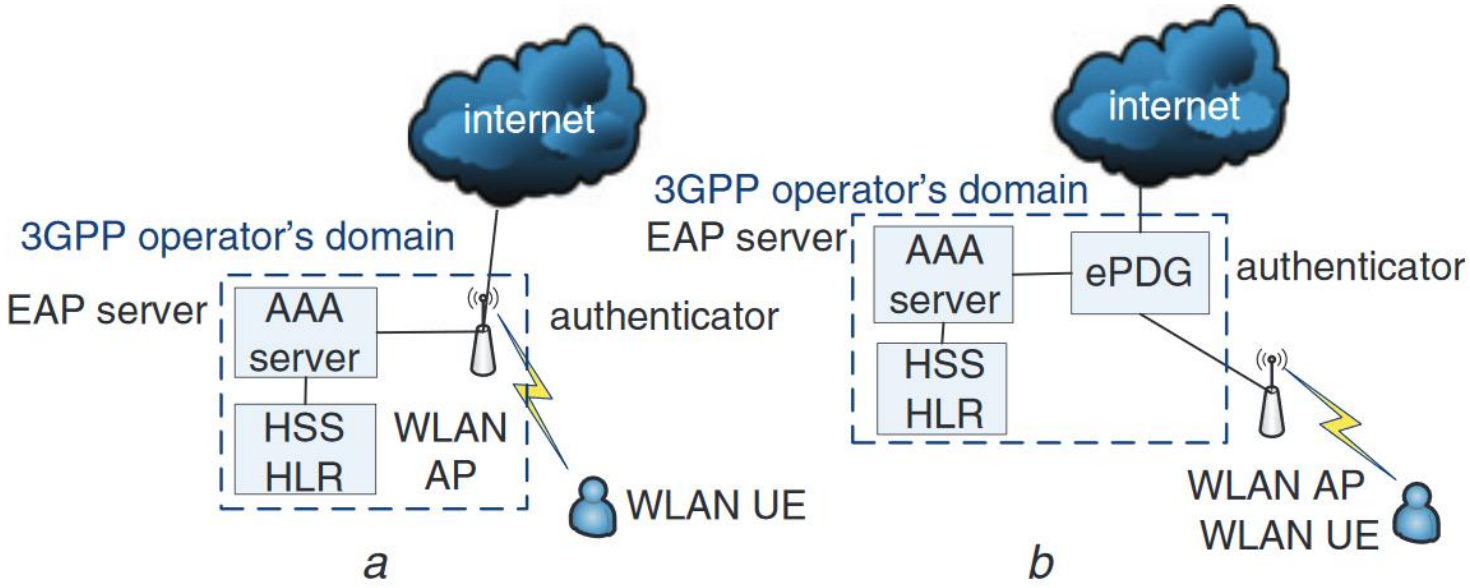
- In 2009, IEEE released standard **IEEE 802.21,** which refers to Media Independent Handover (MIH) services and is an IEEE standard published in 2008. The standard supports algorithms enabling seamless handover between wired and wireless networks of the same type as well as handover between different wired and wireless network types also called Media independent handover (MIH) or vertical handover.
- **IEEE 802.21a-2012** - IEEE Standard for Local and Metropolitan Area Networks: Media Independent Handover Services - Amendment for Security Extensions to Media Independent Handover Services and Protocol



http://epubs.surrey.ac.uk/812743/1/thesis.pdf

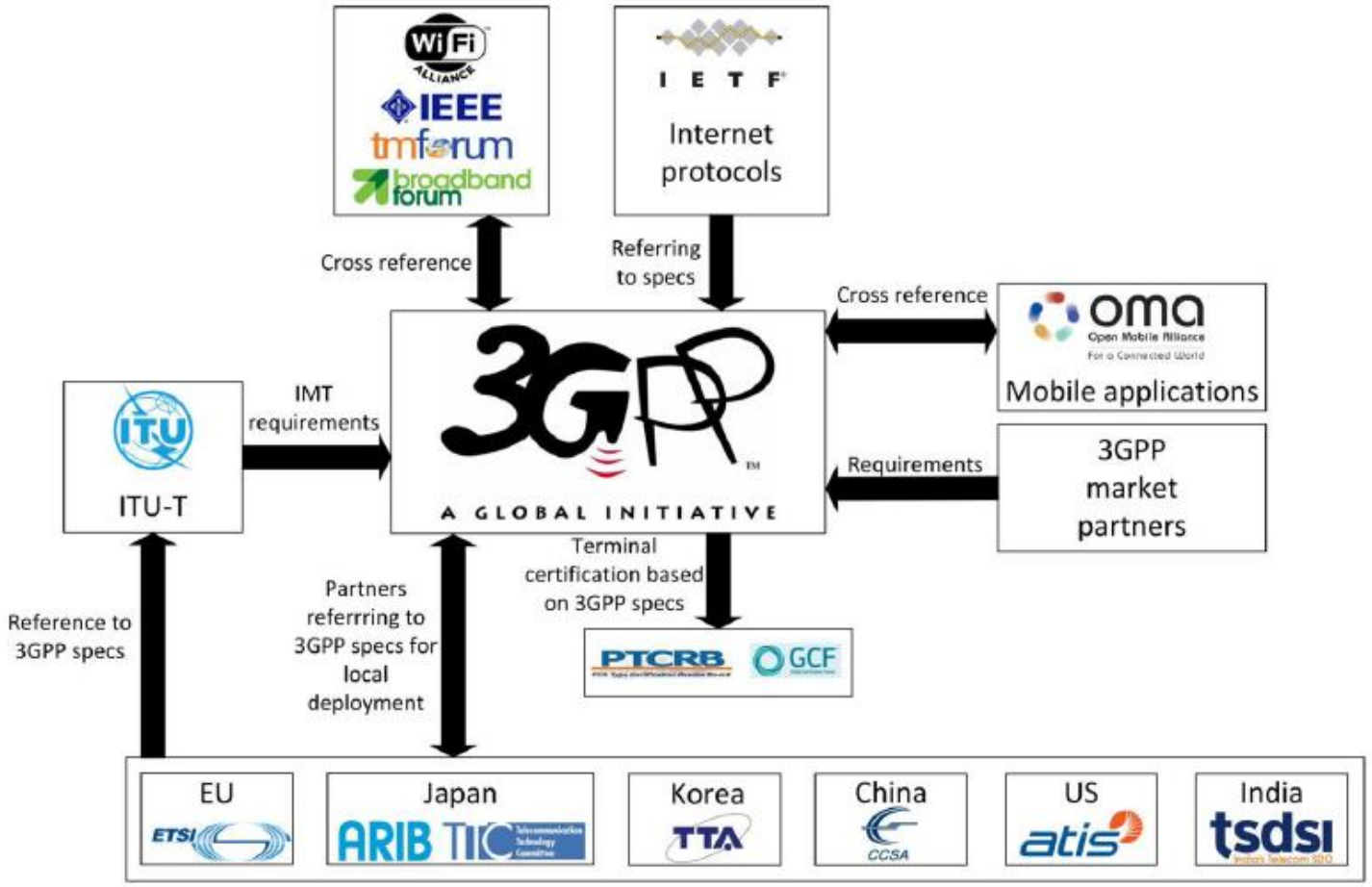
IEEE vs 3GPP – Vertical Handovers

- In 2014, **3GPP** published its standard to provide secure solutions for **interworking WLAN-EPS** (evolved packet systems).
- The main scope of this standard is to allow 3GPP user equipment (UE) to securely authenticate when they want to access the internet via non-3GPP access points (APs): in this case, they are named WLAN UEs.



R. Bassoli, H. Marques, J. Rodriguez, C. Gruet and R. Tafazolli, "Enhanced authentication for WLAN–EPS interworking systems," in *Electronics Letters*, vol. 51, no. 19, pp. 1544-1546, 17 9 2015.

5G Standardisation – A Global Collaborative Effort



Frank H. P. Fitzek; Fabrizio Granelli; Patrick Seeling **Computing in Communication Networks – From Theory to Practice Book** 1st Ed., Elsevier, 2020, ISBN: 9780128204887, (https://cn.ifn.et.tu-dresden.de/compcombook/).

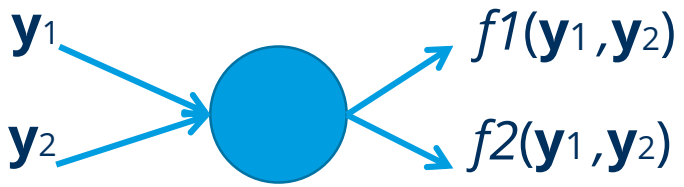
Network Coding

The transmission of information through a network would then be interpreted as an exchange of commodities, without the capability of combining or mixing what was sent (**commodity flow**).

In 2000, the concept of **information flow** was introduced to demonstrate that the combination of information could increase the capacity of a network over the limit achieved by routing. This extension represented the birth of **network coding**.

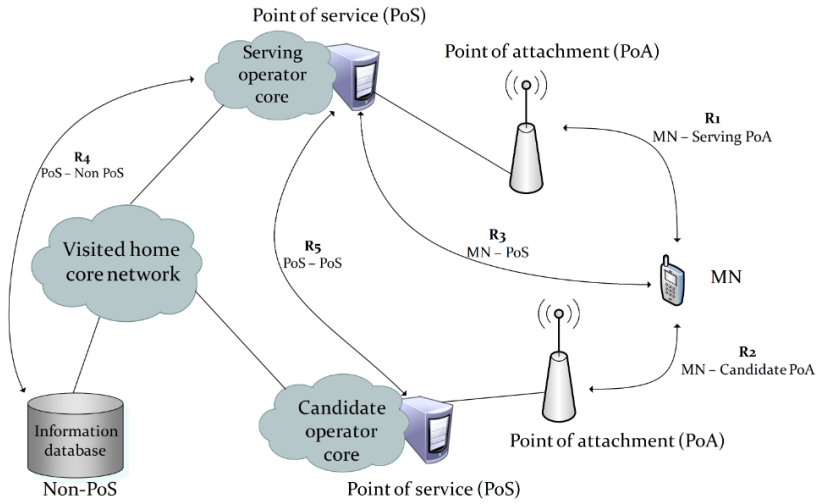
Prior to that, the family of coding operations were **source coding** (the way to compress the information at the source to increase the efficiency in the transmission), and **channel coding** (the operation of introducing redundant bits in the information sequence to make it reliable by converting the noisy channel into a noiseless one).

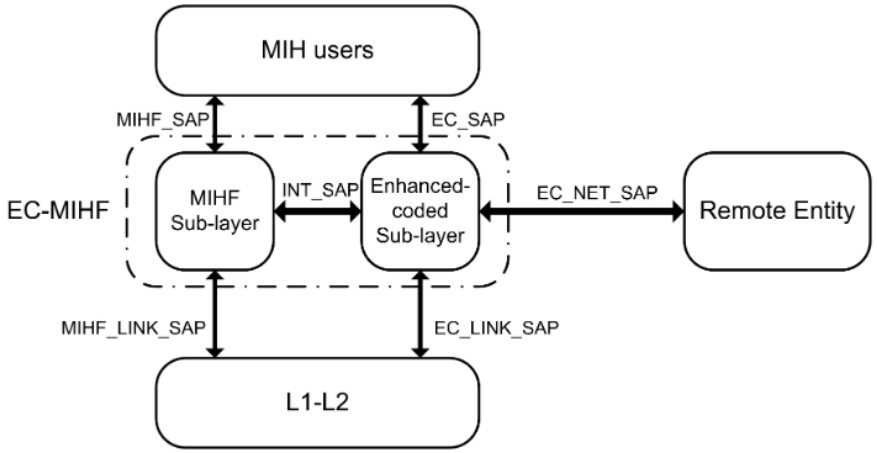
Network coding opened the way to yet another coding operation, realised at the packet level: the principal idea is to allow nodes in the network to transmit functions of the messages received previously on the ingoing edges, onto the outgoing ones.



R. Bassoli, H. Marques, J. Rodriguez, K. W. Shum and R. Tafazolli, "Network Coding Theory: A Survey," in *IEEE Communications Surveys & Tutorials*, vol. 15, no. 4, pp. 1950-1978, Fourth Quarter 2013, doi: 10.1109/SURV.2013.013013.00104.

Network Coding for Efficient Vertical Handovers





Vertical handover modelled as a packet erasure channel, so implementation of network coding as pure forward error correction (FEC) towards seamless handovers

Timeline

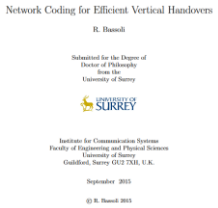
Network coding for efficient vertical handovers – **10 years timeline**.

IEEE 802.21

Published in **2009**

3GPP Evolved Packet Core (EPC)

Published in fall **2008**


Network Coding for Efficient Vertical Handovers

R. Bassoli

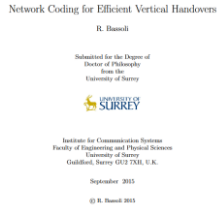
Submitted for the Degree of Doctor of Philosophy from the University of Surrey

2011 – Start of Ph.D.

3GPP

4G LTE

2014 – Worldwide diffusion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R. Bassoli

Submitted for the Degree of Doctor of Philosophy from the University of Surrey

2015 – End of Ph.D.

2019 – 304 commercially launched LTE-Advanced networks in 134 countries. Overall, 335 operators are investing in in 141 countries.

NO IEEE 802.21

NO Network coding

Competition between IEEE and 3GPP for 4G standardisation

THE END