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# Mobile communications – on standards, classifications and generations

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28<sup>th</sup> European Regional Conference of the International  
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# Mobile communications – on standards, classifications and generations

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## *Abstract*

*The research question addressed in this paper is concerned with the manners in which the general technological progress in mobile communications is presented and the reasons for the differences in these manners of presentation. The relevance of this research question is that the different presentation modes create a degree of confusion in communications and discussions on mobile technologies. At the same time, it should be recognized that different manners of categorizing technologies illustrate the fact that categorizations are based on different purposes of the classification exercises.*

*In common parlance, progress in mobile technologies is mostly referred to as generations. In the International Telecommunication Union (ITU), the classification terminology is that of International Mobile Telecommunication (IMT) standards. In the specialized standards body with a central position in the standardization of core mobile technologies, namely 3GPP (3<sup>rd</sup> Generation Partnership Project), the terminology of ‘releases’ is used. In order to address the research question, the paper uses an analytical framework based on the differences and relationships between the concepts of standards, classifications and generations, and it examines the role of organizations involved in the development and marketing of new mobile technologies.*

## **1. Introduction**

Mobile communications is often classified in generations - beginning with 1G or even ‘0G’ (legacy public or private land mobile radio systems) and currently with the processes of 5G standardization. The concept of generations is in a sense fortunate as it indicates that there are ongoing processes with different ‘steps’ and that each generation includes different solutions. But it is also a vague concept and not much appreciated by technical specialists in the mobile field. They consider the G-concept to be a marketing tool for mobile operators and equipment manufacturers and prefer to talk about ‘releases of specifications’ from the bodies standardizing mobile technologies and to refer to the classification system institutionalized by the International Telecommunication Union (ITU) on the progression of IMTs (International Mobile Telecommunications), from IMT-2000 and IMT-Advanced to IMT-2020.

The overlap between the concept of mobile generations and the ITU classification of IMTs is not complete. The 3G-category and the IMT-2000-category do, for instance, not entirely correspond, and there is a discussion as to whether the LTE standard (Long Term Evolution) can be called a 4G

technology. The Norwegian consumer ombudsman, for instance, in 2010 accused the operator Netcom of false marketing when offering LTE as a 4G-technology (PCWorld, 29 Oct. 2010), and ITU does not consider LTE as an IMT-Advanced standard (ITU, 2014).

There are thus different ways of categorizing the advances in mobile communications. In general parlance, the concept of generations is used. In the ITU context, progressing versions of IMTs is the terminology applied. And then, there are the releases from the standardization bodies.

In the paper, we will discuss these concepts – how they are used and how they relate to one another. The framework for this discussion will be the concepts of standards, classifications and generations. Standards are prescriptive norms for ‘how things should be’, while classifications are descriptive categorizations. There is, obviously, a relationship between the concepts of standards and classifications. There needs to be standards for how to classify, standards are classified, and classifications are necessary tools when standardizing. Furthermore, the concept of generations will be applied. While standards and classifications are often used in a static manner, the concept of generations adds a dynamic perspective to the analysis.

The purpose of the paper is two-fold: On the one hand, we aim at clarifying the relationships between the mobile generations and the consecutive IMTs and the releases from the standardization bodies. On the other hand, we wish to examine the concepts of standards, classifications and generations to see how they can be used for analyzing the developments of mobile standards.

First, there is a discussion on the concepts of standards, classifications and generations. Thereafter, the concepts of mobile generations, IMTs and releases are presented. This is followed by an analysis and a conclusion.

## **2. Standards, classifications and generations**

Standards are prescriptive norms for ‘how things should be’, while classifications are descriptive categorizations. A paper by Bowker & Star (1998) says: “Classifications and standards are two sides of the same coin ... classifications are containers for the description of events ... whereas standards are procedures for how to do things”. And they add: “Every standard imposes a classification system”.

Though it happens that the two concepts are mixed up, the difference is clear. The same does not entirely apply to the concept of generations. Generations are classifications but in a diachronous manner as opposed to a synchronous classification. At the same time, there is a sense of ‘something that has to be lived up to’ (standards) and that the new generations are better than the former.

There is a growing literature on standards and standardization, and classification is one of the oldest tools of science (see following sub-sections). Generations have also been subject to research in different lines of scientific work. However, the relationships between these three concepts and how they can help analyze different aspects of technology developments are very little explored.

### *2.1 Standards*

While classifications are descriptive, standards are prescriptive. Now and then, however, the word 'standard' is also used for how things are mostly done without any prescriptive qualifications. But at a point in time, somebody (a group of people or otherwise) has determined explicitly or implicitly 'how to do things'. The prescriptive character certainly applies to technical standards as in the case of the different generations of mobile communication standards, but standards are found in all aspects of life. Languages are standards, and there are standards for good behavior. Measuring is based on standards, and technical specifications are standards.

In a seminal paper, Paul David (1987) differentiates between three basic types (classifications) of standards: Reference standards, quality standards, and compatibility standards. Reference standards are used for measurements; quality standards are used for setting the bounds for acceptable qualities; and, compatibility standards are used for ensuring interoperability between different parts of systems. While there are surely reference standards and quality standards used for the various generations of mobile standards, mobile standards like all other ICT standards are basically compatibility standards. They provide the basis for making certain that devices and infrastructure elements can communicate with one another.

Other useful categorizations of technical standards are concerned with the differentiation between de facto and de jure standards and the differentiation between sponsored and unsponsored standards. De facto standards are also called industry standards and are the standards that are established in the markets either by dominant players or by other selection mechanisms. De jure standards are the standards being negotiated and decided upon in official standardization bodies - national, regional or international. Even if the concept of 'de jure' linguistically implies that the standards have a legal status, this is mostly not the case. Most standards developed in de jure standardization bodies are voluntary. But the organizations in which standardization takes place are recognized by public institutions.

Sponsored standards are standards which are supported (sponsored) by specific market players, and the 'sponsorship' is often based on intellectual property rights (IPRs). Unsponsored standards, on the other hand, are standards where there are no intellectual proprietary rights involved and where the dominant standards arise more spontaneously. Sponsorship happens in the markets (de facto), however, sponsored technology solutions may also enter de jure processes, as companies participating in de jure standardization processes will carry their proprietary solutions into the de jure standardization bodies.

All these issues – and many more – are part of standardization processes. The implications are that the developments of standards often constitute very complex processes with many different market players and with many public as well as semi-public and non-public bodies involved. Interests of the different players will often diverge and conflicts of interest can be intense, but, at a point in time, convergence or dominance will in most cases prevail and standards are created.

There are, however, many areas where one unified standard is not the outcome, as different standards can live side-by-side. But if we are dealing with compatibility standards with strong network effects, there will be a tendency towards one or very few dominant standards, and so-called ‘standards wars’ may erupt (Shapiro and Varian, 1999a; Stango, 2004). The network effects based on increased utility for the individual user with a growing number of users and demand-side economies of scale will drive the markets towards unified standards (Shapiro and Varian, 1999b).

This applies to the mobile standards in question and has been a recurring issue with every new generation of mobile standards – from 1G all the way to the 5G standardization processes presently going on. In the analogue 1G phase in the 1980s, mobile standards were either national or regional and the unification of standards driven by network effects was confined to limited geographical areas. But already with the 2G technologies (GSM, cdmaOne, etc.), stakes were much higher and a ‘standards war’ between the newly developed digital mobile standards erupted. As opposed to most text book examples of standards wars such as the classical case of VHS vs. Betamax, the struggle between the 2G standards was not only fought out in the markets. There were strong national and regional industry policy interests at play as was clearly illustrated in Europe by the backing by the European Community of the GSM standard and the prominent role of ETSI - the European Telecommunications Standards Institute.

The struggle between competing standards continued with the development of 3G standards but was relaxed with the development of 4G technologies. In a paper by Sørensen et al. (2016), these developments are described and the question is raised whether the ongoing processes of standardization of 5G technologies will become a standards war or whether cooperation between different companies, nations and regions will prevail to a larger extent. This is not clear yet, but indications are, at present, that the increasing degree of cooperation seen in connection with 4G technologies will continue with 5G technologies.

This does in no way mean that the standardization of 5G technologies will go smoothly without any controversies and problems. There are very strong industrial interests in the promotion of standards, which are in line with previous technology developments and resources and capabilities of companies and regions and where there are IPRs. There is thus considerable sponsorship of specific standards or standards elements, which have been developed by the different companies in cooperation with national institutions, and these sponsored standards will go into the de jure standardization processes of 5G technologies.

## 2.2 Classifications

Standardization and standards are 'as old as mankind' and the same applies to classification. Classification is one of the oldest human, and more specifically, scientific activities, namely the ordering of plants, animals and things and phenomena in different categories. The works of Aristotle in 'Historia Animalium' and 'De Partibus Animalium' are classical examples including classifications of animals. Classifications constitute an important basis for conceptualizations and, therefore, for languages, and they are the basis for analytical activities. Classifications are also prerequisites for standardization, but this is a topic that this paper will not be concerned with. We will only be concerned with classes of standards and standards (criteria) for classification.

Classification is the sorting of things, phenomena or concepts in different 'boxes' or categories. It is, in other words, a descriptive activity as opposed to standardization. Obviously, such categories do not 'come out of the blue'. They have to be developed and can be constructed in many diverse ways. There needs to be standards for how to classify.

Such standards can also be termed criteria, i.e. the criteria for differentiating between different classes. The precision of such criteria are important for the quality of the classification. As is explained in Bailey (1994), overlaps between the different classes should be avoided to the widest extent possible. Therefore, the aim is to obtain as much homogeneity within each class and as much heterogeneity between the classes as possible. The criteria are thus important and so are the dimensions. A classification can be one-dimensional but are often two-dimensional or multi-dimensional. Again, the clarity of such dimensions is important for the quality of the classification.

Often, different kinds of classification are denoted, with the major differentiation being between taxonomies and typologies - where taxonomies are generally considered to be classifications of empirically observable things and phenomena and typologies are classifications of concepts (Bailey, 1994). There is obviously also something in between – or combinations. Typologies will be used for finding empirical examples, and the analysis of empirical cases can be used for constructing conceptual categories. The first mentioned process is a deductive ex ante exercise, while the second process is inductive ex post. This topic is important with respect to how the criteria for including standards in the ITU IMT framework are elaborated: Are the criteria determined in advance and, therefore, requirements that need to be fulfilled in order to live up to being part of a special IMT class, or are they determined on the basis of what comes out of the actual standardization processes?

The basic reason for discussing classification in connection with mobile standards is that the consecutive generations of mobile standards can be seen as kinds of classification. Within all the hitherto existing generations, there are different standards. The first generation of analogue mobile technologies included a relatively wide range of different technologies (standards). The same applies to the following generations, though the variety of different overall system standards is lower with respect to 4G technologies, and the same probably will apply to 5G.

This means that when in daily parlance we talk about 3, 4 or 5G standards, we are talking about a type of classification of standards. This also applies to the IMT standards categories of ITU. The question is whether there are differences in the ways that these two kinds of classifications (generations and IMTs) are conceptualized and performed. This is an issue which is thoroughly discussed in the section of this paper on generations, IMTs and releases.

An additional topic to be dealt with in connection with classification of mobile standards is the issue of synchronicity or diachronicity. With respect to mobile generations, the classifications are clearly diachrone. The standards develop over time and they build on one another. For mobile communications, this is extremely important, as the sponsors of different standards will have an interest in future standards building on their antecedent technologies.

### *2.3 Generations*

A dictionary definition of 'generations' (Oxford Dictionaries) points to the reproduction of living creatures or to a group of people "born and living at about the same time". The word is, however, also used in a metaphorical sense, indicating a technical development or the transition from one system to another. Oxford dictionaries provide a rich collection of examples, ranging from "next generation of high-performance, flame-retardant technical yarns" to "a new generation of spacecraft". The use of the term for the development of mobile telecommunication falls within this metaphorical use of the word.

As a metaphor for the development of technologies, the generation concept is a diachrone classification. It connotes progress and ongoing development. The generation concept is more dynamic than synchronous classification. It signifies improvement as opposed to the concept of, for instance, versions, which could also have been used. It denotes that something new builds on previous manifestations.

Thus, it must clearly be something new and distinct compared to the earlier manifestations. This double property is found in mobile generations. They build on the previous generations but are at the same time distinctly different from the previous generations. A criterion for labelling it as a new generation has in the mobile field been that core technologies are not backward compatible. The radio interfaces of the different generations are not backward compatible though the mobile devices using the most recent radio interfaces obviously can communicate with older generations. But this is only because there is interconnectivity at the system level.

The use of the generation concept for technology developments is sometimes retrospective and sometimes prospective – or a mixture. In the prospective use of the term, there are positive connotations associated with the generation concept. It signals that something new has happened and it must partly be therefore that it is used for mobile generations. In a marketing context, the 'generation' concept signifies that a new and improved version has been developed and that consumers will need to switch to the new technology.



The 2G concept was first used in this manner. There was no mention of 1G before 2G came about. The 2G concept was used to differentiate the new digital mobile technology from the former analogue technology solutions. In that sense, the 1G is a retrospective concept and the 2G concept was developed to announce the new development. Since then the different mobile generations have been used in a prospective manner announcing the new and coming technology solutions.

#### *2.4 Summary and link*

The generation concept is a kind of classification, which puts emphasis on development. It's a diachrone type of classification. The mobile generation concept as well as ITU's IMTs has the purpose of categorizing mobile standards. At the same time, it is important to examine the criteria (standards) for the classifications of mobile standards. In the following section, there is a discussion on the concepts of mobile generations, IMTs and releases. In order to examine the similarities and differences between these concepts, we introduce the concept of 'phases' of technology developments focusing on the radical changes taking place over time. The aim is not to introduce an alternative classification to mobile generations and IMTs. The purpose is only to set a benchmark for how the concepts of mobile generations, IMTs, and releases relate to radical changes in mobile technologies.

### **3. Generations, IMTs and releases**

Mobile communication has witnessed radical changes during the past decades, from a voice communication service for rich people and wealthy businesses to a converged service platform offering essentially all communication services at generally affordable prices. The development is going beyond communication services between people and enables communication services with things and objects - the so-called Internet of Things (IoT).

The development of mobile technologies has been characterized in three different ways: 1) Generations, where the different phases of development are distinguished and categorized in (now) five generations; 2) IMTs, where ITU develops specifications and standards for new developments of technologies called International Mobile Telecommunication (IMT) standards - so far there are three IMTs: IMT-2000, IMT-Advanced, and the upcoming IMT-2020; and 3) standards and releases, where developments can be studied looking at specific standards and, in the case of 3GPP, at the different releases.

In the following, these three different ways of characterizing the evolution of mobile communication systems and services are analyzed in detail. In order to do this, the concept of 'phases' is introduced, where the transition from one phase to the next indicates radical changes and radically new capabilities in the radio access or/and core technologies of mobile communication systems. The idea of introducing this benchmark is to provide hard technological

measures for the distinctions between the different phases and to relate the different mobile generations, IMTs and releases to these phases.

### *3.1 Development phases*

The *first phase* of mobile communication developments was characterized by circuit switched voice centric systems based on analogue radio access networks. There were a number of different standards in different regions with no interoperability and no roaming possibility: NMT (Nordic), AMPS (USA), NTT (Japan), SIP (Italy), C-Netz (Germany), TACS (Great Britain), Radiocomm 2000 (France), etc. The key important driving force in this phase was mobility, and the major users were business people due to the high costs of devices and communication tariffs.

The *second phase* of development was still based on circuit switched technology and was voice centric but the radical change was the digitization of the access network. Still, there were different technologies in different regions, but this time harmonized spectrum was allocated with larger footprints for the major standards, enabling roaming. In the second phase, only limited data communication was possible at the beginning, using circuit switched technology, which is sub-optimal for data communications. In the further developments of this phase, packet switched technology was added to the systems, more spectrum was allocated and assigned to mobile operators, modulation technologies with higher efficiency were developed, and gradually higher throughputs were, consequently, offered in the mobile communication systems for data services. The major standards used in different markets were PDC in Japan, cdmaOne in the US and GSM in Europe. GSM became the dominant standard in Europe and far beyond Europe.

To illustrate the incremental development of the technology development in the second phase, a brief illustration of the development of the GSM standard is given: Data connectivity was not the primary focus of GSM, but was introduced via the HSCSD (High-Speed Circuit Switched Data) technology. Data communication was based on circuit switched technology, and by bonding 4 timeslots throughputs of 57 Kbps could be achieved. The next development was the introduction of GPRS (General Packet Radio Service) based on packet switching. The initial throughputs were the same as HSCSD, but GPRS was packet based and utilized the network resources in a more efficient way. Using advanced modulation schemes and by bonding, e.g., 8 time slots, throughputs of 170 Kbps were achievable in GPRS. The throughput was further improved to 384 Kbps via EDGE (Enhanced Data rates for GSM Evolution), which is also packet based but uses more advanced modulations and 8 GSM time slots.

The characteristics of the second phase of development were, therefore, the shift to a digital platform in the radio access network, packet switching was introduced, affordable voice services and text messaging were offered, and data connectivity of acceptable quality was offered.

The *third phase* of development built on the second phase, and the communication infrastructure was based on the combination of circuit switched (for voice) and packet switched (for data)

technologies. The radical changes here were new radio access technologies, more harmonization of spectrum, allocation of more spectrum for mobile communication, and in particular for data services, harmonization of standards by ITU and the formation of different consortia to develop common standards for mobile communication like 3GPP. Another important characteristic of the third phase was that the combined packet/circuit switched technology was part of the fundamental design of the standards unlike the late versions of the standards in the second phase where packet switched network was an add-on to the circuit switched networks. Because of the aforementioned harmonization by amongst others ITU there were fewer standards on the market. The major driving force was the ability to offer network connectivity acceptable for multimedia services, including audio-visual services. The standards in this phase would be able to deliver minimum throughputs to enable the provision of such services. Specific requirements on technologies were developed by the ITU in the IMT-2000 specifications. In this phase, a number of standards were developed including UMTS and CDMA2000, standardized respectively by 3GPP and 3GPP2.

The *fourth phase* of development is characterized by 1) data centric and pure packet based technology without any circuit switched voice, 2) new radio access technologies, 3) flat network architecture enabling low latency, and 4) wide spectrum bandwidths, efficient modulation technologies, and advanced antenna structures enabling very high throughput. In the beginning of the fourth phase, voice services have been offered by fallback to legacy circuit switched technologies but more and more voice over packet networks are being implemented in the new networks. Also in this phase, we are witnessing incremental advancement of technologies enabling even higher throughput in the networks making them competitive with the fixed broadband infrastructures.

The standards in this phase have been developed mainly by 3GPP and IEEE, resulting in the two major competing standards: LTE and Mobile WiMAX. ITU has continued defining the criteria for new standards and formed the IMT-Advanced classification. The further development of LTE and Mobile WiMAX towards LTE-Advanced and Mobile WiMAX 2 are very much driven by offering more throughput using, for example, carrier aggregation but also by the development of specific protocols that can solve the demand for higher capacity by adapting the network resources to the applications and use situations, for instance, by enabling broadcast using some portion of the spectrum for offering audio/visual services like LTE broadcast. Furthermore, seamless roaming and mobility with other networks like Wi-Fi are used to enable better indoor coverage and offload of data from mobile to fixed networks when appropriate. Furthermore, and specifically in the development of LTE, we see a new development towards Internet of Things (IoT) that kick starts a new phase of development in the mobile communication systems.

The *fifth phase* of development is being driven by a number of requirements like low latency and high throughput but also by requirements from the Internet of Things and objects like high reliability, scalability, low power consumption, etc. In particular with regards to the Internet of

Things, the harmonized regime of development of standards that has worked relatively well in the third and fourth phase is being challenged by a number of new standards initiatives from alternative consortia and from single large companies. Also here, the ITU is trying to lead the development by defining the requirements for the new technologies in the framework of IMT-2020 specifications.

### *3.2 Generations*

The notion of 'generation' has been helpful in categorizing the requirements, capabilities and characteristics of certain levels of development of mobile communications and standards. However, it has also been used in the promotion and marketing of certain technologies by the industry and its lobbyists. The marketing divisions of mobile operators have from time to time brought the use of the generation concept very far by artificially pushing less advanced technologies and standards to higher generations and by introducing finer grades of generations like 2.5G, 2.9G, etc., which makes the use of the concept blurry and sometimes useless. Consequently, there is not always overlap between the phases presented above and the mobile generations and there is, consequently, not always agreement on which standard belongs to which generation. In the following, the relationships between the different generations and phases are discussed with the purpose of identifying where the two concepts overlap and, if there are differences, what these differences are.

#### 1G

In this case, there is a tight overlap between the first generation (1G) of mobile standards and the first phase of developments discussed above.

#### 2G

With regards to the standards belonging to the second generation (2G) there is also generally overlap between phase 2 and 2G. However, there is a smaller degree of correspondence regarding the later developments in phase 2 and the start of third generation. A prominent example is EDGE which often is characterized as a third generation technology due to the radical increase in the data throughput compared to previous standards. However, others classify it as a second generation standard.

#### 3G

Also the third generation (3G) has quite an overlap with the characteristics of the above mentioned phase 3. The differences are that there is some disagreement as to what extent the later developments of standards in phase 2 belong to 3G (like EDGE) and to what extent the major standards in phase 4 (LTE and Mobile WiMAX) belong to 3G. The later standards have been promoted as 4G with resistance from some market players who believe that 4G technologies should meet the specifications of IMT-Advanced.

## 4G

In some presentations, 4G is directly equivalent to the technologies that meet the IMT-Advanced specifications. However, 4G has also been used as having the same characteristics as the above mentioned phase 4. In later categorizations, LTE is categorized as a 4G standard while formerly LTE would be 'beyond 3G' and only LTE-Advanced would be 4G.

## 5G

As discussed in (Sørensen et al., 2016) there are two main visions/illustrations of what 5G is: 1) '5G as a new paradigm, where the aim is to utilize the available and new mobile communication standards in a more coordinated and integrated way with seamless mobility between different networks and integration of object communications and Internet of Things objects (IoT)' . In this illustration 5G has obvious overlaps with characteristics discussed in the phase 4 and 5. 2) '5G is a radical transition from 4G with advancements of next generation mobile communication standards in terms of radio interface, core network, network topology..'. In this illustration, 5G is a pure phase 5 technology and it is important that it meets the IMT-2020 specifications.

### *3.3 IMTs*

#### IMT-2000

The IMT classification system is the way in which the ITU seeks to influence the shaping of the developments of mobile communication systems. The first extensive standardization initiative was the provision of criteria and requirements for the IMT-2000 family of standards. As in the other IMT standards, IMT-2000 defines various requirements for mobile communication systems, and the standards that fulfill these requirements can be labeled IMT-2000 standards. Fundamental issues for the IMT-2000 standards were the facilitation of international roaming and the enabling of mobile multimedia applications as defined in the ITU-R M.1455 recommendation (Fukada et al., 2002). As illustrated by Fukada et al. (2002), the process of development of IMT-2000 initiated huge development activities in different regions and countries. It was in this process that important organizations like 3GPP and 3GPP2 were formed, which later in the standardization processes have been instrumental in developing specific standards for mobile communications.

ITU received a number of proposals for terrestrial components for IMT-2000. However, the most important and dominating standards were UMTS and CDMA2000. The IMT-2000 standards belong to the third phase of the developments discussed above including major changes in the radio access networks, higher throughput and with data/multimedia communication as an inherent part of the networks, still having dedicated circuit switched networks for the voice communication.

## IMT-Advanced

IMT-Advanced contains a number of criteria with the most important criterion being the minimum downlink data rate of 1000 Mbps, which, looking at the spectrum allocations, puts specific requirements on the spectral efficiency achieved, using more complex modulation and antenna systems like MIMO. Other important criteria are the entire removal of circuit switched networking and having a pure packet based networking based on the IP protocol and requirements for lower latency.

ITU developed the requirements for technologies to be part of IMT-Advanced. Major requirements for being part of IMT-Advanced are, according to Hashimoto et al. (2008), Kumar et al. (2011) and Parkvall et al. (2011), the following:

- Throughput: Downlink peak rate of 1000 Mbps in a low mobility scenario and 100 Mbps in a high mobility situation
- Frequency bandwidth: Scalable bandwidth up to 100 MHz
- Peak and average channel spectral efficiency
  - Downlink peak spectral efficiency is 15 bit/s/Hz
  - Uplink peak spectral efficiency is 6.75 bit/s/Hz.
- Control and user plane latency
  - In control plan, a transition from idle to active state of 100 ms
  - User plane latency of less than 10 ms in unloaded conditions for small IP packets and for both downlink and uplink

Also, there are requirements on VoIP capacity, handover, mobility, QoS, roaming, Internetworking, and cell edge user spectral efficiency.

LTE-Advanced and WiMAX 2 are the standards that meet the IMT-Advanced specifications.

## IMT-2020

As the next step in the IMT standardization activities/process, the ITU started in 2015 to discuss the criteria for the next generation mobile standards, under the title IMT-2020. In resolution ITU-R 56-2, IMT-2020 has been defined as 'mobile systems that include new radio interfaces which support the new capabilities of systems beyond IMT-2000 and IMT-Advanced'.

Further work has been carried out in a number of Recommendations, such as ITU-R M.2083-0, where the IMT vision for IMT-2020 has been specified. The regular requirements on increasing throughput increase, driven by the capacity needs of future applications including enhanced multimedia applications, are discussed. Furthermore, the Recommendation takes new aspects into the picture which will be vital in the future developments of mobile communication technologies, namely, the support for very low latency and high reliability, support for machine-centric

communication, support for high user density, support for ultra-accurate positioning applications, and finally the aspects related to the development of Internet of Things (IoT) (ITU, 2015).

IMT-2020 captures a number of discussions and developments that have been connected to the fifth generation discussions in the literature related to the abovementioned issues and seeks to standardize some of these aspects.

In a recent Recommendation Study Group (5G/TEMP/300 (Rev 1)) from February 2017, the minimum requirements related to technical performance of IMT-2020 radio interface(s) have been specified with special focus on peak and user data rate, latency, mobility, connection density, energy efficiency, spectrum efficiency, and area traffic capacity. Important parameters and requirements specified in the document are (ITU, 2017):

- Peak data rates: The minimum requirements for peak data rate are: Downlink peak data rate of 20 Gbps and uplink peak data rate of 10 Gbps
- User experienced data rates: The target values for user experienced data rates in the dense urban environment are: Downlink user experienced data rate of 100 Mbps and uplink user experienced data rate of 50 Mbps
- Peak spectral efficiency: The minimum requirements for peak spectral efficiency are: Downlink peak spectral efficiency of 30 bit/s/Hz and uplink peak spectral efficiency of 15 bit/s/Hz
- Bandwidth: The requirement for bandwidth is at least 100 MHz and in the above 6 GHz spectrum, bandwidth of up to 1 GHz must be supported
- Latency: The minimum requirements for user plane latency are between 1 and 4 ms; the minimum requirement for control plane latency is 20 ms
- Connection density: The minimum requirement for connection density is 1 mill. devices per square km

Furthermore, in the same document, specific requirements on energy efficiency, reliability, mobility, and more detailed requirements on spectral efficiency are proposed.

### *3.4 Releases*

A large number of standardization organizations formed the consortium called 3GPP to develop harmonized standards for mobile communications. In 3GPP, the concept of releases is used to characterize changes and advancements in the standards. In the following, the main characteristics of different 3GPP releases are outlined.

#### Release 99

3GPP Release 99 is known as UMTS and is designed to meet IMT-2000 specifications. Both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are implemented and for FDD, the uplink spectrum is allocated at 1920-1980 MHz and downlink in 2110-2170 MHz, and

throughputs of 384 Kbps-2 Mbps are achievable. The switching technology is combined circuit switched for voice and packet switched for data and the air interface is Wideband CDMA (W-CDMA).

#### Releases 4-7

Releases 4-7 are specific evolutions and enhancements of the UMTS standard, where Release 5 is called HSPDA and enables throughputs of up to 14 Mbps for downlink. Release 6 is entitled HSPUA with throughputs of up to 6 Mbps for uplink. Release 7 is entitled HSPDA+, and downlink and uplink are increased to 28 Mbps for downlink and 11.5 Mbps for uplink respectively.

#### Releases 8 -9

3GPP Release 8 is the LTE standard and is pure packet based, i.e., the core network of LTE is all IP-based and is referred to as the Evolved Packet Core (EPC). Channel bandwidths can vary from 1.25 MHz to 20 MHz, and downlink throughputs of about 100 Mbps and uplink of about 50 Mbps can be achieved.

The network is designed as a flat architecture with decentral radio-access network (RAN) architecture, which minimizes the number of node levels and consequently reduces the latency in the network. Call set up time of about 50 ms and latency / round trip delay of 10 to 12 ms can be achieved.

No circuit switching is implemented and voice is provided as VoIP (VoLTE) or other VoIP applications, however, in the beginning fallback to UMTS or GSM can be a necessity to offer voice services.

LTE operates in 1.9-2GHz, extension bands in the 2.5 GHz area, GSM bands in 900 and 1800 MHz, and digital dividend bands and is developed for deployment in both FDD and TDD profiles and it has, consequently, good possibilities to offer spectrum flexibility. Radio access technology is SC-FDMA uplink and OFDMA downlink and it uses MIMO.

Release 9 is an enhancement of release 8 where new spectrum bands were added for FDD, including the 800 MHz digital dividend band. Furthermore, Evolved Multimedia Broadcast Multicast Service (eMBMS) and Home eNB (HeNB) were added, enabling implementation of pico and femto cells.

#### Releases 10-14

Release 10 meets IMT-Advanced requirements and is called LTE-Advanced with peak data rates of 3 Gbps for downlink and 1.5 Gbps for uplink. This is achieved by deploying technologies with high spectral efficiency in the radio access network, where spectral efficiency is growing from a maximum of 16bps/Hz in release 8 and to 30 bps/Hz in release 10. Furthermore, using higher



order MIMO and carrier aggregation has been instrumental in achieving the high throughput performance.

Heterogeneous Network (HetNet) and small cells are also important parts of the standard and also ‘Relays’ are introduced to enhance coverage in a simple manner.

Releases 11-14 are further evolutions of LTE-Advanced with key characteristics including Device to Device communication, LTE TDD-FDD joint operation, Security Assurance Methodology (SECAM) for 3GPP Nodes, and integration of Wi-Fi into mobile operators’ offerings. Also, it includes the introduction of LTE for emergency and security services, work on Mission-Critical Press-to-Talk (MC-PTT) with ‘isolated E-UTRAN operation’ (Direct mode).

Other issues in these releases are: User Equipment (UE) battery saving technique, small cell enhancements, carrier aggregation enhancements, Machine Type Communication (MTC) optimized operations and enhancement, indoor positioning, LTE-Wi-Fi integration and the use of LTE in the unlicensed spectrum.

Release 15

The work on release 15 is planned to start at the end of second half of 2017 and the aim is according to 3GPP ‘to deliver the first set of 5G standards’.

*3.5 Summary*

Figure 1 illustrates the relationship between the phases, standards, releases, generations and the IMTs.

**Figure 1: Phases, standards, releases, generations and IMTs**

Phases	1	2		3	4		5
Standards	NMT	GSM, GPRS	EDGE	UMTS, HSPXA	LTE	LTE-Advanced	
3GPP releases				R 99, R4 -7	R8 – R9	R10 - 14	R15 -?
Generations	1	2	3		4		5
IMTs				IMT-2000		IMT-Advanced	IMT-2020

As mentioned in the beginning of this section, the purpose of introducing the concept ‘phases’ was to be able to discuss the concept of generations, standards and IMTs. As seen in Figure 1, there are some ambiguities regarding standards belonging to which generations and which IMTs. This has resulted in the categorization of standards ‘between the generations’, and concepts like 2.5G, 2.9G, 3.5G, etc. have emerged to distinguish and promote specific standards and technologies. Also, in the specifications of IMTs, ‘beyond IMT-2000’ has been proposed (Fukuda et al., 2002) to be used to categorize the standards that fall between IMT-2000 and IMT-Advanced.

The ambiguities have been mainly between the second and third and the third and fourth generations. The mature technologies at the end of 2G development were comparable with the technologies promoted as 3G. The discussion was mainly if EDGE could be categorized as a 3G technology because it performed as well as the first versions of the 3G technologies. A similar question has been raised in recent developments, namely, if LTE can be categorized as 4G or 3G or beyond 3G. If we follow the argument that the different generations indicate radical changes, then LTE (and the same applies to Mobil WiMAX) can easily be categorized as a 4G standard, as there are radical differences between LTE and 3G technologies, including substantial higher throughput and lower latency than the 3G technologies and the out phasing of circuit switched network for voice, which is also seen as a radical change compared to the 3G technologies. Furthermore, the categorization of LTE in the IMTs is not either very clear. Here, an IMT standard between IMT-2000 and IMT-Advanced could be helpful.

The 3GPP releases constitute a more accurate way of illustrating changes and is mainly used by engineers. However, the releases are not appropriate to illustrate the big picture in the development, and some sort of classification where we pool a number of releases in generations or IMTs is important. This is, furthermore, important in order to be able to compare 3GPP releases with development of standards in other standardization fora like IEEE.

With regards to the 5G, it seems that ITU has been early in developing criteria and requirements for IMT-2020 which can contribute to forming the definition of fifth generation mobile communication technologies (5G). This can reduce the ambiguities in the categorization of future 5G technologies.

#### **4. Analysis**

Mobile standards are compatibility standards. They build on reference standards and include quality standards, but they are first and foremost compatibility standards. Compatibility has the purpose of ensuring interoperability, and in areas like mobile communications, where there potentially are strong network effects, there will be a tendency towards a limited number of standards. In the mobile field, this process is, however, not only driven by demand-side economies of scale but also by traditional supply-side economies of scale, as the costs of producing mobile equipment and the barriers to entry are high. It is thus a combination of demand- and supply-side economies of scale that drive the markets towards a limited number of large producers and standards.

But there are, indeed, different producers of mobile technologies located in the various regions of the world, and there are, consequently, different interests being pursued. Standards or elements of standards are sponsored and there are struggles of interests. Especially, in relation to the developments of the 2G and 3G technologies, there have been 'standards wars' between the different technology producers and solutions – not a winner-takes-it-all kind of standards war on a

global scale, as there is a degree of regionalization and as different mobile systems and end users can communicate on a system level, and different systems, therefore, can exist side-by-side. But standards wars have been fought out involving de facto standardization processes as well as de jure processes, where equipment producers have been developing technologies following specific standards and have taken them to standardization bodies, and where standards have been developed in standardization bodies and later taken up by the equipment producers.

With 4G and probably also with 5G, there are fewer general system standards regarding the core network technologies of the mobile systems. But with the inclusion of IoT and associated network technologies in some interpretations of what 5G is going to be, the picture becomes less transparent once again. When defining and classifying 5G technologies it, therefore, all depends on the boundaries of what to include in the 5G concept.

In Figure 1, the technology 'phases' that we have proposed and the various standards (GSM, UMTS, LTE, etc.) are related to the 3GPP releases, the mobile generations and the IMTs. The phases that we have described relate directly to the releases by 3GPP (though 3GPP was only established later and the 3GPP releases were only issued later in the process). The same applies to the IMTs which closely relate to the 3GPP releases. The 'odd one out' are the generations. Often, EDGE is seen as the beginning of 3G but it is not recognized as an IMT-2000 technology. Also, LTE is by some seen as a 4G technology but is not recognized as an IMT-Advanced technology. There is thus a discrepancy between the IMTs and the mobile generations.

The standards (GSM, UMTS, LTE, etc.) and the releases are standards, while IMTs and generations are classifications, and both classifications are diachrone. The generation concept is obviously diachrone - one generation following the other - however the same applies to IMTs. It was only with the 2<sup>nd</sup> generation mobile technologies that the concept of generations appeared. The purpose was to mark the difference between the previous analogue technologies (now denoted 1<sup>st</sup> generation) and the new digital technologies. Later on came 3G technologies, where the primary criterion was throughput. And, later again, came 4G, and now 5G is on the agenda.

ITU had since the late 1980s worked with future mobile technologies. The Future Public Land Mobile Telecommunications System (FPLMTS) was a project defining a vision for a single global digital wireless network standard. This was later renamed IMT-2000. The purpose was to create a single world-wide standard, but this did not happen. Instead, criteria for being approved as IMT-2000 technologies were developed, and different organizations suggested a range of technologies to be included in the IMT-2000 category. 10 suggestions were put forward and 5 radio interfaces were, at first, approved and later (as late as in 2007) WiMAX was also approved as an IMT-2000 technology.

6 radio interfaces are thus approved by ITU as IMT-2000 technologies and only 2 technologies - LTE-Advanced and WirelessMAN-Advanced - are, at present approved as IMT-Advanced technologies. The intension of ITU to develop towards only one single global standard, therefore,

seems to be progressing. This is underpinned by the fact that there only seems to be one or two technological solutions on the way to strive for IMT-2020 standards. However, with the inclusion of the IoT (Internet of Things) area under the next versions of mobile technologies, there will be a new large variety of technology solutions.

The modus operandi of ITU in the field of mobile communications is that criteria for inclusion in the consecutive IMTs are defined, and then different solutions are suggested. 3GPP is currently working on standards that will live up to the IMT-2020 criteria. This means that ITU holds a central position in the standardization of mobile technologies even though ITU not any longer is the primary site, where the actual standardization takes place. ITU sets the criteria and decides which technologies to approve and publishes the very detailed standards once approved as ITU recommended standards.

The process of standardization is thus an ex ante process, where the criteria are set in advance and the standards are developed before they reach the markets. The purpose of the classification and its criteria (specifications) is to promote the process of development of new standards. It is an anticipatory exercise as opposed to a retrospective exercise where the purpose is afterwards to classify the objects or concepts in question. It is the purpose of the classification which is important. In the case of, for instance, computer technology moving from vacuum tubes to artificial intelligence, the purpose is clearly to structure of developments that have taken place. With respect to mobile communications, the generation concept was first used in a retrospective manner – looking back from the 2<sup>nd</sup> generation. But afterwards the generation concept has become anticipatory.

## **5. Conclusion**

The research question addressed in this paper is concerned with the manners in which the general technological progress in mobile communications is presented and the reasons for the differences in these manners of presentation.

In common parlance, progress in mobile technologies is mostly referred to as generations. The generation concept is not uncommonly used to denote developments in different technology areas. It has been used to denote fundamental developments in computer technology – from vacuum tubes (1<sup>st</sup> generation) to artificial intelligence (5<sup>th</sup> generation). It has been used for jet fighters – from high subsonic (1<sup>st</sup> generation) to supersonic and multirole fighters (6<sup>th</sup> generation). In mobile communications, the terminology is used to provide a nomenclature for consecutive steps in the evolution of mobile communications.

The generation terminology has, however, been subject to criticism from the mobile communications standardization community. The generation concept is criticized for being too sloppy and for being based on unclear and not sufficiently explicit criteria for classification. In the

ITU context, the concept of IMTs is used. This concept and its criteria for classification are far more detailed and explicit and provide a basis for engineers to be able to identify different kinds of standards.

In addition to these two kinds of classifications, the concept of 'releases' is used by the standards body, 3GPP, which has a central position in the standardization of core mobile technologies. These 'releases' are actual standards for different elements of new mobile technologies.

These different kinds of terminologies, generations, IMTs and releases, may create a degree of confusion. However, it should be recognized that these terminologies have different purposes. The 'releases' are simply a numbering of the ongoing released standards from 3GPP; the IMTs are the classifications of mobile standards used by ITU with a high degree of specificity in the criteria for including standards in the different IMT categories; the concept of generations is used as a kind of short-hand with less sharply defined and detailed criteria for denoting the ongoing developments of mobile communications.

Generation is the concept known by the broader public and is used, for instance, for marketing purposes. However, as has been shown in the paper, there could actually be a sensible rationale behind the differentiation between different mobile generations. The 4G concept has been a case in point. The discussion has been whether LTE is a 4G technology or whether it's only LTE-Advanced that can claim to be a 4G technology. If 4G is equated with IMT-Advanced, then LTE is not 4G. But if the rationale is that LTE is OFDM-based and that packet-based voice communications is an integral part of LTE, then there could be good reasons for denoting LTE as a 4G technology. However, if the criterion is that throughput should be 100 Mbps for high mobility and 1,000 Mbps for low mobility, then LTE is not a 4G technology. The question is what the purpose of the classification is.

If the only criterion for defining different classes of mobile technologies is the throughput that the technology allows for, this will define one type of classification. This is how the generations of mobile technologies are used for marketing purposes. If the purpose is to define the basic technological differences between generations of technologies as, for instance, the transition from analogue to digital and the transition from circuit-switched to packet-switched, this will provide another kind of classification. If, finally, the purpose is to define the very detailed specifications of different technologies, this will lead to a third kind of classification. This is what the IMTs are doing, and this provides an explanation for the differences and the reasons regarding the use of the classifications based on generations and IMTs.

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