This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/COMST.2020.2971781, IEEE Communications Surveys & Tutorials

A Survey on 5G Usage Scenarios and Traffic Models

Jorge Navarro-Ortiz, Pablo Romero-Diaz, Sandra Sendra,
Pablo Ameigeiras, Juan J. Ramos-Munoz, Juan M. Lopez-Soler

***Abstract*—The fifth-generation mobile initiative, 5G, is a tremendous and collective effort to specify, standardize, design, manufacture, and deploy the next cellular network generation. 5G networks will support demanding services such as enhanced Mobile Broadband, Ultra-Reliable and Low Latency Communications and massive Machine-Type Communications, which will require data rates of tens of Gbps, latencies of few milliseconds and connection densities of millions of devices per square kilometer. This survey presents the most significant use cases expected for 5G including their corresponding scenarios and traffic models. First, the paper analyzes the characteristics and requirements for 5G communications, considering aspects such as traffic volume, network deployments, and main performance targets. Secondly, emphasizing the definition of performance evaluation criteria for 5G technologies, the paper reviews related proposals from principal standards development organizations and industry alliances. Finally, well-defined and significant 5G use cases are provided. As a result, these guidelines will help and ease the performance evaluation of current and future 5G innovations, as well as the dimensioning of 5G future deployments.**

***Index Terms*—5G, IMT-2020, usage scenarios, traffic models.**

I. Introduction

FITH-GENERATION (5G) is a tremendous and collective effort to specify, standardize, design, manufacture, and deploy the next cellular network generation. 5G is an ambitious and challenging project that involves all the stakeholders and players including standards and normative organizations, telco (real and virtual) operators, manufacturers, content and service providers, academia, and final users.

While 4G was conceived to provide mobile broadband communications, 5G is being designed with the ambitious goal of becoming a key asset in the introduction of the digital technologies in multiple economic and societal sectors. 5G infrastructures are expected to play a key role on the evolution of sectors such as the industry 4.0, automotive and mobility, transportation, healthcare system, energy industry, media and entertainment ecosystem, and additionally bring new value chains for new business models. As a consequence, a wide range of evolving and unprecedented use cases and business models will come along the 5G ecosystem. Therefore, it is fundamental for the success of 5G to accurately establish the use cases for the vertical sectors, as well as the performance requirements they impose.

With these challenging goals, an immense number of initiatives developed by organizations such as ITU (International Telecommunication Union), 3GPP (Third Generation Partnership Project), 5G PPP (5G Infrastructure Public Private Partnership), and NGMN (Next Generation Mobile Networks Alliance) have been launched, along with notable investments.

In this respect, the evaluation and validation methodologies play a key role in the assessment of the potential of any 5G research innovation. The various aspects of the scenario, the different models characterizing the system, the performance targets, as well as the QoS demands completely determine the evaluation outcome.

Accordingly, any present and future 5G deployment should be properly dimensioned. For that, it is necessary to establish and select right usage scenarios which cover the envisaged main environments and services. Complementary, for all the selected use cases, the definition of a traffic load model will allow the research community, manufacturers and developers to estimate future demands. All these issues are of radical importance and will influence the success of 5G.

To achieve these goals, the objective of this survey is to identify and provide an overview of the most significant 5G use cases and, for all of them, to propose the adoption of precise traffic generation models.

As a result, the main contribution of this paper is to serve as a reference work so that 5G researchers and other stakeholders will have a framework of reference with several well-defined use cases with their corresponding selected traffic models. It will allow evaluating the performance of new 5G innovations and dimensioning future deployments. For that purpose, this survey compiles the main references from the major Standards Development Organizations (SDOs) and industry associations. Besides, the most relevant use cases with the corresponding traffic models are suggested.

The rest of the paper is organized as follows. Section II describes the ITU IMT-2020 (International Mobile Telecommunications-2020) usage scenarios and requirements, as well as middle-term traffic forecasts for the period from 2020 to 2030. Section III analyzes the main test cases and their corresponding traffic models from the main SDOs and stakeholders, including regional initiatives and industry alliances. In Section IV we discuss the adoption of a set of relevant use cases, and associated traffic models, for dimensioning and performance evaluation of 5G systems. Finally,

This work is partially funded by the Spanish Ministry of Economy and Competitiveness (project TEC2016-76795-C6-4-R), the H2020 research and innovation project 5G-CLARITY (Grant No. 871428) and the Andalusian Knowledge Agency (project A-TIC-241-UGR18).

J. Navarro-Ortiz (corresponding author), S. Sendra, P. Romero-Diaz, Pablo Ameigeiras, Juan J. Ramos-Munoz, and J.M. Lopez-Soler are with the Department of Signal Theory, Telematics and Communications, University of Granada, Spain (e-mails: {jorgenavarro, ssendra, pabloromerodiaz, pameigeiras, jjramos, juanma}@ugr.es)

the conclusions and future research directions are included in Section VI.

II. 5G USAGE SCENARIOS, REQUIREMENTS AND TRAFFIC ESTIMATES

Fourth-Generation (4G) and 5G are terms used to identify the 4th and 5th generation of mobile technology. While these terms remain undefined [1], it is generally accepted that 4G refers to the mobile technologies fulfilling the IMT-Advanced requirements [2] and 5G refers to mobile systems fulfilling the ITU IMT-2020 requirements.

Since IMT-2020 technologies are not yet completely specified, this section summarizes values and trends from current International Communications Union - Radio-communication Sector (ITU-R) recommendations related to 5G requirements, usage scenarios and traffic estimates for 2020 and beyond.

A. Usage scenarios

Report ITU M.2083-0 [3] defines the framework and overall objectives of the future development of "*IMT for 2020 and beyond*" to better serve the needs of the networked society in the future. IMT-2020 is envisaged to expand and support diverse usage scenarios and applications that will continue beyond the current IMT. These usage scenarios include:

- Enhanced Mobile Broadband (eMBB), which addresses the human-centric use cases for access to multimedia content, services and data (e.g. 3D video, UHD (Ultra-High Definition) screens, augmented reality, etc.).
- Ultra-Reliable and Low Latency Communications (URLLC), which has stringent requirements for capabilities such as throughput, latency and availability (e.g. industry automation, mission-critical applications, self-driving cars, etc.).
- Massive Machine-Type Communications (mMTC), for scenarios with a very large number of connected devices typically transmitting a relatively low volume of non-delay sensitive data (e.g. smart grid, smart home/building, smart cities, etc.).

Since unforeseen use cases are expected to emerge in short future, 5G systems have to provide flexibility to support these new requirements. Fig. 1 shows some examples of envisioned usage scenarios for "*IMT for 2020 and beyond*", whereas Fig. 2 shows the importance of each key capability for the aforementioned usage scenarios (i.e. eMBB requires high data rate, whereas mMTC needs high connection density for massive deployment and, URLLC demands ultra-low latency).

Finally, report ITU-R M.2412 [4] defines the guidelines for evaluation of the candidate IMT-2020 radio interface technologies (RITs) or sets of RITs (SRITs) for IMT-2020 for many test environments. These test environments are defined as a combination of geographic environment and usage scenario. The report defines the following five test environments, including the network layout, the evaluation configurations (in terms of equipment parameters, device deployment, mobility and traffic models), antenna characteristics, and channel models:

- Indoor hotspot-eMBB
- Dense urban-eMBB
- Rural-eMBB[1]
- Urban macro-mMTC
- Urban macro-URLLC

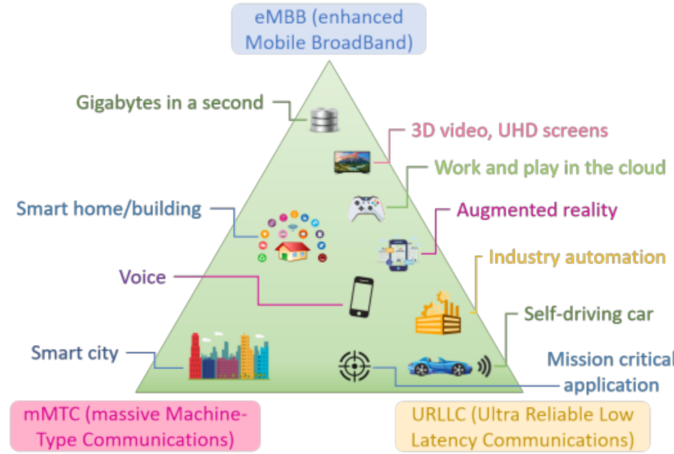

Figure 1: Usage scenarios of IMT for 2020 and beyond [3].

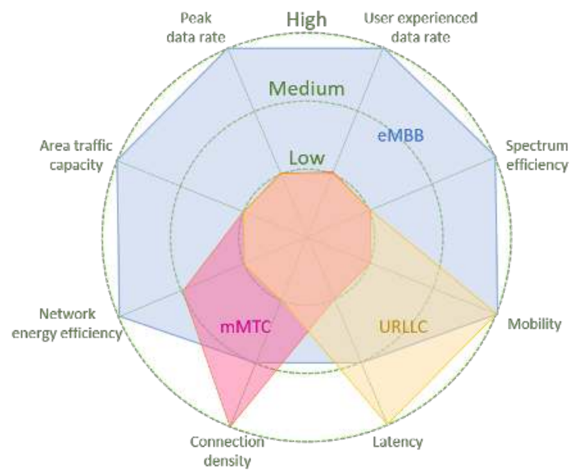

Figure 2: The importance of key capabilities in different usage scenarios [3].

ITU-R M.2412 report makes a comprehensive definition of these test environments (see Table I). In the case of eMBB, which is the logical evolution of conventional data services in 4G, three typical environments are considered (urban and rural for outdoors, and indoor hotspot), but only the urban scenario is contemplated for the new mMTC and URLLC services.

Regarding traffic models, this report only considers the full buffer model[2,3]. However, the usage of the well-known full buffer traffic model may provide non-realistic performance evaluations (e.g. for scheduling in Long Term Evolution (LTE) networks [6]). In this sense, Chiaraviglio [7] also claims

[1]Although rural scenarios are considered, the relevant technologies employed in 5G are "urban" in nature [5].

[2]In the full buffer traffic model, there is an infinite amount of data bits awaiting transmission in the output buffer associated with each data source.

[3]For urban macro-mMTC, a simple non-full buffer traffic model is also considered assuming 1 message/period/device with packet arrivals following a Poisson process.

for new traffic models for 5G, considering the new QoS requirements. He suggests to evaluate 4G using services such as eMBB or URLLC and proposes to employ scaling factors for these services in 5G.

Similarly, the adopted scenario will also be decisive, since it will have an enormous impact on some performance metrics such as user throughput and energy efficiency [8]. Moreover, the combination of scenario and traffic load may be fundamental for the performance evaluation of many features and mechanisms [9].

Table I: Summary of IMT-2020 test environments

Name	Description	Scenario	Traffic patterns
Indoor hotspot-eMBB	Offices and/or shopping malls	*Environment*: floor with an area of 120 m x 50 m *Users*: stationary or pedestrian *Deployment*: 12 sites which are placed in 20 meter spacing	Full buffer
Dense urban-eMBB	City with high user density	*Environment*: urban environment with 19 sites (Inter Site Distance (ISD) = 200m) *Users*: pedestrian and vehicular *Deployment*: Composed of two layers, macro and micro. The macro layer follows a regular grid with three Transmission Reception Points (TRxPs) per site, and the micro layer is composed of 3 micro sites randomly dropped in each macro TRxP area	Full buffer
Rural-eMBB	Rural area with larger and continuous coverage	*Scenario*: rural environment with 19 sites (ISD = 1732 m or 6000 m) *Users*: pedestrian, vehicular and high speed vehicular *Deployment*: regular grid as in the dense urban-eMBB environment	Full buffer
Urban macro-mMTC	City with a high number of connected machine type devices	*Scenario*: urban environment with 19 sites (ISD = 500m) *Deployment*: regular grid as in the dense urban-eMBB environment	Poisson packet arrival (1 message per day or every 2 hours)
Urban macro-URLLC	City with services requiring URLLC communications	*Scenario*: regular grid as in the dense urban-eMBB environment *Deployment*: regular grid as in the dense urban-eMBB environment	Full buffer

B. 5G requirements

Although many organizations (*e.g.* [10], [11], [12], [13]) and works (*e.g.* [14], [15], [16], [17], [18], [19], [20]) have devised the 5G requirements, it has not been until recently that ITU has formally specified them. The IMT-2020 technical requirements are included in Recommendation ITU-R M.2410 [21], summarized in Fig. 3. Some of the main targets are 20 Gbps for eMBB, a latency of 4 ms for eMBB and 1 ms for URLLC and a connection density of 10^6 devices/km^2 for mMTC. Table II provides the required values for these Key Performance Indicators (KPIs).

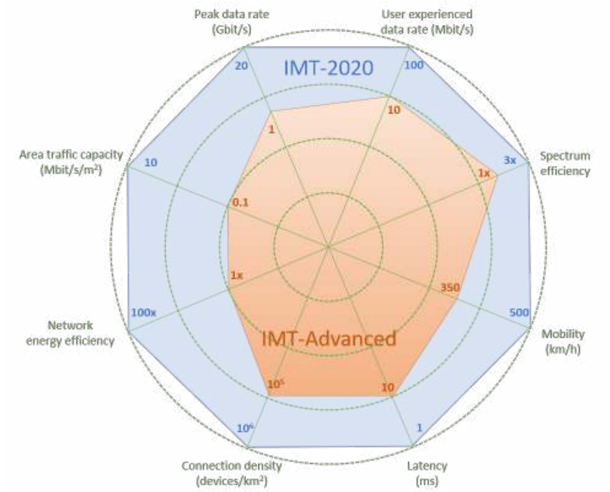

Figure 3: Enhancement of key capabilities from IMT-Advanced to IMT-2020 [3].

C. Traffic estimates from 2020 to 2030

In addition to current traffic mixes and traffic generation models, it is also critical to understand the evolution of the traffic load in the next years for the performance evaluation of these technologies. For that purpose, report ITU-R M.2370-0 [22] analyses trends impacting future IMT traffic growth beyond the year 2020. This work also estimates the traffic demands for the period from 2020 to 2030.

According to this report, the main drivers influencing the growth of future IMT traffic are:

- *Video usage*: video-on-demand services with high-resolution content (HD/UHD) will account for two-thirds of all mobile traffic.
- *Device proliferation*: more than 1.4 billion smartphones and tablets are forecasted.
- *Application uptake*: more than 270 billion apps are expected to be downloaded.

ITU-R M.2370-0 report includes different estimations for traffic forecast from 2020 to 2030 using different sources. This evolution will differ between countries due to social and economic differences, but it is expected that global IMT traffic will grow in the range of 10-100 times over this period. For example, Fig. 4 depicts the evolution of global mobile subscriptions for different devices. It is estimated that the global number of subscribers increases, between 2020 and 2030, from 6.3 to 12 billion for smartphones, from 1.3 to 5 billion for tablets and disappears for non-smartphones. Besides,

Fig. 5 estimates Machine-to-Machine (M2M) subscriptions (with an increase from 7 to 97 billion devices between 2020 and 2030) and Fig. 6 shows the evolution of mobile traffic, differentiating between video, non-video and M2M traffic. As shown, mobile internet and M2M traffic will grow dramatically after 2020, being video traffic 6 times higher than that of non-video in 2030. Additionally, M2M traffic will increase from 7 % to 12 % in that period. Finally, Fig. 7 shows the forecasted increase of mobile traffic compared to the actual

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Table II: Technical performance requirements for IMT-2020 [21]

Performance indicator	Value
Peak data rate	*eMBB*: DL 20 Gbps, UL 10 Gbps
Peak spectral efficiency	*eMBB*: DL 30 bps/Hz (assuming 8 spatial streams), UL 15 bps/Hz (assuming 4 spatial streams)
User experienced data rate	*Dense urban eMBB*: DL 100 Mbps, UL 50 Mbps
5th percentile user spectral efficiency	*Indoor hotspot eMBB*: DL 0.3bps/Hz/TRxP, UL 0.21bps/Hz/TRxP *Dense urban eMBB*: DL 0.225bps/Hz/TRxP, UL 0.15bps/Hz/TRxP *Rural eMBB*: DL 0.12bps/Hz/TRxP, UL 0.045bps/Hz/TRxP
Average spectral efficiency	*Indoor hotspot eMBB*: DL 9bps/Hz/TRxP, UL 6.75bps/Hz/TRxP *Dense urban eMBB*: DL 7.8bps/Hz/TRxP, UL 5.4bps/Hz/TRxP *Rural eMBB*: DL 3.3bps/Hz/TRxP, UL 1.6bps/Hz/TRxP
Area traffic capacity	Depends on average spectral efficiency and site density; target value for indoor hotspot eMBB is 10 Mbps/m^2
User plane latency	4 ms for eMBB, 1 ms for URLLC
Control plane latency	20 ms (recommended 10 ms)
Connection density	$10^6/km^2$ for mMTC
Energy efficiency	Support for a) efficient transmission of data in loaded or power limited case and b) low energy consumption when there is no data.
Reliability	$(1-10^{-5})$ success probability of transmitting a L2 PDU of 32 bytes within 1 ms for urban macro URLLC
Mobility	4 classes defined: stationary (0 km/h), pedestrian (0 to 10 km/h), vehicular (10 to 120 km/h) and high speed vehicular (120 to 500 km/h). Supported mobility and normalized data rate: *Indoor hotspot eMBB*: stationary, pedestrian; 1.5 bps/Hz *Dense urban eMBB*: stationary, pedestrian, vehicular (up to 30 km/h); 1.12 bps/Hz *Rural eMBB*: pedestrian, vehicular, high speed vehicular; 0.8 bps/Hz up to 120 km/h, 0.45 bps/Hz up to 500 km/h
Mobility interruption time	0 ms for eMBB
Bandwidth	At least 100 MHz; up to 1 GHz for frequency bands above 6 GHz

global mobile traffic (2010-2013). As depicted, this estimation implies a global growth between 2 300-times and 14 000-times from 2010 to 2030, assuming 'lower' and 'upper' forecasting scenarios.

ITU-R M.2370-0 report also includes a description of traffic asymmetry for some of the most popular applications (*e.g.* video, audio, web browsing, social networking, file sharing, etc.), showing that downlink represents around 80-90% of the data traffic while UL contributes around 10-20%.

It shall be noticed that [22] also includes the daily traffic profiles for the five major mobile applications (streaming, computing, gaming, communicating, and storage) for some of the regions (North America, Western Europe, and Central & Eastern Europe).

These traffic forecasts will allow researchers to estimate the increase in traffic load for the performance evaluation of 5G and future mobile technologies under e.g the usage scenarios and test cases analyzed in this paper.

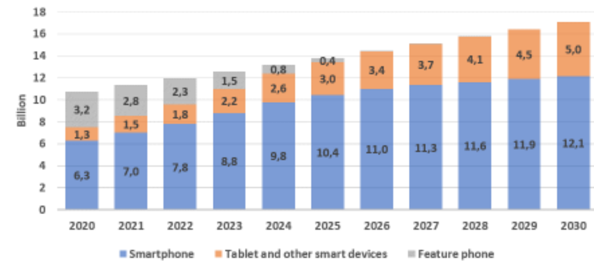

Figure 4: Estimation of global mobile subscriptions with different categories (provided by China) [22].

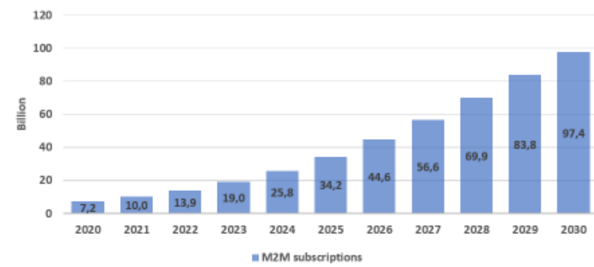

Figure 5: Estimation of global M2M subscriptions (provided by China) [22].

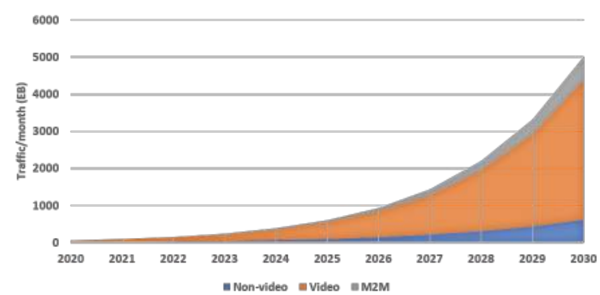

Figure 6: Estimation of mobile traffic by different service types globally (provided by China) [22].

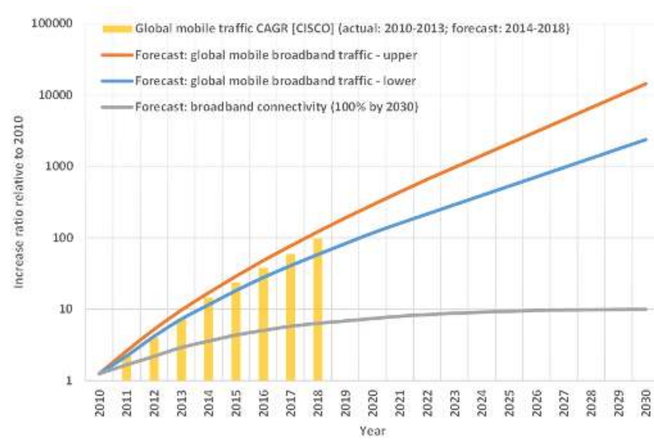

Figure 7: Forecast for global mobile broadband traffic growth for the period 2010 - 2030 (provided by Nokia) [22].

III. 5G Standards Development Organizations and main stakeholders

This section provides a landscape of the 5G-related activities in standards bodies, industry fora, and regional research efforts. Since the number of initiatives is huge, we have focused on those which define performance evaluation guidelines, including use cases and traffic models, specifically for 5G. Besides, we have also included the performance evaluation guidelines for 4G from some of the major players. Following these criteria, we have summarized the test cases for the following organizations / initiatives: ITU, 3GPP, IEEE (Institute of Electrical and Electronics Engineering), WiMAX (Worldwide Interoperability for Microwave Access) Forum, TIA (Telecommunications Industry Association), research projects from 5G PPP (METIS, FANTASTIC-5G, mmMAGIC, SPEED-5G, and 5G-NORMA), and NGMN. We believe they are representative of the different Standards Development Organizations and industry associations.

To the best of our knowledge, most of the works in the literature rely on the use cases and the traffic patterns proposed in these initiatives. For example, the work presented in [23] presents a system-level simulator for 5G mobile networks and utilizes the use cases from 3GPP, assuming a full buffer traffic model. Similarly, [24] proposes another system-level simulator for the performance evaluation of 5G related technologies, identifying five emerging scenarios (some of them from IMT-Advanced and 3GPP): *heterogeneous network*, *high-rise building*, *Device-to-Device (D2D) communication*, *high-speed mobile environment*, and *traditional typical simulation scenario*. Nevertheless, only a brief description of these scenarios is given. Furthermore, [25] presents a solution for ultra-dense heterogeneous networks for 5G including a scenario with femtocells, picocells, mMTC and D2D communications. Another example can be found in [26], which tries to summarize the 5G requirements and related test environments, proposing classical scenarios from 3GPP and IMT-2020 (indoor isolated environment, urban macro coverage environment, dense urban area environment, and high speed train environment).

In addition, there are other research projects on 5G, but most of them also rely on the information from the aforementioned works or consider use cases for specific technologies or infrastructures. For example, the 5GCHAMPION Europe–Korea collaborative project [27] provided the first fully-integrated and operational 5G prototype for the 2018 Winter Olympic Games, so the use cases were specific to the European and Korean infrastructure available for the project [28] [29].

In order to guide the reader, Fig. 8 summarizes the main traffic models proposed by these organizations, which will be explained in detail in the following subsections. Similarly, Fig. 9 depicts the main usage scenarios from these stakeholders.

A. ITU

ITU is the United Nations specialized agency for information and communication technologies (ICTs). Founded on the principle of international cooperation between governments (Member States) and the private sector (Sector Members, Associates and Academia), ITU is the premier global forum through which parties work towards consensus on a wide range of issues affecting the future direction of the ICT industry [30]. Within ITU, the ITU Radio-communication Sector (ITU-R) plays a vital role in the global management of the radio-frequency spectrum and satellite orbits [31].

The guidelines for the evaluation of radio interface technologies for IMT-2020 are included in Section II-A. For the sake of completeness, we also summarize here the guidelines for evaluation for IMT-Advanced (i.e. for 4G), which are included in Report ITU-R M.2135-1 [32]. Focusing on the usage scenarios, it defines four test environments:

- *Indoor*: targeting isolated cells at offices and/or hotspot based on stationary and pedestrian users.
- *Microcellular*: an urban environment with higher user density focusing on pedestrian and slow vehicular users.
- *Base coverage urban*: an urban macro-cellular environment targeting continuous coverage for pedestrian up to fast vehicular users.
- *High speed*: a rural macro-cellular environment with high speed vehicular and trains.

The network layout and the configurations for these scenarios are defined in the report. Although this report is intended for 4G communications, these scenarios are also relevant in today's networks and continue to be used in current relevant works (e.g. [33]).

Regarding traffic models, the report specifies the support of a wide range of services which can be classified under the following classes: conversational, interactive, streaming, and background. However, only two traffic models are defined:

- *Full buffer traffic model*: data sources with an infinite amount of data awaiting transmission.
- *VoIP (Voice over IP)*: 12.2 kbps codec with a 50% activity factor (with the same parameters as 3GPP, see Table V in the 3GPP subsection).

As already commented, the full buffer traffic model has widely been adopted both in simulation-based [34][35][36][37] and theoretical [38][39][40][41] investigations due to its simplicity.

Voice using codecs with 12.2 kbps (e.g. using AMR-NB) has also been highly used for research since GSM and up to current 4G and 5G networks, e.g. [42][43][44][45][46].

Similarly to IMT-2020 [4], there are no service-specific traffic models defined for IMT-Advanced.

B. 3GPP

The original scope (1998) of 3rd Generation Partnership Project (3GPP) [47] was to produce Technical Specifications and Technical Reports for a 3G mobile system based on evolved GSM core networks and their corresponding radio access technologies, i.e. Universal Terrestrial Radio Access (UTRA).

Now, the 3GPP unites seven telecommunications standard development organizations (known as "Organizational Partners") including ARIB (the Association of Radio Industries and Businesses, Japan), ATIS (the Alliance for Telecommunications Industry Solutions, USA), CCSA (China Communications Standards Association), ETSI (the European Telecommunications Standards Institute), TSDSI (Telecommunications

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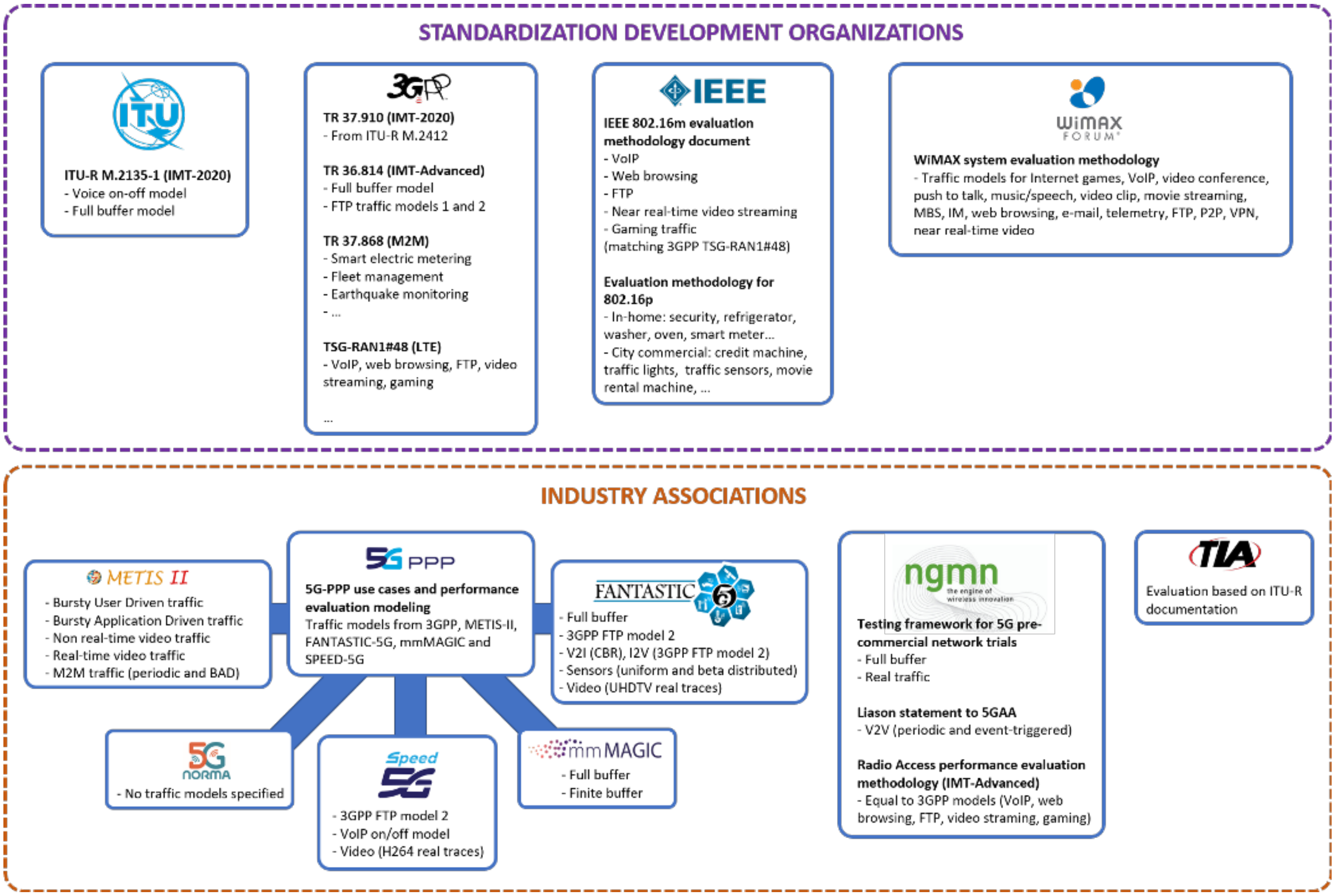

Figure 8: Summary of traffic models proposed by main SDOs and industry associations.

Standards Development Society, India), TTA (Telecommunications Technology Association, Korea), and TTC (Telecommunication Technology Committee, Japan), market associations and several hundred companies, providing a stable environment to produce the Reports and Specifications that define 3GPP technologies. These technologies includes radio access, the core transport network, and service capabilities.

The latest versions of the standard includes Long Term Evolution (LTE) (Release 8), LTE-Advanced (Release 10), and their evolutions (up to Release 14). The works for the first set of 5G standards started in Release 15 during the second half of 2017 were successfully completed in September 2018 [48]. 5G Phase 2 (Release 16) should be completed in December 2019 [49]. 3GPP has decided to submit the final specifications at the ITU-R WP5D meeting in February 2020 [50], based on these specifications, before the ITU-R deadline for the detailed specification submission in October 2020.

Within release 14, report 3GPP TR 38.913 [51] defines typical deployment scenarios and requirements for next-generation access technologies considering, but not limited to, the IMT-2020 requirements. The considered usage scenarios are eMBB, mMTC, and URLLC. The deployment scenarios in this report are summarized in Table III. It shall be noted that most of the scenarios from IMT-2020 are included (indoor hotspot-eMBB, dense urban, rural and urban coverage for massive Machine-Type Communications (MTC)). In addition, some new use cases are also proposed with different requirements, such as speed (high speed trains, highways, urban connected cars, commercial/light aircraft scenarios) or large coverage (extreme long distance, satellite extension to terrestrial).

Interestingly, the KPI targets are in line with those defined by IMT-2020 (see Table II). The target peak data rate is 20 Gbps for DL and 10 Gbps for UL. The target peak spectral efficiency is 30 bps/Hz for DL and 15 bps/Hz for UL. The target control plane latency is 10 ms. The target user plane latency, for both DL and UL, is 0.5 ms for URLLC and 4 ms for eMBB, whereas shall be no worse than 10 s for infrequent small packets. The target for mobility interruption time is 0 ms. The reliability requirement for URLLC is $1-10^{-5}$ with a user plane latency of 1 ms, and $1-10^{-5}$ for eV2X (*enhanced Vehicle to everything*) with a user plane latency of 3-10 ms. The target for link budget is 164 dB. The target UE battery life for mMTC should be beyond 10 years (sending one packet per day in extreme coverage). The TRxP spectrum efficiency shall be 3 times higher than that of IMT-Advanced for the first four deployment scenarios with eMBB. Both the user experienced data rate and the 5th percentile user spectrum efficiency shall also be three times higher than that of IMT-Advanced. The target connection density is 1,000,000 devices/km^2 in urban environment. The target maximum user speed is 500 km/h.

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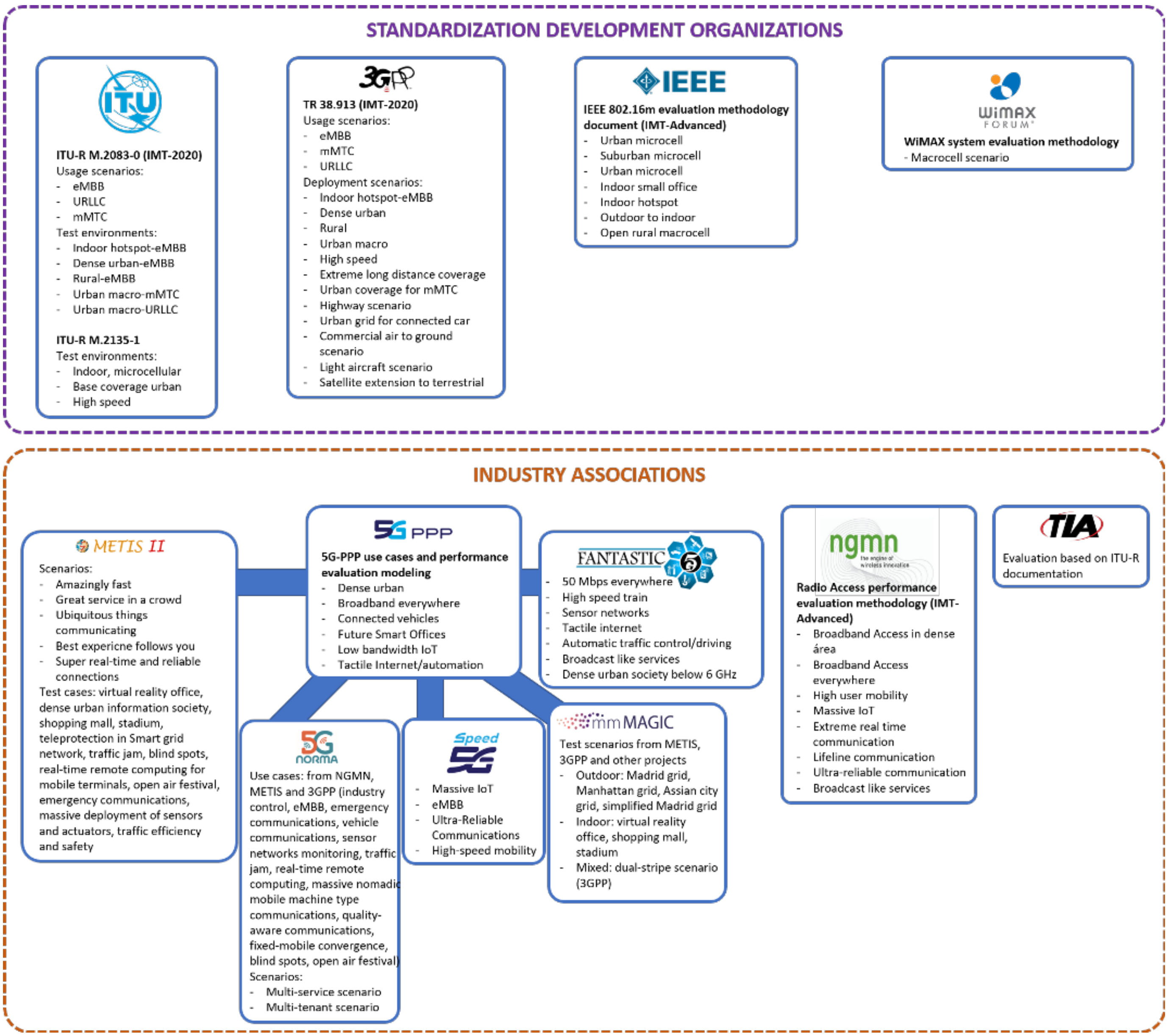

Figure 9: Summary of usage scenarios proposed by main SDOs and industry associations.

It is also proposed that at least 1 GHz aggregated bandwidth shall be supported.

Report 3GPP TR 37.910 [52] provides self evaluation results towards IMT-2020 submission to ITU-R WP 5D. The use cases from IMT-2020 are considered: eMBB (indoor hotspot, dense urban, and rural), URLLC and mMTC. Results include average spectral efficiency, peak data rate, user experienced data rate, area traffic capacity, and latency. For the evaluation, link level assumptions are given but no traffic models are defined (only full buffer for New Radio (NR) and ITU models for mMTC).

Within 4G, report 3GPP TR 36.814 [53] presented the further advancements for E-UTRA (LTE-Advanced) to fulfill the requirements on IMT-Advanced. The simulation model presented in its Annex A identifies two types of simplified traffic models for non-real time services, the well-known *full buffer traffic model* and *FTP (File Transfer Protocol) traffic models 1 and 2*, which are summarized in Table IV. Due to its simplicity, these models have been largely used in the literature. The details of the self-evaluation results are defined in document 3GPP TSG RAN1#59 R1-094954 [54]. Although these models are highly detailed, to the best of our knowledge, they have almost not been used in the literature.

Additionally, document 3GPP TSG-RAN1#48 R1-070674 [55] presents the evaluation cases and the corresponding metrics to verify the performance of the LTE physical layer, including more complex traffic models for some of the most relevant services, i.e. *FTP*, *web-browsing*, *video streaming*, *gaming* and *VoIP* traffic models. Table V summarizes the characterization of these traffic patterns.

Other relevant traffic types are depicted in different 3GPP specifications. For example, Machine-to-Machine is studied in 3GPP TR 37.868 [56]. The study includes a load analysis

Table III: Summary of 3GPP deployment scenarios

Name	Scenario
Indoor hotspot-eMBB	*Description*: offices and/or shopping malls *Environment*: indoor floor (open office) *Users*: 10 users per TRxP, indoor, 3 km/h *Deployment*: 12 TRxPs per 120m x 50m (ISD = 20m)
Dense urban	*Description*: city centres and dense urban areas *Environment*: high user densities and traffic loads, outdoor and outdoor-to-indoor coverage *Users*: 10 users per TRxP, 80% indoor (3 km/h), 20% outdoor (30 km/h) *Deployment*: macro layer with ISD = 200m, micro layer with 3 TRxPs (outdoor) per macro TRxP
Rural	*Description*: larger and continuous coverage *Scenario*: rural environment *Users*: 10 users per TRxP, 50% outdoor vehicles (120 km/h) and 50% indoor (3 km/h) *Deployment*: regular grid with ISD = 1732 m or 5000 m
Urban macro	*Description*: city *Scenario*: urban environment *Users*: 10 users per TRxP, 20% outdoor in cars (30 km/h), 80% indoor in houses (3 km/h) *Deployment*: regular grid (ISD = 500 m)
High speed	*Description*: high speed trains *Scenario*: track in high speed trains *Users*: 100% of users in train, 300 UEs per macro cell (1000 passengers per train and 10% of activity ratio), 500 km/h *Deployment*: ISD 1732m between RRH sites, with two TRxPs per RRH site (following the track)
Extreme long distance coverage	*Description*: very large areas with low density of users *Scenario*: rural environment *Users*: depending on the target user experience data rate (2 Mbps while stationary and 384 kbps while moving); up to 160 km/h *Deployment*: isolated cell with 100 km range
Urban coverage for massive MTC	*Description*: large cells and continuous coverage for mMTC *Scenario*: very high connection density of mMTC devices *Users*: 20% outdoor in cars (100 km/h) or users (3 km/h), and 80% indoor users *Deployment*: macro with ISD = 1732 or 500 m
Highway scenario	*Description*: vehicles in highways with high speed *Scenario*: highway *Users*: 100% in vehicles, with an inter-vehicle distance of 0.5 or 1 sec * average vehicle speed (100-300 km/h), sending 50 messages per second *Deployment*: macro only (ISD = 1732 or 500 m) or macro + RSUs (*Roadside Unit*, i.e. an eNB or UE with V2X communications, ISD = 50 or 100 m)
Urban grid for connected car	*Description*: urban area with highly density of vehicles *Scenario*: urban grid model (1299 m x 750 m with 9 blocks (433m x 250m) with car lanes (2 lanes per direction) and pedestrian/bicycle sidewalks placed around the block) *Users*: vehicles with speeds of 15, 60 or 120 km/h (50 or 10 messages/sec depending on speed), inter-vehicle distance of 2.5 sec * vehicle speed *Deployment*: macro only (ISD = 500 m) or macro + RSUs (placed at intersections, or with ISD = 50 or 100 m)
Commercial air to ground scenario	*Description*: mobile services for commercial aircrafts *Scenario*: services for both humans and machines inside a commercial aircraft *Users*: speed up to 1000 km/h and altitude up to 15 km *Deployment*: macro cells with very large area coverage (up to 100 km) + relay in aircraft (aggregation point)
Light aircraft scenario	*Description*: mobile services for small air planes *Scenario*: services for both humans and machines inside a small air plane *Users*: up to 6 users per airplane, with up to 370 km/h and an altitude of up to 3 km *Deployment*: macro cells with very large area coverage (up to 100 km) without relays
Satellite extension to terrestrial	*Description*: no terrestrial services are available *Scenario*: roadways and rural areas *Users*: 100% outdoors *Deployment*: GEO and LEO satellites

Table IV: Summary of 3GPP simplified traffic models for non-real time services

Parameter	Statistical characterization
Full buffer	
Number of users	Constant during the simulation
Data per user	Infinite
FTP model 1	
Number of users	Poisson distributed arrival rate λ
Data per user S	Each user downloads one file of fixed size S (2Mbytes, optionally 0.5Mbytes to speed-up simulations)
FTP model 2	
Number of users	Constant K during the simulation
Data per user	Each user downloads one file and waits an exponentially distributed *reading time* D before requesting the next file ($f_D = \lambda e^{-\lambda D}, D \geq 0, \lambda = 0.2$, i.e. the average D is 5 seconds)

for *smart electric metering*, *fleet management*, and *earthquake monitoring* applications. From this analysis, two traffic models are proposed which are summarized in Table VI. The amount of data transmitted per arrival is not included in the traffic models definition, although the evaluation assumes one packet of 200 bytes (+UDP/IP headers). Based on this report, 3GPP TR 36.888 [57] also includes two traffic models for MTC, one for regular reporting and another one for triggered reporting, summarized in Table VII.

Additionally, document 3GPP TSG-RAN WG2#68-bis R2-100204 [58] includes a list for some M2M services with their typical traffic characteristics, including session density, bytes in a session, deployment, mobility and machines/km^2, although not clearly specified. These services are summarized in Table VIII. This document also includes session level and packet level modeling, defining three cases for the session initiation time: periodic, random (following an exponential distribution, i.e. $p(t < T) = 1 - e^{-\lambda T}, T \geq 0$), or mixed. In the third case, the session is usually initiated periodically but may also be triggered by random events, so the session can be described by adding up one or several periodical processes and one or several Poisson processes. From the packet level point of view, in pure M2M services, the transmitted packet series inside a session usually is predefined, i.e. the packet number, sizes and intervals are fixed. In some M2M services where human input is present (*interactive session*), there may be different types of sessions, but the packet number, sizes and intervals of each type are still predefined.

As an example, [58] includes a typical smart metering service with metering data report, load control and alarm. The metering data are reported every hour (periodical process), the load control and alarm events take place randomly (two Poisson processes with average session intervals of 12 and 1000 hours, respectively). Each metering report includes only one 100 bytes packet, control sessions contains one 10 bytes packet and alarm messages include one 50 bytes packet.

Another example of application is D2D communications. Report 3GPP TR 36.843 [59] presents the evaluation methodology for D2D proximity services, including scenarios and traffic models. Different layout options are considered, using a hexagonal grid with 19 or 7 macro sites (urban macro scenario) mixed with indoor hotspot zones or dual stripes of

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/COMST.2020.2971781, IEEE Communications Surveys & Tutorials

apartments. The number of active users per cell area are 25 (general scenario) or 10 (public safety scenario), with a total of 150 users for discovery per cell. This report considers full buffer, VoIP and FTP2 (from [53]) for traffic models, assuming file sizes of 10 KBytes and, for VoIP, a source rate of 12.2 kbps with one frame every 20 ms, a voice activity factor of 75%, exponentially distributed talk spurts with a mean of 2.5 s, and payloads of 41 bytes (with header compression) or 70 bytes (without header compression).

Table V: Summary of 3GPP traffic models

Parameter	Statistical characterization
FTP traffic	
File size S	Truncated lognormal distribution (max 5Mbytes) $f_x = \frac{1}{\sqrt{2\pi}\sigma x} e^{\frac{-(\ln x-\mu)^2}{2\sigma^2}}$, $x > 0$, $\sigma = 0.35$, $\mu = 14.45$
Reading time D	Exponential distribution $f_x = \lambda e^{-\lambda x}$, $x \geq 0$, $\lambda = 0.006$
Web-browsing traffic	
Main object size S_M	Truncated lognormal distribution: min. 100bytes, max 2Mbytes, $\sigma = 1.37$, $\mu = 8.37$
Embedded object size S_E	Truncated lognormal distribution: min 50bytes, max 2Mbytes, $\sigma = 2.36$, $\mu = 6.17$
Embedded objects per page N_D	Truncated Pareto distribution (max 53) $f_x = \frac{\alpha_k^\alpha}{\alpha+1}, k \leq x < m$, $f_x = \left(\frac{k}{m}\right)^\alpha, x = m$, $\alpha = 1.1$, $k = 2$, $m = 55$ (subtract k from the random value to obtain N_D)
Reading time D	Exponential distribution: $\lambda = 0.033$
Parsing time T_P	Exponential distribution: $\lambda = 7.69$
Video streaming traffic	
Inter-arrival time between frames	Deterministic: 100ms (based on 10fps)
Packets per frame	Deterministic: 8 packets per frame
Packet size	Truncated Pareto distribution: $\alpha = 1.2$, $k =$ 20bytes, $m = 250$bytes
Inter-arrival time between packets in a frame	Truncated Pareto distribution: $\alpha = 1.1$, $k =$ 2.5ms, $m = 12.5$ms
Gaming traffic	
UL initial packet arrival	Uniform distribution $f_x = \frac{1}{b-a}, a \leq x \leq b$, $a = 0$, $b = 40ms$
UL packet arrival	Deterministic: 40ms
UL packet size	Largest extreme value distribution $f_x = \frac{1}{b} e^{-\frac{x-a}{b}} e^{-e^{-\frac{x-a}{b}}}$, $a =$ 45bytes, $b =$ 5.7bytes 2 bytes UDP header after header compression
DL initial packet arrival	Uniform distribution: $a = 0$, $b =$ 40ms
DL packet arrival	Largest extreme value distribution: $a =$ 55ms, $b =$ 6ms
DL packet size	Largest extreme value distribution: $a =$ 120bytes, $b =$ 36bytes (2 bytes UDP header)
VoIP traffic	
Codec	RTP AMR 12.2 (source rate 12.2kbps) with encoder frame duration T=20ms
Voice activity model	Simple 2-state Markov model with the following parameters: Voice Activity Factor (VAF) λ=0.5, transition probability from inactive to active state c=0.01 $\rightarrow$ transition probability from active to inactive state a=0.01, mean talk-spurt duration μ_{TS}=2s, mean silence period duration μ_{SP}=2s
Packet size	*VoIP frame* of 40 bytes (including all overhead) every T=20ms *Silence Insertion Descriptor* (SID) packets of 15 bytes (including all overhead) every 160ms during silence

Although voice communications has been decreasing in the

Table VI: Summary of 3GPP traffic models for MTC (3GPP TR 37.868)

Parameter	Statistical characterization
Traffic model 1	
Number of MTC devices	1000, 3000, 5000, 10000, 30000
Arrival distribution	Uniform distribution over T=60 seconds
Application packet size	200 bytes
Traffic model 2	
Number of MTC devices	1000, 3000, 5000, 10000, 30000
Arrival distribution	Beta distribution over T=10 seconds (α=3, β=4) $f_t = \frac{t^{\alpha-1}(T-t)^{\beta-1}}{T^{\alpha+\beta-1}Beta(\alpha,\beta)}$, where $Beta(\alpha,\beta)$ is the Beta function
Application packet size	200 bytes

Table VII: Summary of 3GPP traffic models for MTC (3GPP TR 36.888)

Parameter	Statistical characterization
Regular reporting for low-cost MTC (no mobility)	
UL interval	1 min (optional), 5 min, 30 min, 1 hour
Packets (bits)	1000, optional 10000
Mobility	Static, pedestrian (optional)
Regular reporting for low-cost MTC (limited mobility)	
UL interval	5 s (optional), 10 s, 30 s
Packets (bits)	1000
Mobility	Vehicular
Triggered reporting (UL and DL)	
Volume	256 bits, 1000 bits
Inter-arrival time	Exponential with mean of 30 seconds

last years compared to data traffic (now it represents only around 2% of the total mobile traffic [60]), voice remains the principle service for most subscribers. Therefore, voice quality continues to be a major factor to determine what is the subscriber's perception regarding a particular operator. For that reason, current mobile networks are incorporating changes to improve the voice service in networks that are initially recognized as "data oriented" networks [61]. One example is VoLTE (Voice over LTE) in current 4G networks.

Due to the way humans talk with each other, many works (e.g. [62] [63] [64] [65] [66] [67] [68] [69] [70] [71]) utilize a simple on/off model for voice activity, despite of being very old [72]. Even nowadays, as previously commented, the on/off model is used by the 3GPP for the evaluation of LTE [55] (see Fig. 10).

Regarding voice activity, 3GPP uses a VAF of 50 % (i.e. each subscriber speaks during half of the time, being quiet the

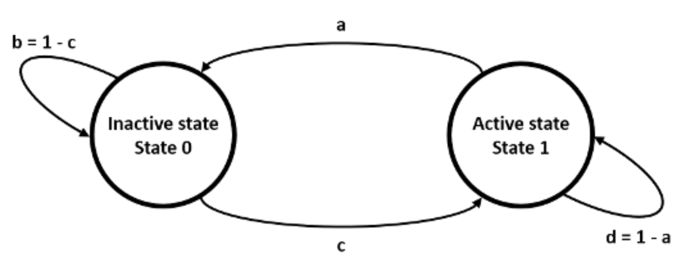

Figure 10: Two-state activity model for one speaker [55].

Table VIII: Summary of 3GPP traffic models for M2M services

Parameter	Statistical characterization
Smart metering	
Description	Periodic or on-demand metering reports
Session density	<50 times/day/metering device
Bytes/session	Tens of bytes
Deployment	Urban/suburban
Mobility	Stationary
Machines/km^2	<10000 (urban), <1000 (suburban)
Point of sale	
Description	Vending machine (transaction randomly triggered)
Session density	<1000 times/day
Bytes/session	Hundreds of bytes
Deployment	Urban
Mobility	Stationary
Machines/km^2	<1000
Fleet management	
Description	Vehicles located periodically or on-demand; also alarm and control data
Session density	<1000 times/day
Bytes/session	KBs
Deployment	Urban/suburban
Mobility	Mobile
Machines/km^2	<5000
Telemedicine	
Description	Periodical patient monitoring; also urgent calls or some control data
Session density	<500 times/day
Bytes/session	Tens to hundreds of KBs
Deployment	Urban/suburban
Mobility	Stationary/mobile
Machines/km^2	<1000
Environment monitoring and control	
Description	Periodic or on-demand sensing data; also alarm and control data
Session density	<1000 times/day/sensor gateway
Bytes/session	KBs (or MBs in special cases)
Deployment	Urban/suburban
Mobility	Stationary
Machines/km^2	<1000 (sensing data aggregated in a gateway)
Home automation	
Description	Home sensing and control, home security
Session density	<100 times/day/home gateway
Bytes/session	Hundreds of bytes
Deployment	Urban/suburban
Mobility	Stationary
Machines/km^2	<10000 (urban), <1000 (suburban)

other half) in document TSG-RAN1#48 R1-070674 [55], but assumes a VAF of 40 % for the performance evaluation of the AMR-WB speech codec [73]. This 40 % is similar to the 39 % specified by the ITU-T in 1993 [74], which utilizes an average ON (talk) duration of $\frac{1}{\lambda} = 1.004$ s and an average OFF (silence) duration of $\frac{1}{\mu} = 1.587$s. The derivation of parameters a to d is also explained in [55].

The latest version of the study on voice and video enhancement for LTE [75] considers the Adaptive Multi-Rate Wide-Band (AMR-WB [76]) and the Enhanced Voice Services (EVS [77]) codecs. These codecs adapt their rate during the conversation depending on current conditions. The standard defines the procedure to change the codec rate (using Codec Mode Request (CMR) messages) but it is up to the manufacturer to decide when the rate adaptation shall be triggered. Both AMR and EVS generate voice frames every 20 ms with a payload size which depends on the selected bit rate. During silence periods, a Silence Insertion Descriptor (SID) is sent every 160 ms with a payload of 39/40/48 bits (AMR-NB/AMR-WB/EVS). 3GPP Technical Report 26.952 [78] comprises the performance characterization of EVS, including a comparison with both AMR-NB and AMR-WB.

In the case of AMR and AMR-WB, many papers e.g. [79] [80] [81] [82] [83] assume that the rate is fixed and no adaptation is performed (e.g. AMR-WB with 12.65 kbps). Similarly, it is typically assumed EVS-WB with 24.4 kbps (since higher bit rates are not commonly implemented) with a VAF of 50 %.

C. IEEE

IEEE, the Institute of Electrical and Electronics Engineers, is an association dedicated to advancing innovation and technological excellence for the benefit of humanity, being the world's largest technical professional society [84].

Although IEEE has its own 5G Initiative [85], they are currently discussing about concepts, future options and roadmaps [86]; unfortunately, there is no clear picture about which current or future standards will be included on a proposal for IMT-2020. However, it is expected that IEEE 802.11 continues to enhance and develop new capabilities which can be RAN components of 5G [87]:

- 802.11ad/ay/aj: 60GHz band operation, applicable to short range and very high bandwidth operation (up to 176 Gbps).
- 802.11ah/ba: Sub 1 GHz band (with a range up to 1 Km), applicable to low power machine type communications.
- 802.11ax: High efficiency WLANs (up to 14 Gbps), applicable to dense deployments.

Previously, IEEE was very active on 4G. In this regard, on October 2009, IEEE submitted to ITU-R Working Party 5D a "Candidate IMT-Advanced RIT based on IEEE 802.16". On October 2010, ITU-R assessment of six candidate submissions for the 4th generation of cellular systems resulted in two technologies, "LTE-Advanced" and "WirelessMAN-Advanced" (IEEE Std 802.16m) being accorded the official designation of IMT-Advanced, qualifying them as true 4G technologies.

Document [88] proposes the baseline evaluation methodology for the IEEE 802.16m standard. This document includes traffic models for web browsing, FTP, VoIP, near real time video streaming, and gaming traffic, which match those defined by 3GPP in [55] (with few changes in some parameters, see Tables V and IX). Specific path loss models are considered for different environments (e.g. urban macrocell, indoor small office, indoor hotspot, etc.) but no specific scenarios are defined.

In the case of VoIP, [88] also summarizes the main parameters for different voice codecs but suggests to assume AMR 12.2 kbps since "*this model captures the worst case scenario*", which is also the codec selected by 3GPP in [55]. In the case of web browsing, this document also incorporates an updated model based on measurements from the top 50 web sites taken on April 2007. Additionally, [88] describes traffic models for video telephony (based on MPEG 4 traces) and e-mail (based on an ON/OFF session model), which are also depicted in Table IX. Section 10.8 in [88] proposes different traffic mixes to be used in system evaluations. However, these traffic mixes are very simplistic, since most of them utilize only one service (e.g. "*HTTP only*") or a mixture of VoIP and full buffer traffic sources. The traffic mixed defined by NGMN in [89] (see Section III-G) is also included for liaison with NGMN.

For M2M communications, IEEE 802.16's Machine-to-Machine Task Group includes in IEEE 802.16p-10/005 [91] usage scenarios, requirements, and standards changes needed for supporting M2M communications. This technical report identifies the following relevant M2M usage models: secured access and surveillance; tracking, tracing, and recovery; public safety; payment; health care; remote maintenance and control; metering; consumer devices; and retail. Besides, the traffic characteristics for Advanced Metering Infrastructure (AMI) is also provided as an example. Later, this Task Group elaborated a proposal for evaluation methodology for 802.16p [92] which includes traffic models for typical M2M services for in-home and city commercial M2M devices deployments. Tables X and XII summarize the traffic models for in-home and city commercial deployments, respectively. In the case of an in-home deployment, typical *smart* home appliances are included, such as the refrigerator, clothes washer/dryer, dishwasher, oven, etcetera. For the city commercial deployment, usual pieces of urban furniture are contemplated such as credit machines, traffic lights, roadway signs, etcetera. Deployments (cell radius and number of devices) are included in Tables XI and XIII.

D. WiMAX Forum

The WiMAX Forum is an industry-led, not-for-profit organization that certifies and promotes the compatibility and interoperability of broadband wireless products based upon IEEE Standard 802.16 [93].

The WiMAX Forum presented a system evaluation methodology for mobile WiMAX systems [94], including application traffic models (summarized in Table XIV) for: Internet games, VoIP, video conference, PTT (Push-to-Talk), music/speech, video clip, movie streaming, MBS (Multicast Broadcast Services), IM (Instant Messaging), web browsing, e-mail, telemetry, FTP, P2P (Peer-to-Peer), VPN (Virtual Private Network) and near real-time video. These application traffic models include user level and IP packet level models. The former considers user behavior interactions in an application, whereas the later contemplates packet size and packet interarrival time distributions at the IP layer. This document only considers a macrocell scenario with 19 hexagonal cells. Since this document was intended for WiMAX (which fulfills the requirements for IMT-Advanced), these models are not used in the current literature.

E. TIA

The Telecommunications Industry Association (TIA) [95] is the leading trade association representing the global information and communications technology (ICT) industry through standards development, policy initiatives, business

Table IX: Summary of IEEE 802.16m traffic models

Statistical characterization
Web-browsing traffic
Same statistical characterization as 3GPP (see Table V) **Updated model** (Appendix P in [88]): this model separates the UL and DL traffic and maintains the same reading and parsing times. *UL*: main object size with truncated lognormal distribution (min. 100 bytes, max. 100 Kbytes, $\sigma = 1.37$, $\mu = 8.35$), embedded object size with truncated lognormal distribution (min. 50 bytes, max. 100 Kbytes, $\sigma = 1.69$, $\mu = 7.53$), and number of embedded objects per page with truncated Pareto distribution (max. 53, $\alpha = 1.1$, $k = 2$, $m = 55$) *DL*: main object size with truncated lognormal distribution (min. 1290 bytes, max. 0.25 Mbytes, $\sigma = 0.8$, $\mu = 10.55$), embedded object size with truncated lognormal distribution (min. 5 bytes, max. 6 Mbytes, $\sigma = 1.97$, $\mu = 7.1$), and number of embedded objects per page with truncated Pareto distribution (max. 165, $\alpha = 1.1$, $k = 2$, $m = 55$)
FTP traffic
Same statistical characterization as 3GPP (see Table V)
VoIP traffic
Same statistical characterization as 3GPP (see Table V), but with different parameter values: $\mu_{TS} = \mu_{SP} = 1.25s$, a=c=0.016 *VoIP frame* of 44-46bytes (including all overhead), SID packets of 18-20bytes (including all overhead) during silence The main parameters (source bit rate, frame duration and information per frame) for typical voice codecs (EVRC, AMR-NB, GSM 6.10, G.711, G.723.1, and G.729A) are also included.
Near real time video streaming traffic
Same statistical characterization as "*video streaming traffic*" 3GPP (see Table V), except $k = 40$bytes for the packet size distribution
Video telephony traffic
Based on an Office Cam trace (from [90]) with high or medium quality. The video codec is MPEG-4 and it is transmitted over UDP. The main parameters are: 25 frames/sec, Group of Pictures with N=12 and M=3, display size is 176x144 pixels, color depth is 8 bits, the video quality is medium, the mean bandwidth is 110 kbps, the I frame size (bytes) follows a Weibull distribution ($\alpha = 5.15$, $\beta = 863$, shift=3949, $\mu = 4742$, $\sigma = 178$, min=4034, max=5184), the P frame size (bytes) follows a lognormal distribution ($\mu = 259$, $\sigma = 134$, min=100, max=1663), and the B frame size (bytes) follows a lognormal distribution ($\mu = 147$, $\sigma = 74$, min=35, max=882)
Gaming traffic
Same statistical characterization as 3GPP (see Table V), except: *Uplink*: packet arrival with largest extreme distribution ($a = 40$ms, $b = 6$ms) and packet size parameters ($a = 45$bytes, $b = 5.7$bytes) *Downlink*: packet arrival parameters ($a = 50$ms, $b = 4.5$ms) and packet size parameters ($a = 330$bytes, $b = 82$bytes)
E-mail traffic
Traffic characterization: ON/OFF states. During ON-state an email could be transmitted or received, and during OFF-state a client is writing or reading an e-mail E-mail protocol: POP3, MAPI E-mail average header size: Deterministic distribution: 1Kbyte Number of e-mail received: Lognormal distribution: $\sigma = 3.262$, $\mu = 0.5277$ Number of e-mail sent: Lognormal distribution: $\sigma = 2.364$, $\mu = 0.742$ E-mail reading time: Pareto distribution: $\alpha = 1.1$, $k = 2$s, $m = 65$s E-mail writing time: Pareto distribution: $\alpha = 1.1$, $k = 2$s, $m = 125$s Size of e-mail received/sent without attachment: Cauchy distribution $f_x = \frac{A}{\pi((x-\mu)^2+1)}$, $\mu = 22.7$Kbytes, A is selected to satisfy 90%-tile=80Kbytes Size of e-mail received/sent with attachment: Cauchy distribution: $\mu = 227$Kbytes, 90%-tile=800Kbytes Ratio of e-mail with attachment: Deterministic: 80% without attachment, 20% with attachment

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/COMST.2020.2971781, IEEE Communications Surveys & Tutorials

Table X: In-home M2M devices traffic parameters

Device	Transaction rate	Transaction size (bytes)	Devices per home	Distribution
Home security system	1 per 10 min	20	1	Poisson
Elderly sensor devices	1 per min	128	0.1	Poisson/uniform
Refrigerator	1 per hour	30	1	Poisson/uniform
Clothes washer	1 per day	8	1	Poisson/uniform
Clothes dryer	1 per day	8	1	Poisson/uniform
Dishwasher	1 per day	8	1	Poisson/uniform
Freezer	1 per day	30	1	Poisson/uniform
Stove/oven	1 per day	8	1	Poisson/uniform
Microwave	1 per day	8	1	Poisson/uniform
Coffee maker	1 per day	8	1	Poisson/uniform
Toaster oven	1 per day	8	1	Poisson/uniform
Plug in electric vehicles in smart grids	1 per 1.15 hours	97.6	2	Poisson/uniform
Smart meter	1 per 2.5 hours	2017	3	Poisson/uniform

Table XI: Average home numbers in a cell

Scenario	Max cell radius (m)	Min cell radius (m)	max no. homes within cell	min no. homes within cell
Urban (New York city)	1000	500	12077	3021
Suburban (Washington D.C.)	1500	1000	10456	4647

Table XII: City commercial M2M devices traffic parameters

Device	Transaction rate	Transaction size (bytes)	Distribution
Credit machine in grocery	1 per 2 minutes	24	Poisson
Credit machine in shop	1 per half an hour	24	Poisson
Roadway signs	1 per half a minute	1	Uniform
Traffic lights	1 per minute	1	Uniform
Traffic sensors	1 per minute	1	Poisson
Movie rental machines	1 per day	152	Poisson

Table XIII: City commercial facilities deployment

Scenario	grocery stores /m^2	shops and restaurants /m^2	roadway signs /m^2	traffic lights /m^2	traffic sensors /m^2	movie rental machines /m^2
Urban (New York city)	2.09e-4	0.0022	3.16e-4	1.50e-5	1.50e-5	6.98e-5
Suburban (Washington D.C.)	2.31e-5	3.49e-4	9.43e-4	1.14e-4	1.14e-4	1.15e-5

Table XIV: Summary of WiMAX traffic models

Parameter	Statistical characterization
Internet game, e.g. Quake II (see Xbox Halo2 and Toon Town in [94])	
Session duration (hours)	Extreme distribution ($F(x) = 1 - e^{-e^{(x-a)/b}}$, $a = 1$, $b = 0.1$), truncated (0,2)
Client to server packet IAT (msec)	Lower 4.5%, $x < 18$: Extreme ($a = 6.57$, $b = 0.517$); Upper 95.5%, $x >= 18$: Extreme (a=37.9, b=7.22)
Client to server packet sizes (bytes)	Around 45 (see [94] for more details)
Server to client packet IAT (msec)	Lower 4.8%, $x < 60$: Extreme ($a = 58.2$, $b = 7.47$); Upper 95.2%, $x >= 60$: Normal ($a = 100$, $b = 17.7$)
Server to client packet sizes (bytes)	Lower 27.6%, $x < 55$: Extreme ($a = 46.7$, $b = 4.39$); Upper 72.4%, $x >= 55$: Extreme ($a = 79.7$, $b = 11.3$)
VoIP	
Average call holding time	Exponential: $\mu = 210$ sec
Voice codec	AMR (12.2kbps)
Frame length	20 msec
Talk spurt length	Exponential: $\mu = 1026$ ms
Silence length	Exponential: $\mu = 1171$ ms
Silence suppression	Yes
Protocols	RTP/UDP/IP, with header compression
Speech activity	47.17%
UL:DL ratio	1:1
Total MAC PDU size during a talk spurt	MAC header (6 bytes) + compressed RTP/UDP/IP header (3 bytes) + voice packet (33 bytes) = 42 bytes
Total MAC PDU size during a silence	MAC header (6 bytes) + compressed RTP/UDP/IP header (3 bytes) + voice packet (7 bytes) = 16 bytes
Average bandwidth usage at MAC layer	9.25 kbps (w/o HARQ), 9.71 kbps (w/ HARQ CRC 2 bytes)
Video conference, e.g. H.264 with 320x240 pixels and 8-bit color depth	
Session duration	3600 sec
Protocols	RTP/UDP/IP, with header compression
Scene length	Lognormal ($\mu = 5.1$ sec, $\sigma = 9.05$ sec)
Direction	Bidirectional (UL and DL)
Group of Pictures	N=12, M=2
Subsampling method	4:1:1
Mean bandwidth for uncompressed stream	23 Mbps
Compressed ratio	13.95
I frame size	Lognormal ($\mu = 18793$, $\sigma = 5441$)
P frame size	Lognormal ($\mu = 8552$, $\sigma = 3422$)
B frame size	Lognormal ($\mu = 6048$, $\sigma = 2168$)
AR coefficient	$a_1 = 0.39$, $a_2 = 0.15$, $\sigma_\epsilon = 4.36$
Push to talk (PPT)	
Call type mix	90% one-to-one, 10% group talk (avg. 5 persons/group)
Voice codec	AMR (12.2kbps)
Speech activity	40%
Protocols	SIP/RTP/UDP/IP, with header compression, 10 voice frames (100 msec) per RTP packet
Inactivity timer expire	15 sec
No. transactions	Avg. 2.5 talk + 2.5 listens for one-to-one, avg. 1 talk + 4 listens for group
Talk burst duration	Exponential ($\mu = 6$ sec)
Each volley latency	2.75 sec
Instant messaging (IM)	
Considerations	Only IM background traffic is consider due to the very low user-generated events
Presence update or status check	Exchange 4 packets between client and server every 40 seconds (see Fig. 3.9.2 in [94])
Music / speech	
Session duration	1800 sec
Bit rate	128 kbps
Protocols	TCP
Direction	DL only
Frames/sec	10 frames/sec

Table XIV: Summary of WiMAX traffic models (cont.)

Parameter	Statistical characterization
Video clip	
Video characteristics	H.264 with 320x240 pixels with 8 bit color depth and 25 fps
Length	Truncated exponential ($\mu = 15$ sec, max = 60 sec)
Protocols	TCP
Direction	Unidirectional (UL or DL)
Subsampling method	4:1:1
Mean uncompressed frame size	115 Kbytes
Compression ratio	13.95
Movie streaming	
Video characteristics	Similar to video conference, with the following differences
Direction	DL only
Compression ratio	13.22
I frame size	Lognormal ($\mu = 17068$, $\sigma = 7965$)
P frame size	Lognormal ($\mu = 9190$, $\sigma = 7005$)
B frame size	Lognormal ($\mu = 6839$, $\sigma = 5323$)
MBS	
Video characteristics	Similar to video conference, with the following differences
Direction	DL only
Compression ratio	6.87
I frame size	Lognormal ($\mu = 59025$, $\sigma = 6697$)
P frame size	Lognormal ($\mu = 29933$, $\sigma = 6990$)
B frame size	Lognormal ($\mu = 19658$, $\sigma = 5737$)
Web browsing	
Considerations	Two models are included: the first one with the below parameters, and the second one from 3GPP (see Table V)
No. pages per session	Lognormal (mean=17 pages, std=22 pages)
Page request size	Constant (350 bytes)
Main object size (S_M)	Truncated lognormal (mean=52390 bytes, std=49591 bytes, min=1290 bytes, max=0.25 Mbytes)
Embedded object size (S_E)	Truncated lognormal (mean=8551 bytes, std=59232 bytes, min=5 bytes, max=6 Mbytes)
No. embedded objects per page (N_d)	Truncated Pareto (mean=51.1, max=165)
Reading time (D_{pc})	Exponential (mean=30 sec)
Parsing time (T_p)	Exponential (mean=0.13 sec)
E-mail (POP3, MAPI)	
Considerations	Similar to the model from IEEE 802.16m (see Table IX)
No. e-mail received	Lognormal (mean=30, std=17)
No. e-mail sent	Lognormal (mean=14, std=12)
Reading time	Pareto (mean=60 sec)
Writing time	Pareto (mean=120 sec)
Avg. e-mail header size	Constant (1 Kbyte)
E-mail size	Cauchy distribution (mean=22.7 Kbytes, std=200.3 Kbytes, 90%-tile=80 Kbytes)
Telemetry	
Message frequency	One every hour
Message size	10 bytes
FTP	
Considerations	From 3GPP (see Table V)
P2P (file sharing)	
Session duration	1800 sec
Average DL bit rate	500 kbps
Direction	DL only
Protocol	TCP (FTP for the application layer)
VPN	
Considerations	A brief analysis about VPN traffic using IPSec is included, but it is recommended that the traffic model should utilize traffic measurements from the real target network.
Near real-time video (NRTV)	
Considerations	From 3GPP (see Table V)

opportunities, market intelligence and networking events. With support from hundreds of members, TIA enhances the business environment for companies involved in telecommunications, broadband, mobile wireless, information technology, networks, cable, satellite, unified communications, emergency communications and the greening of technology. TIA is accredited by ANSI.

Committee TR-45 was registered as an independent evaluation group for candidate radio interface technologies for the terrestrial components of the radio interface(s) for IMT-Advanced. The evaluation methodology is based on relevant ITU-R documentation (e.g. ITU-R M.2135 [32]). [96] presents the results for such evaluation. The system-level simulation assumptions used full-buffer data traffic to evaluate cell and cell-edge user spectral efficiency, and VoIP traffic (12.2 kbps codec with a 50% activity factor, with the same parameters as 3GPP, see Table V) to evaluate the VoIP capacity. No other traffic models were assumed for the evaluation of IMT-Advanced.

F. 5G PPP

The 5G Infrastructure Public Private Partnership [97] has been initiated by the EU Commission and industry manufacturers, telecommunications operators, service providers, SMEs and researchers. In the 5G PPP, the 5G Infrastructure Association (5G IA) represents the private side and the European Commission the public side. The 5G IA is committed to the advancement of 5G in Europe and to build global consensus on 5G. To this aim, the Association and its Members carry out a wide-range of activities in key strategic areas including standardization, frequency spectrum, R&D, cooperation with other strategic industry sectors.

White paper [98] provides an overview of use cases and performance evaluation models that were developed for an early evaluation of different 5G radio access network concepts. It includes the following use case families, which have different type of requirements:

- Dense urban
- Broadband (50+Mbps) everywhere
- Connected vehicles
- Future smart offices
- Low bandwidth IoT (Internet of Things)
- Tactile internet/automation

These use case families are mapped onto the following vertical industries business cases:

- Automotive
- e-Health
- Energy
- Media & entertainment
- Factories of the future

Section 4 of [98] includes the performance evaluation models proposed for simulations, including the models and use cases from METIS-II [99], FANTASTIC-5G [100], mm-MAGIC [101], SPEED-5G [102] and 3GPP [47]. Network deployments include *synthetic scenarios* for indoor hotspot, urban macro, outdoor small cells, and rural macro, as well as *realistic scenarios* for indoor office, Madrid Grid, Future

Home Environment, and Extended Suburban HetNet, which are mapped to specific use cases of the aforementioned projects. More details can be found in [98]. Table XV summarizes the traffic models included in [98], which will be discussed in this section, for the main use cases treated by 5G PPP: indoor, dense urban, broadband access everywhere, high speed, mMTC, vehicular safety and broadcast and moving hot spots.

Following subsections summarize the test environments and traffic models extracted from the major 5G PPP projects.

1) METIS: METIS [103], Mobile and wireless communications Enablers for Twenty-twenty (2020) Information Society, was an Integrated Project co-funded by the European Commission under the Seventh Framework Programme for research and development (FP7). The consortium was composed of 29 partners coordinated by Ericsson, including manufactures, network telecommunications operators, academic institutions, automotive industry and a research centre. The project started at November 2012 and finished at April 2015, and aimed at providing a foundation for a future mobile and wireless communications system for 2020 and beyond, paving the way for future standardization.

METIS proposes a 5G system [104] that integrates the following services:

- Evolved mobile broadband (eMBB)
- Massive Machine Communications (MCC)
- Vehicle to Vehicle, Device and Infrastructure (V2X)
- Ultra-Reliable Communications (URC)

METIS-II [99] built on the METIS project and aimed at providing the 5G collaboration framework within 5G PPP for a common evaluation of 5G radio access network concepts and preparing concerted action towards regulatory and SDOs. Started at July 2015 and with a duration of 24 months, METIS-II comprised partners from all regions with strong 5G R&D initiatives, including major international vendors, major operators, and key researchers. METIS-II also built on the previous 5G system concept, now considering three generic services (extreme mobile broadband, massive machine-type communication, and ultra-reliable machine-type communication), and four main enablers (a lean system control plane, a dynamic ran, localized contents and traffic flows, and a spectrum toolbox) [13].

The METIS project proposes 5 scenarios [107] [108] based on five challenges, namely "*amazingly fast*", "*great service in a crowd*", "*ubiquitous things communicating*", "*best experience follows you*" and "*super real-time and reliable connections*". Additionally, it further defines 12 test cases (TC1 - TC12) which contain challenges from one or more scenarios. The aim of the test cases is to describe different problems, including their requirements and the end-user expectations.

These test cases are further described in [105] and summarized in Table XVI, including the environment, network deployment, system load, traffic patterns and requirements for each use case. TCs include virtual reality office, dense cities, shopping malls, stadiums, traffic jams, open air festivals, emergency communications, massive deployment of sensors, traffic safety, etcetera. For the sake of readability, only requirements related to traffic volume, user data rate and latency are

Table XV: Summary of traffic models for 5G PPP performance evaluation

Use case	Traffic model
Indoor environment	**METIS-II** Virtual reality office: Full buffer, bursty traffic FTP model 3 (file size = 3.5 MB, varying IAT (*InterArrival Time*)
	SPEED-5G Future home environment: Full buffer, 20 Mb packet generated according to a Poisson process with mean IAT = 20ms, UL/DL/D2D/no tx probability = 50/50/0/0 or 40/40/10/10
Dense urban	**METIS-II** Dense urban: Full buffer, bursty traffic FTP model 3 (file size 3.5 MB, varying IAT)
	mmMAGIC Cloud services: Full buffer and finite buffer
	mmMAGIC Media on demand: Full buffer
Broadband access everywhere	**FANTASTIC-5G** 50 Mbps everywhere: Mix of Bursty User-Driven (BUD) traffic, video traffic (VT), Bursty Application-Driven (BAD) traffic and RTAD (real-time video application driven) (from METIS [105])
	METIS-II Broadband access everywhere: Full buffer, bursty traffic FTP model 3 (file size 3.5 MB, varying IAT)
High speed	**FANTASTIC-5G** High speed train: Mix of V2I (Vehicle-to-Infrastructure, UL), I2V (Infrastructure-to-Vehicle, DL), and V2V (Vehicle-to-Vehicle) traffic - V2I traffic is mapped with BUD traffic [105] - V2V traffic: messages of 1.6 KBytes - I2V: mix of BUD, VT, BAD and RTAD as defined for "50 Mbps everywhere"
mMTC	**FANTASTIC-5G** Sensor networks: Constant packet generation intervals (uplink) [57]
	METIS-II Massive distribution of sensors and actuators: Bursty traffic FTP model 3, file size 125 bytes, IAT down to 1 s
	3GPP Massive connection: Non-full buffer with small packets
Vehicular safety	**METIS-II** Connected cars: Bursty traffic [106]
	3GPP Highway scenario: 50 messages/sec
	3GPP Urban grid: [TBD]/50/15 messages/sec at the speed of 120/60/10 km/h
Broadcast and moving hot spot	**FANTASTIC-5G** Broadcast-like services: Mix of V2I and V2V traffic (as in high speed use cases)
	mmMAGIC Moving hot spots: Constant packet generation intervals (uplink) [57]

included [107]. Propagation and mobility models are included in [105]. Traffic generation models for the proposed traffic mixes are outlined in Table XVII. As shown, these models are rather simplistic since they are based on the well-known 3GPP FTP model 2, CBR (Constant Bit Rate) sources or VBR (Variable Bit Rate) sources with uniform packet size. Moreover, the reading time (e.g. for BUD and BAD traffic) is derived from traffic volume which is clearly a non-realistic assumption if user-level granularity is desired.

2) FANTASTIC-5G: FANTASTIC-5G [100] is the 5G-PPP project on 5G air interface below 6 GHz, aiming at concurrently supporting a wide range of use cases with a single modular air interface. For the development and evaluation of the proposed air interface, the following services have been considered [109]: mobile broadband, massive machine communications, mission critical communications, broadcast/multicast services, and vehicular communications.

Deliverable D2.1 [110] provides the guidelines for the system level simulations within this project. Seven use cases are

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Table XVI: Summary of METIS test cases

Test case	Description	Scenario	User Requirements	System requirements	Traffic patterns
TC1 *Virtual reality office*	An office with rooms, cubicle offices and tables	*Environment*: realistic office (10x20 m^2) environmental model *Deployment*: one main base station ceiling-mounted	*Data rate*: 1Gbps (UL and DL) with 95% availability, 5Gbps with 20% availability, 0.5Gbps in busy period *Latency*: 10ms (MAC RTT)	*Connections*: 0.1UEs/m^2 *Traffic*: average 100Mbps/m^2, peaks 500Mbps/m^2 DL and UL	FTP-based model with varying *reading time*
TC2 *Dense urban information society*	Future urban setting with high traffic volumes and high experienced data rates	*Environment*: Madrid grid (an area of 387mx552m) *Deployment*: one single three-sector macro station with 12 micro/pico cells	*Data rate*: 300(60)Mbps DL(UL) with 95% availability, 5(1)Mbps DL(UL) in busy period *Latency*: <0.5s for web and video starting (E2E), <2-5ms for augmented reality (E2E), certain D2D discovery and setup time requirements	*Connections*: max 0.2UEs/m^2, 75% of users are located indoor and 25% outdoor *Traffic*: 700Gpbs/km^2 (DL+UL), 500Gbyte/month/subscriber (DL+UL)	40% BUD traffic (6% UL, 34%DL), 40% Non Real-Time Video Traffic (NRT VT) (6% UL, 34% DL), 7.5% BAD traffic (1.5% UL, 6% DL), 7.5% Real-Time Video Traffic (RT VT) (1.5% UL, 6% DL), traffic generated by sensors 5%
TC3 *Shopping Mall*	Setting with a high density of customers and staff with high traffic volumes, high experienced data rates and good availability	*Environment*: 300m x 200m mall area with stores and passage ways *Deployment*: pico and femto cells placed regularly along the passage way	*Data rate*: 300(60)Mbps DL(UL) under below availability, 20Mbps (DL and UL) for continuous traffic, 1.7(0.7)Mbps DL(UL) in busy period *Latency*: user plane RTT <5ms, control plane for sensor network attach <5ms	*Connections*: 0.1UEs/m^2 and 0.7 sensors/m^2 *Traffic*: 170(67)Gbps/km^2 DL(UL), 1.07Gbps/subscriber (DL+UL) in busy period	FTP-traffic model (20MB for regular users and 8KB for sensors)
TC4 *Stadium*	A mass event with a very high probability of correlated demand for data transfer	*Environment*: stadium with ellipse shape with 105m x 150m of radii, covered with a deck of height 33m *Deployment*: 27 small cells deployed on the roof	*Data rate*: 0.3-20Mbps DL+UL, 0.3-3Mbps DL+UL in busy period *Latency*: RTT <5ms	*Connections*: 50 000 active users *Traffic*: two cases (both with 9Gbytes/h/user, 0.1-10Mbps/m^2): a) DL heavy traffic + UL + optional D2D traffic (ratio 7:1:1), with transfers of 50Mbytes files every 20s; b) UL heavy traffic + DL + optional D2D traffic (ratio 1:7:1), with transfers of 75Mbytes (37.5MBytes for D2D traffic) files every 30s	Video upload; mixture of video traffic and BUD traffic
TC5 *Tele-protection in smart grid network*	Smart grid network with low latency and high reliability requirements	*Environment*: 3GPP or TC2 models *Deployment*: 200, 15 and 1 substation per km^2 in dense urban, urban and rural environments, respectively	*Data rate*: 0.15-1.5Mbps *Latency*: 8ms one trip time for event triggered message	*Connections*: 1-1000 per km^2 No specific requirement for traffic volume	Small net payloads (from 200 to 1521 bytes)
TC6 *Traffic jam*	In-vehicle users that utilize bandwidth-demand services during traffic jam situations	*Environment*: Madrid grid model (TC2) or other Manhattan grid models for urban scenarios, a single road for motorways scenarios *Deployment*: base stations placed regularly along the road (2-sector BSs with ISD of 25 km for motorways)	*Data rate*: 100(20)Mbps DL(UL) with 95% availability *Latency*: <100ms (E2E)	*Connections*: 4000 per km^2, max 0.2/m^2 on the lane in traffic jam *Traffic*: 480Gbps/km^2 DL+UL (1000 vehicles per km^2, with a maximum of 4 active users per vehicle)	Traffic model defined for TC2 for in-vehicle users

Table XVI: Summary of METIS test cases (cont.)

Test case	Description	Scenario	User requirements	System requirements	Traffic patterns
TC7 *Blind spots*	E.g. rural areas with sparse network architecture or deeply shadowed urban areas	*Environment*: blind spots such as rural areas or deeply shadowed urban areas *Deployment*: vehicles equipped with relays which can be integrated into the infrastructure of the operators (Madrid grid)	*Data rate*: 100(20)Mbps DL(UL) with 95% availability in blind spots *Latency*: <100ms	*Connections*: 100-1000 per km^2 *Traffic*: 12-120Gbps/km^2 DL and UL (rural-urban)	Same as TC2
TC8 *Real-time remote computing for mobile terminals*	Access to remote computing and cloud facilities (high data rates and low latency for terminals with mobility)	*Environment*: same as TC2 *Deployment*: same as TC2	*Data rate*: 100(20)Mbps DL(UL) *Latency*: <10ms (E2E)	*Connections*: up to 5 active devices per car, 100 cars/km^2, 50 per bus, 300 per train *Traffic*: 60Gbps/km^2	Same as TC2
TC9 *Open air festival*	Small rural area during a few days with lots of visitors	*Environment*: small rural area of 1km x 1km *Deployment*: possible deployments: 5, 9 or 25 base stations	*Data rate*: 30Mbps (DL or UL), 9Mbps (DL/UL) in busy period *Latency*: <1s for machine traffic, 10-50ms for user traffic, <10min for delay tolerant traffic	*Connections*: 0.1 per m^2, max 4 per m^2 *Traffic*: 900Gbps/km^2 (DL+UL), 3.6Gbyte/subscriber DL+UL in busy period	Real time traffic (from TC2), delay-tolerant traffic (from TC2) and device communications (100KB transmitted every 10 minutes for each sensor)
TC10 *Emergency communications*	After a natural disaster in dense urban environment	*Environment*: same as TC2 but after a natural disaster (no 3D buildings) *Deployment*: macro cells with an inter site distance (ISD) of 5km	No requirements regarding user data rate or latency	*Connections*: 10 UEs/km^2 with 10 voice calls and 10 SMS during a week	Voice traffic from survivors and voice traffic between first responders (rescue teams)
TC11 *Massive deployment of sensors and actuators*	Large number of devices which transmit data occasionally	*Environment*: 3GPP or TC2 models, 300 000 devices per macro cell area (3GPP) or per Madrid grid area (TC2) *Deployment*: 3GPP or TC2 models	No requirements regarding user data rate (1kbps) or latency	*Connections*: 3×10^5 per cell *Traffic*: up to 300Mbps per cell	125 bytes transmitted every 5 minutes
TC12 *Traffic efficiency and safety*	Automotive safety services with reliability, availability and latency requirements	*Environment*: any road environment, whether this is urban, rural or highway *Deployment*: all vehicles equipped with the METIS system and some road infrastructure equipped with communication modules	*Data rate*: 100kbps *Latency*: <5ms	*Connections*: up to 1000, 100 and 100 users/km^2 for urban, rural or highway environments, respectively *Traffic*: 0.01-0.1Gbps/km^2	Periodic and event-driven broadcast traffic (1600 bytes with repetition rate from 5 to 10Hz from local environment perception and 500 bytes for communication between vehicles)

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/COMST.2020.2971781, IEEE Communications Surveys & Tutorials

considered, which are summarized in Table XVIII: 50 Mbps everywhere, high speed train, sensor networks, tactile internet, automatic traffic control/driving, broadcast like services and dense urban society. Most of these scenarios employ macrocell deployments except tactile internet and dense urban society, which also use small cells.

3) mmMAGIC: Co-funded by the European Commission's 5G PPP program, the mmMAGIC project is focused on the research and development of novel radio access technologies at the millimeter-wave frequency bands (from 6 to 100 GHz). mmMAGIC [111] [112] presents the initial concepts envisioned for 5G mm-wave architecture, discussing some crucial aspects including use cases, deployments and requirements.

Test scenarios are grouped into outdoor, outdoor-to-indoor, and indoor. These scenarios have been derived from other projects like WINNER-I/II, METIS, and 3GPP recommendations. Outdoor scenarios include Madrid grid, Manhattan grid, Asian city grid and simplified Madrid grid. Indoor scenarios include virtual reality office, shopping mall, and stadium. For mixed indoor/outdoor scenarios, the dual-stripe scenario from 3GPP is proposed. [111] provides more details about these scenarios.

In mmMAGIC, few details are given about the traffic models for evaluating the different use cases. [111] only specifies that full buffer as well as finite buffer traffic models will be investigated for both *50+ Mbps everywhere* and *Cloud services* use cases.

4) SPEED-5G: The Speed-5G project [102] aims to achieve a better exploitation of heterogeneous wireless technologies, supporting ultra-densification and the new QoE 5G requirements.

Deliverable D3.2 [113] contains a detailed description of the use cases for this project. The main scenarios investigated in SPEED-5G refer to indoor and indoor/outdoor scenarios where capacity demands are the highest: *Massive IoT communications* (mIoT), *enhanced Mobile Broadband* (eMBB), Ultra-Reliable Communications (URC), and High-Speed Mobility.

According to [114], the main sources of scenarios for 5G system level simulations in this project are 3GPP, NGMN and METIS. No new traffic models are defined in the deliverable documents of this project, since only 3GPP FTP traffic model 2, VoIP, and H264 video traffic (using real traces) are used [115].

5) 5G-NORMA: This project [116] aims to develop a conceptually novel, adaptive and future-proof 5G mobile network architecture. For that purpose, it relies on NFV (*Network Functions Virtualization*) and SDN (*Software Defined Networking*) paradigms, as well as the usage of network slicing [117].

Deliverable 2.1 [118] includes the following use cases, which has been built on those developed by NGMN, METIS and 3GPP: industry control, enhanced mobile broadband, emergency communications, vehicle communications, sensor networks monitoring, traffic jam, real-time remote computing, massive nomadic mobile machine type communications, quality-aware communications, fixed-mobile convergence, blind spots, and open air festival.

The requirements from these use cases can be grouped around three main axes: very low latency and reliability for critical machine type communications; high throughput for massive broadband communications and the ability to support high volumes of devices for massive machine type of communications.

Table XVII: Summary of METIS traffic models [105]

Traffic type	Burst size / Packet size	Reading time / Inter packet delay
Based on 3GPP FTP Model 2 [53]		
Bursty User-Driven (BUD) traffic	20 Mbytes	Derived from traffic volume
Non Real-Time Video Traffic (NRT VT)	Derived from target coding rate (e.g. 50Mbps)	1s
Bursty Application-Driven (BAD) traffic	2 Mbytes	Derived from traffic volume
Real time streaming		
Real-Time Video Traffic (RT VT)	Uniformly distributed between 3 and 6 kbytes	36ms
Moving networks		
Vehicle to Infrastructure (V2I) traffic	20 Mbytes	Derived from traffic volume
Vehicle to Vehicle (V2V) traffic	1.6 kbytes	100ms
Massive Machine Communication (MMC)		
BAD RT streaming 1 Mbps	125 kbytes	1s
BAD NRT	2 Mbytes	Derived from traffic volume
BAD NRT for TC11	125 bytes	300s
Direct D2D communication		
BUD traffic	20 Mbytes	Derived from traffic volume
VoIP WB AMR	69 bytes	20ms

To validate the proposed architectural solutions, 5G NORMA defines two scenario frameworks comprising the previous use cases:

- Multi-service scenario framework: focused on multi-service and context-aware adaptation of network functions. It comprises the following use cases: enhanced mobile broadband, vehicle communications, emergency communications, traffic jams, real-time remote computing, quality-aware communications, blind spots, and open air festival.
- Multi-tenant scenario framework: based on the idea of sharing the same infrastructure among different tenants (participant operators, vertical market players, etc.), transparent to end users. It comprises the following use cases: industry control, vehicular communications, sensor network monitoring, traffic jam, and open air festival.

Table XIX presents the performance requirements for the aforementioned use cases according to 5G-NORMA. We refer the reader to [118] for more information about these use cases, such as a complete description, functional requirements and relevant KPIs.

In this case, no details are given about traffic models, although deliverable D2.3 [120] includes data volumes for some of the aforementioned use cases.

G. NGMN

The NGMN Alliance (Next Generation Mobile Network Alliance) is an open forum composed of mobile network

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Table XVIII: Summary of FANTASTIC-5G use cases

Use case	Scenario	Traffic pattern
50 Mbps everywhere	19 macro base stations with ISD of 250m (suburban) or 500m (rural) in a hexagonal grid [51]; 400 users/km^2 (suburban) or 100 users/km^2 (rural), 80% UEs indoor, 20% UEs outdoor	Infinite buffer or 3GPP FTP Model 2 [54]
High speed train	Hexagonal grid with macro BTSs (ISD 1732m) in the corner of the cell [51]; 2000 users/km^2 (in a straight line)	Mix of V2I (UL) and I2V (DL). I2V modeled as 3GPP FTP Model 2 [54] and V2I modeled as CBR sources [105].
Sensor networks	Macro cells (hexagonal grid with BTSs in the corner of the cell [51]), Small cells with random deployment [119]; thousands of households (13 devices/household) [57] and 500 cars/km^2 (6 devices/car)	"Regular reporting" and "triggered reporting" from [57], generation throughout time based on Model 1 (uniform distribution) and Model 2 (beta distribution) from [56].
Tactile Internet	Hexagonal grid with BTSs in the corner of the cell [51]. Macro cells for urban (ISD 500m) or suburban (ISD 1732m), small cells for urban (ISD 50m); up to 20,000 users/km^2	As for use case 1
Automatic traffic control / driving	Macro BTSs with ISD 1732m (suburban) or 4330m (rural); 1000 (rural), 2000 (suburban) or 3000 (urban) devices/km^2	Mix of V2I (BUD traffic [105] and V2V (messages of 190, 300, 800 bytes) [106]
Broadcast like services: local, regional, national	Macro BTSs and user distribution as for use case 1	Real time streaming (17 Mbps for 4K UHDTV using real traces) and non-real time applications ($1/3$ of the rate for use case 1)
Dense urban society below 6 GHz	Macro cells (ISD 500m) and small cells (ISD 50m); up to 2500 users/km^2	As for use case 1

operators (members), vendors/manufacturers (sponsors) and universities or non-industrial research institutes (advisors). Its goal is to ensure that the standards for next-generation mobile networks will meet the requirements of operators and, ultimately, will satisfy end user demand and expectations.

The 5G vision of the NGMN Alliance [121] defines 5G as "*an end-to-end ecosystem to enable a fully mobile and connected society*". 5G will be able to be *available anywhere-anytime*, be *delivered with consistent experience*, be *accessible on multiple devices / interfaces*, *support multiple interaction types*, be *supported transparently across technologies*, be *delivered in a personalized and contextual fashion*, be *enabled by trusted & reliable communications*, be *highly reliable and resilient network*, and support *responsive and real-time* communications. In that sense, it will provide higher data rates and lower latencies for consumers, providing differentiated capabilities depending on enterprise application needs, and the required flexibility for verticals to operate their own applications in a profitable manner.

For these purposes, NGMN [122] envisions a 5G system architecture comprising three layers: the infrastructure layer (physical resources exposed to higher layers), the business

Table XIX: Performance requirements of 5G-NORMA use cases

Use case	Description	Requirements
Industry control	Industrial process monitoring and control services	Very low latency (less than 1 ms), tens of Mbps per device in dense environment, high reliability (error rates lower than 10^{-9}), seamless connection re-establishment, large user densities, highly accurate position information (from 1 m to 1 cm)
Enhanced Mobile Broadband	User can ubiquitously connect with extremely high data rates	Peak bit rate (indoors and outdoors 10s of Gbps), low latency (e.g. 10s ms), high traffic density (indoors and outdoors of Tbps/km^2), high mobility (e.g. 500 km/h with 10 Mbps and 10 ms)
Emergency communications	Part of the network is destroyed due to a natural disaster (e.g. earthquake, tsunamis, floods, and hurricanes)	Network connectivity re-establishment in less than 60 s. Support more than 1000 simultaneous connections per cell and MHz.
Vehicular communications	Real-time information about road and traffic conditions for traffic safety and driving assistance	Latency for critical messages related to safety lower than 5 ms, high number of active connections (1500-2500 vehicles expected per lane)
Sensor network monitoring	Monitoring a wide area for a particular measured property	100 % geographic coverage, support unsolicited information from sensor devices, highly reliable communication and prioritization (but not stringent latency restrictions)
Traffic jam	Public cloud services (e.g. video, web browsing, file downloading) for users inside vehicles during traffic jams	Voice with 21-320 Kbps and < 150 ms, video with 100 Mbps DL and 20 Mbps UL and < 300 ms, public cloud services with 100 Mbps DL and 20 Mbps with < 100 ms, 1000 attach attempts/second
Real-time remote computing	Variety of future applications such as cloud computing, remote gaming, remote device control, tactile internet, etc.	Latencies between 100 and 170 ms for RT voice and video communications, < 10 ms for remote execution of application, augmented reality, virtual office, tactile, and remotely controlled vehicles; 100 Mbps DL and 20 Mbps UL; high speed (350 km/h); availability 99%; reliability 95%
Massive nomadic/ mobile MTC	For sensors or actuators physically mounted on nomadic and mobile objects	Small data payloads (20-125 bytes) with moderate latency requirements ($\sim$1s); high speed (500 Km/h); long battery lifetime (up to 15 years) and low cost; high density (up to 200.000 active sensor connections per km^2
Quality-aware communications	Network reacts to the quality of the services provided to the users (both QoS and QoE)	Support changing conditions (e.g. mobility) and highly scalable to handle a high number of users simultaneously
Fixed-Mobile Convergence (FMC)	Seamless customer experience within the fixed and mobile domains, independently of his access type	Fast and seamless handover between wireless technologies as well as between mobile and fixed access domains
Blind spots	High QoE in blind spots	100 Mbps DL and 20 Mbps UL, latency < 100 ms, availability 95%, reliability 95%
Open Air Festival	Remote and rural area with tens of thousands of a visitors for a multi-day open air music festival	Data rate 30 Mbps per user, < 1 s for machine/devices, delivery of delay tolerant data in less than 10 min with 95% probability, availability for users 95%, availability for sensors 100%

This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/COMST.2020.2971781, IEEE Communications Surveys & Tutorials

Table XX: Summary of NGMN use cases

Family	**Category**	**Use case**	**User requirements**	**System requirements**
Broadband access in dense area	Broadband access in dense area	Pervasive video Operator cloud services Dense urban society	*Data rate*: 300(50)Mbps DL(UL) *E2E latency*: 10ms	*Connections*: 200-2500/km^2 *Traffic*: 750(125)Gbps/km^2 DL(UL)
	Indoor ultra-high broadband access	Smart office	*Data rate*: 1000(500)Mbps DL(UL) *E2E latency*: 10ms	*Connections*: 75 000/km^2 *Traffic*: 15(2)Tbps/km^2 DL(UL)
	Broadband access in a crowd	HD video/photo sharing in stadium/open-air gathering	*Data rate*: 25(50)Mbps DL(UL) *E2E latency*: 10ms	*Connections*: 150 000/km^2 *Traffic*: 3.75(7.5)Tbps/km^2 DL(UL)
Broadband access everywhere	50+ Mbps everywhere	50 Mbps everywhere	*Data rate*: 50(25)Mbps DL(UL) *E2E latency*: 10ms	*Connections*: 400/km^2 in suburban, 100/km^2 in rural *Traffic*: 20(10)Gbps/km^2 DL(UL) in suburban, 5(2.5)Gbps/km^2 DL(UL) in rural
	Ultra low-cost broadband access for low ARPU areas	Ultra-low cost networks	*Data rate*: 10(10)Mbps DL(UL) *E2E latency*: 50ms	*Connections*: 16/km^2 *Traffic*: 16Mbps/km^2
High user mobility	Mobile broadband in vehicles	High speed train Moving hot spots Remote computing	*Data rate*: 50(25)Mbps DL(UL) *E2E latency*: 10ms	*Connections*: 2000/km^2 *Traffic*: 25(12.5)Gbps/train DL(UL), 50(25)Mbps/car DL(UL)
	Airplanes connectivity	3D connectivity: aircrafts	*Data rate*: 15(7.5)Mbps DL(UL) *E2E latency*: 10ms	*Connections*: 80/plane *Traffic*: 1.2(0.6)Gbps/plane
Massive Internet of Things	Massive low-cost/long-range/low-power MTC	Smart wearables (clothes) Sensor networks	*Data rate*: low (typically 1-100kbps) *E2E latency*: seconds to hours	*Connections*: 200 000/km^2 *Traffic*: not critical
	Broadband MTC	Mobile video surveillance	Same as *Broadband access in dense areas* and *50+Mbps everywhere* categories	
Extreme real time communication	Ultra low latency	Tactile internet	*Data rate*: 50(25)Mbps DL(UL) *E2E latency*: <1ms	*Connections*: not critical *Traffic*: potentially high
Lifeline communication	Resilience and traffic surge	Natural disaster	*Data rate*: 0.1-1Mbps DL and UL *E2E latency*: not critical	*Connections*: 10 000/km^2 *Traffic*: potentially high
Ultra-reliable communication	Ultra-high reliability & ultra low latency	Automatic traffic control/driving Collaborative robots Remote object manipulation - remote surgery	*Data rate*: from 50kbps to 10Mbps (from a few bps to 10Mbps) DL(UL) *E2E latency*: 1ms	*Connections*: not critical *Traffic*: potentially high
	Ultra-high availability and reliability	e-Health: extreme life critical Public safety 3D connectivity: drones	*Data rate*: 10(10)Mbps DL(UL) *E2E latency*: 10ms	*Connections*: not critical *Traffic*: potentially high
Broadcast like services	Broadcast like services	News and information Broadcast like services: local, regional, national	*Data rate*: Up to 200Mbps (modest, e.g. 500kbps) DL(UL) *E2E latency*: <100ms	*Connections*: not relevant *Traffic*: not relevant

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enablement layer (library of all functions in the form of modular building blocks), and the business application layer (specific applications and services of the operator, enterprise, verticals, or other third parties).

NGMN has developed twenty five use cases for 5G [123] (summarized in Table XX), as representative examples, that are grouped into fourteen categories and into eight families. The specified families are: broadband access in dense area, broadband access everywhere, high user mobility, massive Internet of Things, extreme real time communication, lifeline communication, ultra-reliable communication and broadcast like services. For each use case category, the main requirements in terms of user experience and system performance are specified.

No traffic patterns are specified in [123] but only brief descriptions of the expected services, e.g. watch high definition playback video, share live video or post HD photos to social networks in the use case *HD video/photo sharing in stadium/open-air gathering*.

NGMN also describes how to test the performance of individual features (such as massive MIMO, beamforming for eMBB, waveforms, etcetera) in [124]. However, only few and simplistic traffic models were included: Poisson distributed packet arrivals, full buffer, FTP traffic model 3, and FTP traffic model 1.

Similarly, in [125] NGMN describes the testing framework for the NMGN 5G pre-commercial network trials. Five scenarios are considered for eMBB and URLLC, out of the twelve defined in [51] for eMBB, URLLC, mMTC and eV2X (enhanced Vehicle to Everything). Only full buffer or real traffic (e.g. using traffic generators, the iperf tool, or real applications) are considered.

Additionally, NGMN presents in [126] the simulation assumptions and results for their liaison to 5GAA (5G Automotive Association) in order to compare LTE-V2X (also known as C-V2X, Cellular Vehicle to Everything) to DSRC (Dedicated Short Range Communications). The scenarios cover both NLOS and LOS with vehicle speeds from 15 to 250 km/h, with two use cases for urban (with 2 lanes for each direction) and freeway (with 3 lanes for each direction). The traffic model for V2V (vehicle to vehicle) includes periodic and event-triggered traffic cases. For periodic traffic, it is assumed that one application layer message of 300 bytes is followed by four messages of 190 bytes. The first message is randomized among vehicles. For event-triggered traffic, the event arrival follows a Poisson process with an arrival rate to be defined. Once the event is triggered, 6 messages of 800 bytes are generated (separated 100 ms). The link layer overhead is 16 bytes for C-V2X (MAC (10 bytes) / RLC (1 byte) / PDCP (5 bytes)) and 38 bytes for DSRC (MAC (30 bytes) / LLC(8 bytes)).

In the case of 4G, NGMN [89] proposed a complete evaluation methodology for the requirements for IMT-Advanced (LTE and WiMAX), defining a set of common evaluation scenarios. These traffic models match those defined by 3GPP (see Table V).

IV. Discussion

As it is noticed, there are many different use cases depending on the particular objective(s) of the organization or research project. This is legitimate since each technology, scenario, environment, type of device, type of service, etcetera, has its own particularities that must be considered for a realistic and fair performance evaluation.

However, in many cases some general test scenarios could be enough to assess a specific solution. In this sense, we believe that the IMT-2020 test environments presented in Table I could be utilized. These test cases are also found, with minor differences, in the proposals from the organizations and projects analyzed in this survey. Table XXI presents a mapping between these use cases. For example, most of the organizations define test scenarios for indoor isolated environments such as offices and shopping malls, which can be mapped to the ITU's indoor hotspot scenario. Urban environments with high user density and traffic loads are contemplated as well, which can be mapped to the ITU's dense urban case. And similarly for the other cases (rural environment, and mMTC and URLLC services).

Since the objective of the research and proposals for 5G is the fulfillment of IMT-2020 requirements, we propose to utilize the five IMT-2020 test environments (indoor hotspot-eMBB, dense urban-eMBB, rural-eMBB, urban macro-mMTC, and urban macro-URLLC) as the general use cases for 5G performance evaluation. Report ITU-R M.2412 [4] defines all the details such as the scenario, power values, frequency range, base station deployment, mobility, user/device density, traffic load, propagation models, among many others.

However, in these test environments invariably the traffic is generated assuming a full buffer model. Since this traffic model is clearly unrealistic, which may impact on the performance evaluation [127], we propose to utilize the traffic mixes shown in Table XXII based on the METIS project. Additionally, due to its importance from the end-user experience point of view, we believe that voice should be included. Although voice only represents 2 % [60] of the total traffic, its performance should be assessed in the general use cases in order to have a complete vision of the end-user's experience.

The METIS traffic models (summarized in Table XVII) have also some drawbacks from end-users perspective, since the time between packets or sessions is derived from the traffic volume. This assumption is not realistic, because the traffic generated by one user should not be affected by the global traffic load. For that reason, we propose here the usage of other traffic models instead of those from METIS. Table XXII presents our proposal. As shown, *dense urban information society* (TC2) is recommended for the dense urban scenario; *blind spots* (TC7) represents the rural environment; *massive deployment of sensors and actuators* (TC11) defines the connection density for the urban macro-mMTC deployments; and *traffic efficiency and safety* (TC12) is employed as the URLLC service. Besides, since METIS TC1 (*virtual reality office*) only includes FTP-based models (like ITU and 3GPP), we propose

Table XXI: Mapping of use cases from different sources to IMT-2020 use cases

IMT-2020	3GPP	5G PPP	METIS	FANTASTIC 5G	5G-NORMA	NGMN
Indoor hotspot-eMBB	Indoor hotspot-eMBB	Future smart offices	TC1 virtual reality office			Smart office
Dense urban-eMBB	Dense urban	Broadband access everywhere	TC2 dense urban information society	50 Mbps everywhere Dense urban society below 6 GHz	Enhanced mobile broadband	Dense urban society 50 Mbps everywhere
Rural-eMBB	Rural		TC7 blind spots		Blind spots	Ultra-low cost networks
Urban macro-mMTC	Urban coverage for massive connection	mMTC	TC11 massive deployment of sensors and actuators	Sensor networks	Massive nomadic/mobile MTC	Sensor networks
Urban macro-URLLC	eMBB deployment scenarios may be reused to evaluate URLLC	Connected vehicles Tactile internet/ automation	TC12 traffic efficiency and safety	Tactile internet Automatic traffic control/driving	Industry control Vehicular communications	3D connectivity: aircrafts Mobile video surveillance Tactile internet Automatic traffic control/ driving Collaborative robots Remote object manipulation: remote surgery e-Health: extreme life critical Public safety 3D connectivity: drones

Table XXII: Proposal for 5G performance evaluation

IMT-2020 use case	Traffic pattern
Indoor hotspot-eMBB	Traffic mix defined for METIS TC2 + 2% of voice traffic, with traffic density from METIS TC1 (0.1 UEs/m^2)
Dense urban-eMBB	Traffic mix defined for METIS TC2 (see Table XVI) + 2% of voice traffic: 39% BUD traffic (6% UL, 34%DL), 39% NRT VT (6% UL, 34% DL), 7.5% BAD traffic (1.5% UL, 6% DL), 7.5% RT VT (1.5% UL, 6% DL), 5% traffic generated by sensors, 2% voice traffic
Rural-eMBB	Traffic mix defined for METIS TC7 (same as TC2, see Table XVI) + 2% of voice traffic
Urban macro-mMTC	Traffic mix defined for METIS TC11: 3×10^5 devices per cell
Urban macro-URLLC	Traffic mix defined for METIS TC12 for urban environment: up to 1000 users/km^2

Table XXIII: Proposed traffic models

Name	Traffic model
BUD traffic	Web traffic model from [132], i.e. web page size with uniform distribution between 60 and 1500 KB
NRT VT	Video encoded with 50 Mbps and 30 fps
BAD traffic	3GPP MTC traffic models 1 and 2 defined in Table VI
RT VT	CBR source with 1.5 Mbps
Voice traffic	EVS-WB with 24.4 kbps, call duration with log-normal distribution and average 202 seconds, VAF = 50 %

to utilize the traffic mix from METIS TC2 but assuming the connection density from TC1.

For realistic performance assessment, we suggest to use the traffic models included in Table XXIII. Starting with the bursty-user driven traffic, we propose to employ the web browsing service. Although we have already analyzed some web browsing models in this paper, they are obsolete (from 2008 or older). Fortunately, the literature that analyzes the traffic patterns produced by this service is abundant, e.g. [128][129][130][131][132]. Due to the detailed analysis performed, we have selected the model from [132]. In this work, the average web page size is defined by a uniform distribution between 60 and 1500 KB.

Following with non-real time video, YouTube recommends to encode videos with 4k resolution for uploading to their platform using 35-45 Mbps for standard frame rate (24, 25, 30 fps) and 53-68 Mbps for high frame rate (48, 50, 60 fps) [133]. These values are in line with those proposed by METIS (50 Mbps, see Table XVII) and NGMN (25(50) Mbps UL(DL), see Table XX). Thus, we recommend an encoding rate of 50 Mbps with a frame rate of 30 fps.

For mMTC we select 3GPP traffic models 1 and 2 defined in Table VI. The first model is suitable for MTC devices accessing the network uniformly over a period of time, i.e. in a non-synchronized manner. The second model is appropriate for an extreme scenario in which a large amount of MTC devices access the network in a highly synchronized manner, e.g. after a power outage.

In the case of real-time video, we choose a CBR source with 1.5 Mbps, which is the Skype recommendation [134] for HD video calling. This data rate is in line with that of METIS, which demands a maximum of 1.37 Mbps (required data rate $= \frac{\text{max. packet size}}{\text{inter packet delay}} = \frac{\text{6Kbytes}}{\text{36ms}} = 1.37\text{Mbps}$, see Table XVII).

For voice traffic, we assume the EVS-WB codec at 24.4 kbps following a Log-normal distributed call duration with an average of 202 seconds (value suitable for residential environments [135]). For the voice activity factor, we select 50 % like 3GPP and many works in the literature.

Finally, we would like to express that the guidelines provided in this survey may be useful for the performance assessment of many solutions, which may be more specific. In this regard, we believe that the scenarios and traffic models (and, in general, the performance evaluation guidelines) from 3GPP and the METIS project are very relevant, detailed and complete. Similarly, the use cases from NMGN are also very interesting, and we hope that they will provide in the future performance evaluation guidelines for 5G similar to those provided for 4G [89].

V. Open research issues

In this section, we identify usage scenarios and services that are foreseen for future mobile communication systems. We consider their definition and the elaboration of the required traffic models as open issues that shall be studied to facilitate further research on these new technologies.

These new applications will demand requirements several orders of magnitude higher than those of 5G. As an example, we include next the speculated requirements for IMT-2030 [136]:

- A peak data rate of at least 1 Tb/s, i.e. 100 times that of 5G.
- A user-experienced data rate of 1 Gb/s, i.e. 10 times that of 5G (up to 10 Gb/s in particular).
- Very low over-the-air latency (10–100 μs) and high mobility ($\geq$ 1,000 km/h for e.g. hyper-high-speed railway and airline systems).
- Connectivity density of up to 10^7 devices/km^2, i.e. ten times that of 5G.
- Area traffic capacity of up to 1 Gb/s/m^2 for scenarios such as hotspots.
- An energy efficiency of 10–100 times and a spectrum efficiency of 5–10 times those of 5G.

Several works [137][138][139][140][141][142][143][136] have already predicted which will be the services supported by next-generation systems that cannot be fully integrated in 5G. Most of the foreseen usage scenarios will evolve from the emerging 5G use cases, which will add further performance enhancements and new applications. Based on the previous works, we classify them into the following categories:

- Further enhanced Mobile BroadBand (FeMBB): the successor of eMBB in 5G, for ubiquitous conventional mobile communications but with much higher requirements. It should be capable of big data transmission and processing, in addition to new functionalities such as accurate indoor positioning and global compatible connections among different mobile network operators.
- Extremely Reliable and Low-Latency Communications (ERLLC): enhancement of URLLC in 5G but with higher requirements, e.g. reliability of 99.9999999%, i.e. 'seven sigma', and a latency lower than 0.1 ms. ERLLC would allow industrial and military communications, e.g. robots, high precision machine tools and conveyor systems, as well as autonomous vehicular communications.
- Ultra-massive Machine-Type Communications (umMTC): improvement of mMTC with up to 10 times higher connectivity density, extending the Internet of Things concept to new paradigms such as the Internet of Nano-Things, the Internet of Bodies or nanonetworks, and expanding others such as smart cities and e-health.
- Long-Distance Communications (LDC): for moving or fixed base stations, achieving long-distance transmissions in futuristic scenarios such as hyper-high-speed railway or intersatellite communications in free space. Additionally, this use case is also intended to provide good services not only to dense areas but to remote areas. In such scenarios, the network coverage should be large enough so as to provide an acceptable service independently on where the subscribers are living or moving to.
- Extremely Low-Power Communications (ELPC): novel IoT scenarios such as nanodevices, nanorobots, nanosensors, or Internet of Bio-Nano-Things will require the design of new air-interfaces for ultra-low-power communications, even allowing nanodevices to operate without batteries thanks to energy harvesting technologies.
- Three-Dimensional Integrated Communications (3DIC): extension of the current 2D approach for network analysis, planning and optimization. By considering the height (3D), novel communication types can be implemented such as satellite, UAV (Unmanned Aerial Vehicle), and underwater communications. New features such as beamforming with full-dimensional MIMO architectures may enable these scenarios.
- Unconventional Data Communications (UCDC): this category is intended to cover those novel communication paradigms that cannot be classified into the previous ones. It may cover holographic, tactile, and human bond communications.

The support of these scenarios will allow the development of novel services. Some of these foreseen applications, which might be somewhat futuristic, are summarized next.

- Extremely High-Definition (EHD) video: thanks to the popularity of over-the-top (OTT) services such as Netflix and YouTube, the demand for video content is increasing exponentially. EHD videos with 16K and 32K formats will become a reality at the same time that the screens of mobile devices and TVs will increase their resolutions. Thus, future wireless networks will have to provide higher bandwidths and lower latencies to cope with these new demands.
- Tactile Internet: this concept, introduced by ITU-T in 2014, enables real-time interactions for services which may vary from medical, education, industrial or entertainment segments. Extremely low-latency, ultra-reliable and secure communications are required.
- Holographic telepresence applications: near-real personal communication or immersive live models with multiple digital avatars from different places are becoming a reality, requiring bandwidths up to terabits per second.
- Haptic communications: this type of communications adds the sense of “touch” to traditional audio-visual communications and will be key for Virtual and Augmented Reality (VAR). Haptic communications may be used for different sectors such as manufacturing, education, healthcare, smart utilities, gaming, etc. Some of these ultra-sensitive applications will require latencies lower than 1 ms and massive real-time data transfers over the air. This will enable the Internet of Skills (IoS), a new paradigm which allows to “store” the skills of

different persons which can be shared with anyone who wants to learn something, e.g. painting, playing a musical instrument, or sports. With the help of tactile globes and other wearable devices, the person can use the stored "skill" as a movement reference.

- Automation and manufacturing: many potential application scenarios are expected for the industry, such as extended reality (XR), massive incorporation of robots into automation, warehouse transportation, etcetera. Low-latency connectivity and accurate indoor positioning are examples of the requirements needed in this area.
- Smart healthcare: a number of solutions for ubiquitous health monitoring have been developed to monitor indicators such as temperature, heart rate, glucose levels, etc. As this information is very sensitive, a high level of security, reliability and availability must be ensured. Other applications such as secure high-definition video conferencing will also be required in order to ensure a seamless experience for remote diagnosis by doctors.
- The Internet of Nano-Things and Bodies: using smart wearable devices, integrated headsets, implantable sensors, etc., this concept will require ultra low-power consumption to support applications from different segments e.g. from military to healthcare.
- Massive IoT integrated smart city: current smart cities can only be fragmentally smart, i.e. considering only some aspects of utilities, healthcare, transportation but separately. Future smart cities are expected to take an integrated approach, which will support massive amounts of data and will require a high level of security.
- Fully autonomous vehicles: the automotive and transportation industries are experiencing a generation change, with standards for vehicle-to-everything (V2X) communications. Nevertheless, the movement of people and goods remains a critical challenge. Autonomous vehicles will require ultra-high reliability, in addition to low latencies and high bandwidth.
- High-quality communication services on board: emerging scenarios such as hyper-high-speed railways or aircrafts will require consistent service experiences, similar to those of conventional mobile environments.
- Underwater and space communications: it is expected that next-generation communication technologies will significantly expand the boundaries of human activity to environments such as deep-sea or outer space.
- Flying networks: providing ubiquitous connectivity to e.g. Unmanned Aerial Vehicles (UAVs) may be challenging for the upcoming wireless networks. In addition to low-latency and high bandwidth requirements, three-dimensional analysis, planning and optimization shall be performed to ensure reliability and availability. Considering the node height will be required to implement elevation beamforming with full-dimensional MIMO architectures, which may be required for the proper network functioning.

As commented, the definition of these use cases, their requirements, specific environments and traffic mixes shall be further investigated and incorporated for the design and performance analysis of future mobile systems.

VI. Conclusions

In this survey, we have presented an overview of the most significant 5G usage scenarios and traffic generation models. These environments and traffic models will allow 5G stakeholders and researchers to evaluate the performance of 5G solutions under the most exigent requirements.

Thanks to the initiatives from many organizations, including standardization development organizations, regional projects, and industry alliances, there is a large number of performance evaluation guidelines for different 5G innovations intended for particular use cases. We have summarized the contributions from the main SDOs (ITU, 3GPP, IEEE, WiMAX Forum, and TIA) and from the main regional projects and industry alliances (5G PPP -including METIS-II, FANTASTIC-5G, mmMAGIC, SPEED-5G, and 5G-NORMA-, and NGMN). We believe that the work from 3GPP, METIS-II and NGMN should be taken as main references.

Finally, we have discussed which general test cases and traffic models should be considered for the performance evaluation of 5G solutions. In this regard, we propose to utilize the five usage scenarios from IMT-2020 recommendations, using traffic patterns from the METIS project but updated with some traffic models from the literature.

As a result, the review presented in this paper provides the guidelines to ease the research (validation and testing) as well as future dimensioning of 5G mobile communications systems and technologies.

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