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Assessment of socio-techno-economic factors affecting the market adoption and evolution of 5G networks: Evidence from the 5G-PPP CHARISMA project

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ABSTRACT

5G networks are rapidly becoming the means to accommodate the complex demands of vertical sectors. The European project CHARISMA is aiming to develop a hierarchical, distributed-intelligence 5G architecture, offering low latency, security, and open access as features intrinsic to its design. Finding its place in such a complex landscape consisting of heterogeneous technologies and devices, requires the designers of the CHARISMA and other similar 5G architectures, as well as other related market actors to take into account the multiple technical, economic and social aspects that will affect the deployment and the rate of adoption of 5G networks by the general public. In this paper, a roadmapping activity identifying the key technological and socio-economic issues is performed, so as to help ensure a smooth transition from the legacy to future 5G networks. Based on the fuzzy Analytical Hierarchy Process (AHP) method, a survey of pairwise comparisons has been conducted within the CHARISMA project by 5G technology and deployment experts, with several critical aspects identified and prioritized. The conclusions drawn are expected to be a valuable tool for decision and policy makers as well as for stakeholders.

1. Introduction

We are currently witnessing a tremendous increase in the use of mobile devices. In the near future, mobile devices are also expected to be connected to a wide range of other devices such as sensors. The number of connected devices is estimated by several industry analysts to rise from 20 billion to 100 billion by 2020.[1] In addition, ever more bandwidth hungry applications and services are constantly being developed. Although these applications can be supported by current mobile

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[1] http://www.businessinsider.com/75-billion-devices-will-be-connected-to-the-internet-by-2020–2013-10; https://www.abiresearch.com/market-research/product/1016390-over-30-billion-wireless-connected-devices/; 'Forecast: The Internet of Things, Worldwide 2013', Gartner, 2013; 'The State of Broadband 2012: Achieving digital inclusion for all', Broadband commission, 2012; 'The Internet of Things: How the next evolution of the Internet is changing everything', Cisco Systems, 2011; 'Towards50 Billion Connected Devices', Ericsson Research, 2010; http://www.itpro.co.uk/626209/web-connected-devices-to-reach-22-billion-by-2020.

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broadband networks, future applications will impose additional stricter requirements that cannot be supported by the current networks. Furthermore, optical wired networks that could be used in order to accommodate the above requirements are characterized by their high deployment costs. Thus, 5G networking seems to be the only means in order to support both high performance and device heterogeneity (First Vision and Societal Challenges WG Brochure, 2015).

5G is a continuously evolving and very broad concept (C.V. Report, 2015) covering many different aspects. On the one hand, there are the quantifiable technical aspects such as: the expected end-user high bandwidths (e.g., 1–10 Gb/s to end-users), low latency (1-ms access times), and the ability to network a very high number of devices in a small geographic location. On the other hand, the more functional features of 5G such as fixed-mobile convergence, device-to-device (D2D) communications, ad-hoc meshing, and Open Access are also justifying the high global interest in 5G research currently occurring. Indeed, each of these various 5G features mentioned here are very large subjects in their own right; with many directions of research into each of these new technologies, new functionalities, and new means to improve efficiencies (e.g., energy efficiency, use of scarce network resources, improved CapEx, OpEx, and Total Cost of Ownership (TCO) profiles).

Changes at the network edge are a specific characteristic of the new 5G architectures, particularly as they absorb the recent advances in cloud computing, software defined networking (SDN) (Haleplidis et al., 2015) and network functions virtualization (NFV) (Liang and Yu, 2015). Softwarization and virtualization of networks, as well as the use of general purpose computers instead of specialized devices, enable the automation of network service provisioning and management, and facilitate the introduction of new network functions into the value chain leading to significant cost reductions, increased flexibility and more efficient use of resources.

5G network infrastructures are also anticipated to a critical asset that will support observed societal transformation, leading to the fourth industrial revolution (Second Vision and Societal Challenges WG Brochure, 2016). It will also impact multiple sectors and enable vertical sectors (Factories of The Future, Automotive, Health, Energy and Media & Entertainment) to enter the value chain and generate revenues. It is expected that 5G networking will offer various social impacts, such as better rural/urban integration, decentralization of work, reduced physical mobility needs, reduced CO_2 emissions, increased security, better and more complete entertainment, better social inclusion, increased wellbeing, enhanced medical support, fewer accidents and enhanced life experience for older people (G.W. Report, 2015). Apart from the social impact, 5G is also expected to significantly contribute towards the EU and Global economy by increasing countries' GDPs and creating hundreds of thousands of new jobs.[2]

All these many facets contribute into creating a very complex landscape with many possibilities for successful innovation and new business opportunities. However, navigating such a futuristic landscape, with so many unknowns and as yet untried and untested technologies, concepts and services, becomes a very risky business venture. In order to mitigate some of the business risks involved in investing in 5G technologies, a better understanding of the many issues surrounding the 5G business context is vital.

The objective of CHARISMA, a Research and Innovation project financed within the 5G Public-Private Partnership (5G-PPP) initiative by the European Commission (Horizon 2020 program), is the development of an open access, converged 5G network, via virtualized slicing of network resources to different service providers (SPs), with network intelligence distributed out towards end-users over a hierarchical architecture. Such an approach offers a means to achieve important 5G key performance indicators (KPIs) related to low latency, high and scalable bandwidths, energy efficiency and virtualized security (v-security). CHARISMA's ambitious approach for low latency and enhanced security builds upon present and future high-capacity developments that are currently being mooted for 5G deployment, such as 60 GHz/E-band, CPRI-over-Ethernet, cloud-RAN, distributed intelligence across the back-, front-and perimetric-haul, ad-hoc mobile device interconnectivity, content delivery networking (CDN), mobile distributed caching (MDC), and improved energy efficiency.

This paper aims to assess and prioritize several crucial technological and socio-economic issues that are expected to influence the deployment and market adoption of the CHARISMA solution in particular and 5G networks in general. This evaluation is carried out through a number of surveys conducted using elements of the Fuzzy Analytical Hierarchy Process (Fuzzy AHP) framework, and more specifically pairwise comparisons. This paper is mainly addressed to a technical audience, but it also aims to motivate the interest of a general audience in the CHARISMA solution and future 5G networks in general. The obtained results will be a valuable tool for policy and decision makers, in order to accelerate the successful deployment of 5G networks and increase their market adoption.

The rest of the paper is organized as follows: In Section 2, the fuzzy AHP methodology is presented. The survey design, along with the derived hierarchy and the defined criteria and sub-criteria are described in Section 3. Section 4 presents the results obtained by the surveys providing a discussion on their impact for 5G networks deployment. Global priorities and policy implications are given in Section 5. Some concluding remarks, limitations and future works are provided in Section 6.

2. Fuzzy AHP method for prioritizing critical factor for 5G adoption

The Analytic Hierarchy Process (AHP) was proposed and developed by Saaty (1977) in the early 1970s mainly for military purposes. AHP can be considered to be a multi-criteria decision making methodology, with AHP extensively used over the

[2] 5G Infrastructure Public Private Partnership (PPP): The next generation of communication networks will be Made in EU, European Commission, Digital agenda for Europe, February 2014.

years to cover various application areas such as education (Bahurmoz, 2003), engineering (Kengpol and O'Brien, 2001), industry (Noci and Toletti, 2000), manufacturing (Albayrakoglu, 1996) and resource allocation (Saaty, 1980). Recently, AHP has also been widely used for selecting and ranking alternatives in the field of Information and Communication Technologies (ICT) (Dede et al., 2011a, 2011b; Nikou et al., 2011; Qingyang and Jamalipour, 2005).

2.1. The Method

Analytic Hierarchy Process is a structured technique for dealing with complex decisions based upon a rational and comprehensive framework for decomposing an unstructured complex problem into a multi-level hierarchy of interrelated criteria, sub-criteria and decision alternatives. By incorporating judgments on qualitative and quantitative criteria, AHP manages to quantify decision makers' preferences. The relative priorities of the criteria, sub-criteria and alternatives are finally reached by a mathematical combination of all these various judgments.

In the first step, the problem to be investigated is framed (i.e., its formation articulated) while the criteria and sub-criteria contributing to achieving the problem objective are determined through interviews and/or group discussions with experts. The multi-level hierarchy is then constructed, consisting of three levels. In the first level, the objective under investigation is shown, which in the context of the work being described in this paper, consists of the factors affecting the adoption and evolution of the CHARISMA architecture and 5G networking in general. In the next level, the criteria, C_{rk} with $k = 1,2,\ldots,N$ and N the total number of criteria affecting the objective are determined. The criteria should be general enough to incorporate several features resulting in a rough description of the objective. In the next level, the criteria are further analyzed into their sub-criteria SCr_{jk}, where $j = 1,2,\ldots,M_k$, and M_k is the number of sub-criteria under criterion k. Sub-criteria represent a specific feature characterizing a criterion. Identification of the criteria and their sub-criteria is accomplished based on the focus of their preferential independence.

Once the hierarchical structure has been constructed and the criteria and sub-criteria determined, appropriate questionnaires are conducted and distributed to experts (step 2) for them to fill in. This procedure is based upon pairwise judgments of the experts from the second to the lowest level of the hierarchy. At each level, the criteria (sub-criteria) are compared pairwisely according to their degree of influence and based upon the specified criteria at the higher level. The described comparisons are performed using the standardized nine levels scale shown in Table 1.

Table 1
The Saaty rating scale.

Intensity of importance	Definition	Explanation
1	Equal importance	The two criteria contribute equally
3	Moderate importance	Experience and judgment favour one of the criteria
5	Strong importance	A criterion is strongly favoured
7	Very strong importance	A criterion is very strong dominant
9	Extreme importance	A criterion is favoured by at least an order of magnitude
2, 4, 6, 8	Intermediate values	Used to compromise between two of the above numbers

However, AHP can be highly subjective and inaccurate, mainly due to its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of a decision-maker's perception to exact numbers. In this case, the Fuzzy Analytic Hierarchy Process (FAHP), an extension/improvement of the AHP methodology has been proposed (Chang, 1996; van Laarhoven and Pedrycz, 1983; Chang and Wang, 2009) as a means to address this uncertainty. Fuzzy numbers are used in order to model the relative importance of criteria and sub-criteria. Let $\tilde{A}$ represent a fuzzified reciprocal $N \times N$-judgment matrix containing all pairwise comparisons between elements i and j for all $i, j \in (1,2,\ldots,N)$.

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \ldots & \tilde{a}_{1N} \\ \tilde{a}_{21} & (1,1,1) & \cdots & \tilde{a}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{N1} & \tilde{a}_{N2} & \ldots & (1,1,1) \end{bmatrix} \tag{1}$$

where $\tilde{a}_{ji} = \tilde{a}_{ji}^{-1}$ and all $\tilde{a}_{ij}$ are fuzzy numbers. The use of fuzzy numbers as answers (vague comparisons), although increasing the processing complexity, provides for more accurate and meaningful results. A fuzzy weight for each criterion and sub-criterion is evaluated, while crisp weights can also be obtained through the defuzzification process.

Fuzzy numbers are a part of the fuzzy sets theory, introduced by Zadeh (1965) as a modeling tool for complex systems under uncertainty. In fuzzy sets, grades of membership in [0, 1] are assigned to objects through a membership function $\mu_A(x)$. As shown in Fig. 1, in the special case of triangular fuzzy numbers, the membership is defined by three real numbers, (l, m, u),

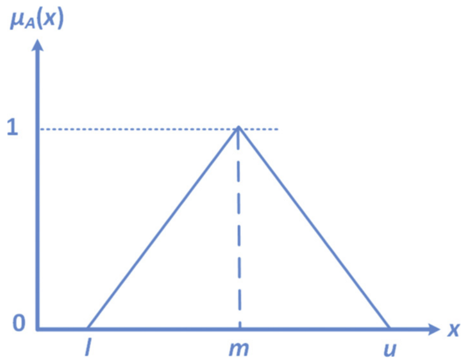

Fig. 1. Triangular fuzzy numbers membership function.

where l is the lower limit, m the most promising and u the upper limit value. In the limit, $l = m = u$, fuzzy numbers become crisp numbers. Eq. (2) describes the membership function of triangular fuzzy numbers.

$$\mu_A(x) = \begin{cases} \frac{x-l}{m-l}, & x \in [l, m] \\ \frac{u-x}{u-m}, & x \in [m, u] \\ 0, & otherwise \end{cases} \tag{2}$$

Assuming that $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are triangular fuzzy numbers, the operations on them can be:

$$Addition: \; M_1 \oplus M_2 = (l_1 + l_2, \; m_1 + m_2, \; u_1 + u_2) \tag{3}$$

$$Multiplication: \; M_1 \otimes M_2 = (l_1 \cdot l_2, \; m_1 \cdot m_2, \; u_1 \cdot u_2) \tag{4}$$

$$Inverse: \; M_1^{-1} = (l_1, m_1, u_1) = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right) \tag{5}$$

In order to evaluate the final weights of the decision elements (criteria and sub-criteria) the popular Fuzzy Extent Analysis, proposed by Chang (1996) is used. The first step towards weights evaluation is to calculate the value of the fuzzy synthetic extent with respect to the ith object using the fuzzy arithmetic operations of Eqs. (3)–(5):

$$\widetilde{S}_i = \underset{j=1}{\overset{N}{m}} \tilde{a}_{ij} \otimes \left[\sum_{i=1}^{N}\sum_{j=1}^{N} \tilde{a}_{ij}\right]^{-1} \tag{6}$$

According to Chang's method, the possibility of $\widetilde{S}_1 \geqslant \widetilde{S}_2$ can be expressed as:

$$V(\widetilde{S}_1 \geqslant \widetilde{S}_2) = \begin{cases} 1, & m_1 \geqslant m_2 \\ 0, & l_2 \geqslant u_1 \\ \frac{l_2 - u_1}{(m_1 - u_1) - (m_2 - l_2)}, & otherwise \end{cases} \tag{7}$$

To compare $\widetilde{S}_1$ and $\widetilde{S}_2$, it is necessary to evaluate both values of $V(\widetilde{S}_1 \geqslant \widetilde{S}_2)$ and $V(\widetilde{S}_2 \geqslant \widetilde{S}_1)$. The possibility for a convex fuzzy number to be greater than k convex fuzzy numbers S_i ($i = 1, 2, \ldots, k$) is defined by:

$$V(\widetilde{S} \geqslant \widetilde{S}_1, \widetilde{S}_2, \ldots, \widetilde{S}_k) = V[(\widetilde{S} \geqslant \widetilde{S}_1) \; and \; (\widetilde{S} \geqslant \widetilde{S}_2) \; and \; \ldots \; and \; (\widetilde{S} \geqslant \widetilde{S}_k)] = \min V(\widetilde{S} \geqslant \widetilde{S}_i), \quad i = 1, 2, \ldots, k \tag{8}$$

Through normalization, one can calculate the non-fuzzy (crisp) weight vector W, given by:

$$W = (\min V(\widetilde{S}_1 \geqslant \widetilde{S}_k), \; \min V(\widetilde{S}_2 \geqslant \widetilde{S}_k), \ldots, \; \min V(\widetilde{S}_N \geqslant \widetilde{S}_k))^T \tag{9}$$

Another approach that can be implemented in order to estimate the final weights is the use of the geometric means method of Buckley (Buckley, 1985; Buckley et al., 2001), where:

$$\tilde{r}_i = \left(\prod_{j=1}^{N} \tilde{a}_{ij}\right)^{\frac{1}{N}} \tag{10}$$

and

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\sum_{i=1}^{N} \tilde{r}_i\right)^{-1}, \quad i = 1, 2, \ldots, N \tag{11}$$

Finally, a simple centroid method can also be used to defuzzify the fuzzy weights $\tilde{w}_i$:

$$w_i = l_i + \frac{(m_i - l_i) + (u_i - l_i)}{3} = \frac{l_i + m_i + u_i}{3}, \quad i = 1, 2, \ldots, N \tag{12}$$

2.2. Consistency of pairwise comparison matrices

In order to assess a certain quality level for the decisions of an expert (i.e., for quality control of the data being gathered) the consistency of the data from each expert should also be investigated during the analysis. It should be noted that the rank of the matrix A (or A_k) equals to 1 and $\lambda_{\max} = N$ (or M_k) if the pairwise comparisons are completely consistent. In this case, weights can be estimated by normalizing any of the columns or rows of A (A_k). A consistency index (CI) was introduced by Saaty in 1977:

$$CI = \frac{\lambda_{\max} - N}{N - 1} \tag{13}$$

where $\lambda_{\max}$ is the largest (maximum) eigenvalue and N is the number of criteria. The final consistency ratio (CR), showing how consistent the judgments have been relative to large samples of purely random judgments, is given by:

$$CR = \frac{CI}{RI} \tag{14}$$

where RI is the random index, calculated as the average CI across a large number of randomly filled matrices using the scale described earlier in this section. The random indices for several values of N were calculated by Saaty and Ozdemir (2003) and are given in Table 2. The consistency ratio should be less than 0.1. A CR larger than the tolerable level of 0.1 demonstrates the need to exclude the pairwise comparison matrix of this expert respondent from further analysis, so as not to affect the overall accuracy of the results.

Table 2
RI values for different values of *n*.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

In the case of fuzzy pairwise comparison matrices, there are authors in the literature who do not verify their consistency at all (Enea and Piazza, 2004; Güngör et al., 2009; Tiryaki and Ahlatcioglu, 2009). Buckley (1985) proposed that $\tilde{A} = [\tilde{a}_{ij}]$ is consistent if and only if:

$$\tilde{a}_{ij} \otimes \tilde{a}_{jk} \backsimeq \tilde{a}_{ik} \tag{15}$$

where $\otimes$ is the fuzzy multiplication symbol. In order to reduce the complexity and without loss of generality, authors usually verify the consistency only for crisp matrices whose elements are the middle significant values of the triangular fuzzy numbers from the corresponding fuzzy pairwise comparison matrix (Pan, 2008; Vahidnia et al., 2009; Tesfamariam and Sadiq, 2006). This approach will also be used in this work in order to assess the consistency of the pairwise comparison matrices. In a similar manner (Gerdsri and Kocaoglu, 2007), the consistency ratio CR is calculated for the crisp matrix $N_{\tilde{A}} = \{n_{ij}\}_{i,j}^{p}$ where:

$$n_{ij} = \frac{a_{ijl} + 4a_{ijm} + a_{iju}}{6}, \quad i,\ j = 1, \ldots, p \tag{16}$$

3. Survey Design, data collection and analysis

In this section, we describe the expert survey carried out within the CHARISMA project as part of our effort to determine the relative importance of the various criteria associated with 5G networks deployment and adoption. Although the survey was conducted among CHARISMA experts and other experts are planned to be included in the next phase, the future results are not expected to be very deviant. Fig. 2 illustrates the derived multi-level hierarchy while along with Table 3 summarize the identified criteria and sub-criteria.

The hierarchy, criteria and sub-criteria were initially drafted by INCITES CONSULTING and were further refined according to feedback from the rest of the CHARISMA partners leading to the design of the final survey. A brief description of criteria and their sub-criteria is shown in Table 3.

Invitations were sent to all partners within the CHARISMA project in order to have a well balanced mix of experts between industry, research institutes and academia from various European countries (France, Germany, Greece, Israel, Lux-

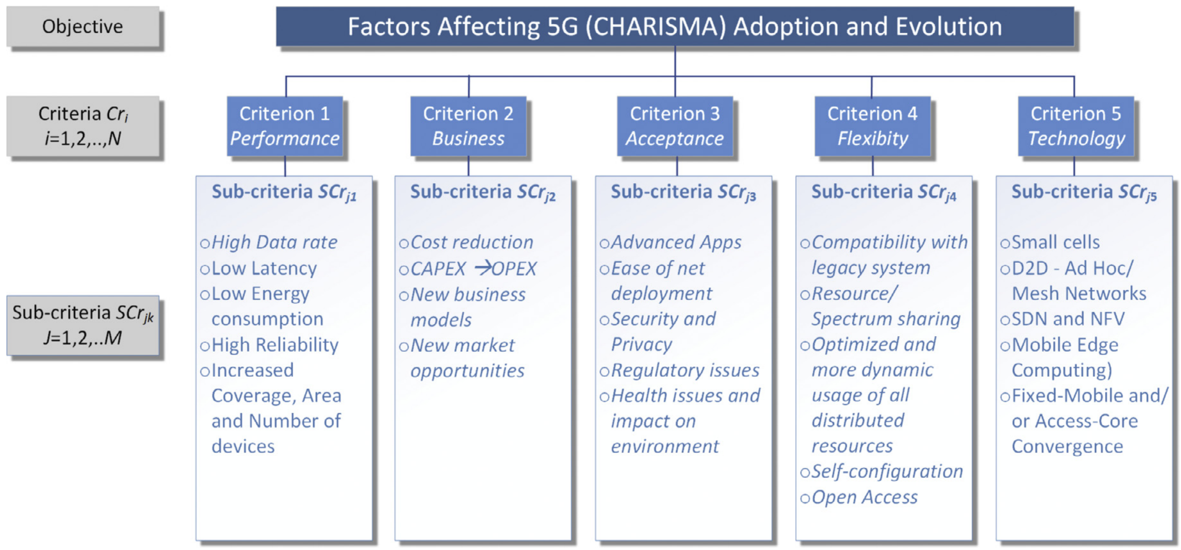

Fig. 2. Multi-level hierarchy of interrelated criteria and sub-criteria.

embourg, Portugal, Slovenia, Spain and United Kingdom). The main expertise of the people who responded lies primarily in the field of telecommunication technologies. From the twenty-two experts who initially participated in the survey, six questionnaires were discarded as inconsistent, since their associated Consistency Ratio (CR) was >0.1. The questionnaires were conducted and completed during a period of 1 month (15 March 2016–15 April 2016) with the final set of sixteen experts. This can be assumed a sufficient size for the purpose of a Fuzzy AHP analysis since as shown in Gerdsri and Kocaoglu (2007), Dede et al. (2015, 2016), the changes in the probability of rank reversal when an additional expert is added in the group are below 1% at M = 15 (where M is the number of experts).

The pairwise comparisons were conducted by a web-based survey/roadmapping platform incorporating all elements of the Fuzzy AHP framework, where experts accessed the platform and filled out the questionnaires. In detail, experts were asked to determine the (sub-)criterion of his/her preference (for every pair of (sub-)criteria) and provide the upper and lower limit of their relative importance using any number between 1 and 9. The web-platform was implemented using Lime Survey (https://www.limesurvey.org/), an open source tool for web surveys and hosted by INCITES.

The data supplied by the users was saved in a database. Since Lime Survey doesn't have inbuilt modules for implementing a fuzzy logic AHP, the necessary calculations were performed using Matlab, leading to an estimation of the weights signifying the importance of criteria and sub-criteria according to Eqs. (6)–(9).

At the end of the survey two more questions were posed about the gender and the sector (academia-research institute, SME or industry) of the participants. Fig. 3 illustrates the statistics of the participants.

4. Results and discussion

In this section, we present and discuss the results of the survey concerning the evaluation of the importance of the criteria and sub-criteria that are expected to affect the deployment of 5G networks. Using the methodology described above, one can easily estimate both fuzzy and crisp weights prioritizing the criteria and sub-criteria. The derived results are shown in Table 3.

4.1. Weighting of criteria

The results concerning the weights of the criteria that are expected to affect 5G network deployment are shown in Table 3 and illustrated in Fig. 4. It is interesting to note, that according to the opinion of the experts, the criterion that is the most important one to take into account as its weight reaches 0.36 (or 36%) is that of Performance. This is also a confirmation of the fact that previous technologies have presently reached the limits of their performance. Thus, experts are now waiting for new technological innovations in order to support the anticipated advanced services and applications with their increased requirements.

The Business criterion has the second largest weight, emphasizing the need for a credible business plan exploiting the new market opportunities and a clear route to positive cash flow following the necessary 5G capital investment, e.g., reducing the cost (especially the CAPEX) will greatly affect the business perspectives of 5G networking. A portion of the deployment cost reduction is also expected to pass to retail prices too. This is expected to further enhance the penetration of 5G

Table 3
Fuzzy and crisp weights of criteria and sub-criteria.

Criteria (C_i)/sub-criteria (SC_{ij})	Description	Fuzzy weight	Crisp weight
C_1: Performance	It refers to measures of service quality	(0.256, 0.362, 0.513)	0.3622
SC_{11}: High data rate	Maximum achieved rate	(0.148, 0.206, 0.284)	0.206
SC_{12}: Low latency	Round trip delay time	(0.278, 0.368, 0.492)	0.368
SC_{13}: Low energy consumption	Do 5G networks reduce the energy that the involved equipment consumes?	(0.081, 0.114, 0.157)	0.114
SC_{14}: High reliability	Proper operation under stated conditions for a specified time.	(0.156, 0.215, 0.295)	0.215
SC_{15}: Increased coverage	Area that can be covered by 5G systems	(0.071, 0.098, 0.134)	0.098
C_2: Business	Market related issues	(0.136, 0.201, 0.292)	0.2012
SC_{21}: Cost reduction	This cost include installation and maintenance, equipment and SW cost	(0.181, 0.239, 0.317)	0.239
SC_{22}: CAPEX transforming to OPEX	Move competition from HW to SW, lowering the threshold for players to enter the market	(0.151, 0.203, 0.272)	0.203
SC_{23}: New business models	New players will enter the market, traditional roles will be changed. Advance applications/services will emerge changing the revenue streams	(0.161, 0.215, 0.285)	0.215
SC_{24}: New market opportunities	New players and roles will emerge	(0.259, 0.343, 0.456)	0.343
C_3: Acceptance	It incorporates many user-related concerns (health, privacy, etc.)	(0.129, 0.181, 0.255)	0.181
SC_{31}: Advanced applications	Applications with high requirements that cannot be provided by legacy systems	(0.141, 0.198, 0.277)	0.1981
SC_{32}: Ease of deployment	Simplification of how networks are designed, built, deployed, operated and managed	(0.155, 0.217, 0.302)	0.2166
SC_{33}: Security and privacy	Confidentiality of personal data, trustworthiness of information flows, authentication, etc.	(0.25, 0.344, 0.477)	0.3441
SC_{34}: Regulatory issues	Several issues should be addressed. Develop a 5G spectrum band plan, net neutrality, promote competition and investments	(0.098, 0.135, 0.188)	0.1351
SC_{35}: Health issues and impact on environment	Impact of radio waves on health, visual impact on surrounding, etc.	(0.074, 0.106, 0.15)	0.1061
C_4: Flexibility	It refers to the overall usability of the system	(0.119, 0.166, 0.234)	0.166
SC_{41}: Compatibility with legacy systems	Will 5G networks be compatible with existing networks and systems?	(0.09, 0.13, 0.185)	0.13
SC_{42}: Resource/spectrum sharing	Intra-system spectrum use, geographical reuse, use of higher frequency bands, co-existence with new and legacy systems	(0.139, 0.199, 0.283)	0.199
SC_{43}: Optimized and more dynamic usage of all distributed resources	Optimization of resource allocation and usage, use of all the underlying infrastructure resources	(0.204, 0.286, 0.404)	0.286
SC_{44}: Self-configuration	Distributed system architectures that will allow self-healing and self-optimization features	(0.106, 0.147, 0.206)	0.147
SC_{45}: Open access	Enable actors to collaborate in new ways	(0.167, 0.238, 0.339)	0.238
C_5: Technology	Techniques and methods that will be used in 5G networks	(0.064, 0.09, 0.127)	0.089
SC_{51}: Small cells	They will allow the densification of the network	(0.077, 0.112, 0.164)	0.112
SC_{52}: D2D – ad hoc/mesh networks	Direct communication between devices and nodes	(0.114, 0.168, 0.248)	0.168
SC_{53}: Software defined networking (SDN) and NFV	Decouple software and hardware planes and use of general purpose devices	(0.235, 0.344, 0.505)	0.344
SC_{54}: Mobile edge computing (MEC)	Executing network functions closer to the edge	(0.119, 0.175, 0.257)	0.175
SC_{55}: Fixed-mobile and/or access-core convergence	Convergence of fixed mobile networks and integration of access and core networks into a common network	(0.136, 0.2, 0.294)	0.200

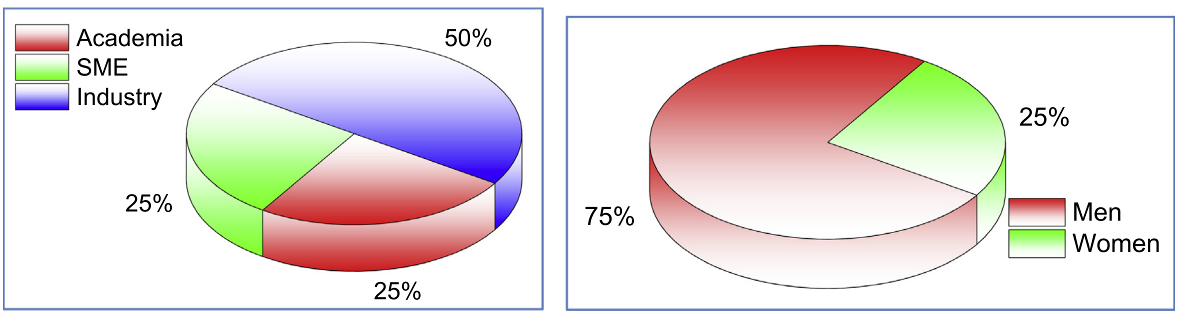

Fig. 3. Statistics of the participants.

technologies, since people are nowadays used to paying a reasonable amount of money for telecom services. Business criteria are very important in any decision making process for telecom products. Simply adding new advanced services does not by itself guarantee a market potential since they must come at the right price and the right time. On the other hand, in recent years, the telecoms market seems to have been stagnating, and therefore needs to be rejuvenated and refreshed. In this

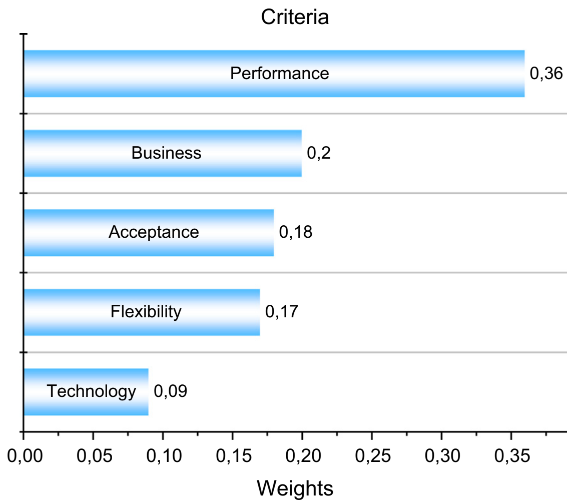

Fig. 4. Relative weights of 5G network criteria.

context, 5G networking is expected to be important in lowering the barriers to entry and helping new players to enter the market.

Acceptance and Flexibility criteria have almost the same weights and are also almost comparable in weight to the business criterion, thus revealing the need to fulfill a number of diverse and possibly conflicting criteria during 5G networks deployment. Acceptance is somehow expected to be among the top criteria since it is related to issues such as security, privacy and health that are of high importance especially for the public. This is a clear indication that the public needs to be made aware of the benefits of 5G networking. One approach for stimulating the public's interest could be to promote benefits of 5G, i.e., its high data rate, low latency and security (especially under the CHARISMA virtualized solution), etc. On the other hand, Flexibility is something that will influence 5G networks deployment, since it deals with several technical issues such as compatibility and self-configuration as well as other factors (e.g., open access, resource and spectrum sharing) that may become obligatory through appropriate regulation.

The Technology related criterion receives the lowest weight, probably because 5G networks is not entirely about introduction of "new" technologies or the enhancement of the existing ones as such, but instead can be assumed to represent the collection and combination of a heterogeneous set of networking technologies with several improvements.

It is also interesting to investigate the ranking of criteria using the fuzzy weights (Fig. 5). If we had to make a single definite choice between the relevant criteria, Performance should be certainly chosen. However, decision making does not

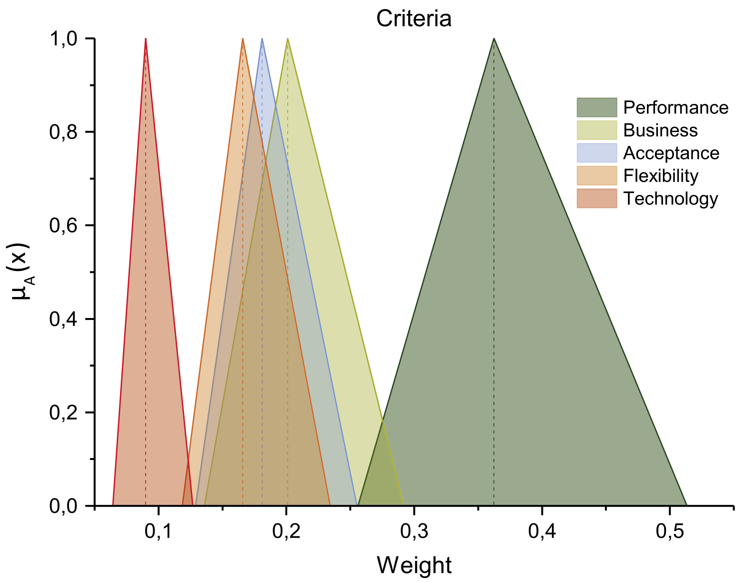

Fig. 5. Fuzzy evaluation of Criteria.

always imply a choice between alternatives; but also references the probabilities, possibilities or considerations concerning opportunities vs. risks. The fuzzy numbers can then be taken to guarantee the minimum and maximum values. An α-cuts can also be taken into account in order to define narrower lower and upper limits of the relevant weightings based on risk considerations. Fig. 10 suggests that there is a large degree of overlapping between the Business, Acceptance and Flexibility priorities, indicating that the ranking of these criteria may possibly change (a situation referred to as rank reversal). However, in order to calculate the probability of rank reversal, one should resort to either Monte Carlo simulations or closed-form approximations (Dede et al., 2016). Also note that the performance criterion is more prone to uncertainty-induced perturbations since its shape (i.e., width) is wider than the rest; the Technology criterion also has the narrowest width, additionally indicating confidence among the experts that it really is the least important consideration in the deployment of 5G networking.

4.2. Weighting of Sub-criteria under each criterion

It is also interesting to examine the weights of the sub-criteria under each criterion. Regarding Performance, as shown in Table 3 and depicted in Fig. 6, the experts seem more concerned about low latency in view of the many new advanced applications and services where latency requirements are very tight and crucial. For example, verticals such as e-health and automotive are expecting low latency in order to support their particular use cases.

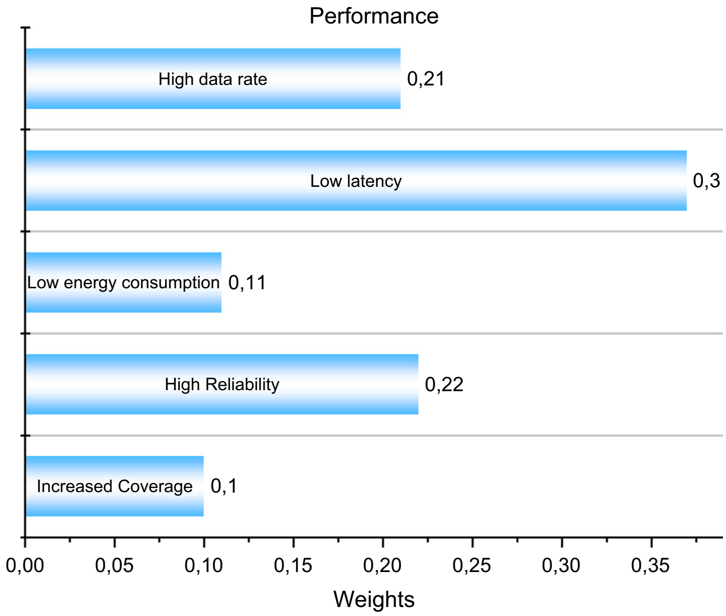

Fig. 6. Relative weights of Performance Sub-criteria.

High data rates and high reliability are the second most important issues, accumulating a weight of 0.21 and 0.22 respectively. A high data rate is also a key issue for 5G networking in both the front-haul and the back-haul, as well as in the access part of the network. 5G has promised end-user data rates up to 10 Gb/s which is currently a challenge necessitating the combination of several technologies. Taking into account the expected increase of traffic, one should look for schemes to further enhance network capacity. Optical communications, both wired (Aleksic, 2015) (along with advanced multiple access schemes, e.g., OFDM (Schaich and Wild, 2014) and wireless, FSO (Pham et al., 2015) and VLC (Schulz et al., 2015), as well as other solutions such as small cells (Tseng et al., 2015) can be used to improve data rates and help traffic off-loading and thus should be explored in future systems. High reliability, of almost equivalent importance with a high data rate, is also a key requirement for 5G networking especially due to the heterogeneous nature of 5G networks.

It is interesting enough that low energy consumption can be found in the second-to-last position. This is something unexpected since 5G is considered as a mobile technology mainly dealing with content, and thus power consumption especially of end users devices will be of high importance. The increased coverage sub-criterion has the lowest weight (0.1). It seems that this sub-criterion is not significant among the experts, maybe due to the compromise between coverage and available bandwidth.

Fig. 7 suggests that there is an overlapping between high data rate and high reliability, as well as between low energy consumption and increased coverage, indicating that the ranking of these sub-criteria may possibly change. Also note that

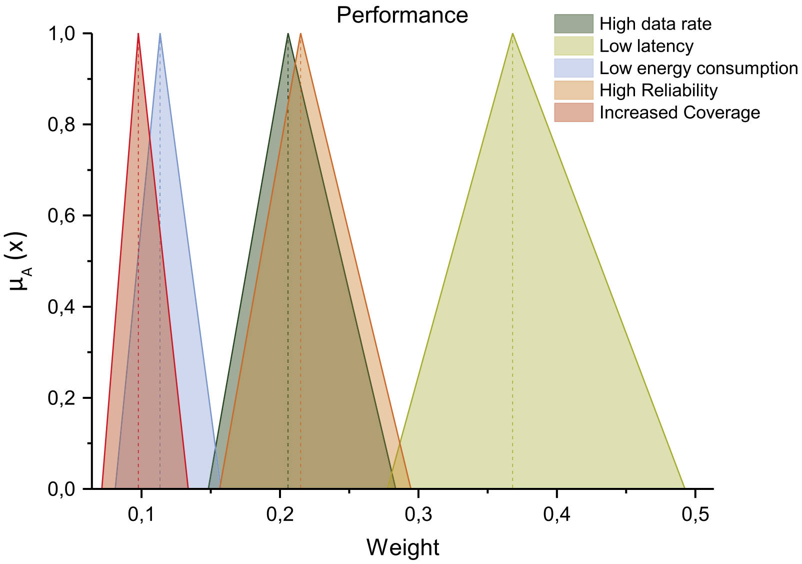

Fig. 7. Fuzzy evaluation of Performance Sub-criteria.

the low latencysub-criterion is more prone to uncertainty-induced perturbations since its shape is wider than the rest, although it only overlaps slightly with high data rate and reliability triangles.

Table 3 and Fig. 8 show that with the exception of new market opportunities, all other sub-criteria have comparable weights. This suggests that 5G networks should be designed in order to fulfill a number of diverse sub-criteria related to the market. In detail, the weight for new market opportunities is 0.34 indicating its increased importance and revealing market expectations. 5G will significantly contribute to the expansion of existing, as well as the creation of new, market opportunities, leading to increased profitability by mainly adopting NFV technology. 5G will lower the barriers to entry for new players, such as developers of innovative cutting-edge functions as well as for new actors, e.g., facility managers that provide "Small Cells as a Service".

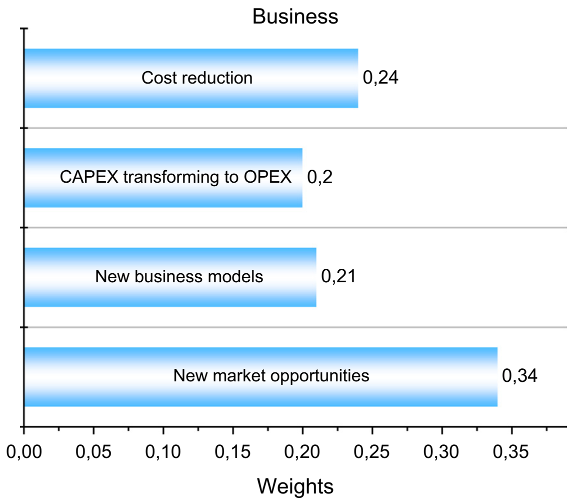

Fig. 8. Relative weights of Business Sub-criteria.

According to the experts' opinions, cost reduction is in the second place (weight: 0.24). This is not surprising as the cost of deployment is very important since it will influence services prices leading to increased or decreased penetration. This also seems consistent with the high combined weight of the CAPEX transforming to OPEX discussed below.

The next sub-criterion is new business model. The whole telecom ecosystem itself has evolved considerably in recent years, illustrating that business relationships are no longer bilateral (Second Vision and Societal Challenges

WG Brochure, 2016). A factor that significantly boosts this trend is that of virtualization, enabling some vertical industries and Over the Top (OTT) players to operate in a Network-as-a-Service (NaaS) mode and offering services on top of telco infrastructure. In addition, 5G will enable new ways for charging and pricing, something that seems necessary in the new ecosystem. The softwarization of the network along with the "as a service" concept is fostering the transition from old-traditional to new pricing and charging schemes that will take into account several issues, e.g., throughput, data volume, latency, device movement, processing, storage, functions or event based charging in real time.

Last but not least, since its weight is comparable to those of cost reduction and new business models, is that of CAPEX transforming to OPEX. This is one of the main characteristics stemming from the use of NFV; that is the softwarization of networks. Several networking functions, which traditionally required specialized network components are now being implemented as software modules in virtual machines. This is accompanied by a significant reduction in CAPEX, a portion of which is transformed to OPEX needed for the development and maintenance of such modules.

Fig. 9 suggests that there is an overlapping between the cost reduction, CAPEX transforming to OPEX and new business models sub-criteria indicating that the ranking of these sub-criteria may possibly change. Contrary to the previous cases, the overlapping between the first sub-criteria (new market opportunities) and the rest is not negligible, leading to increased probability of rank reversal. Also note that the new market opportunities sub-criterion is more prone to uncertainty-induced perturbations since its shape is wider than the rest.

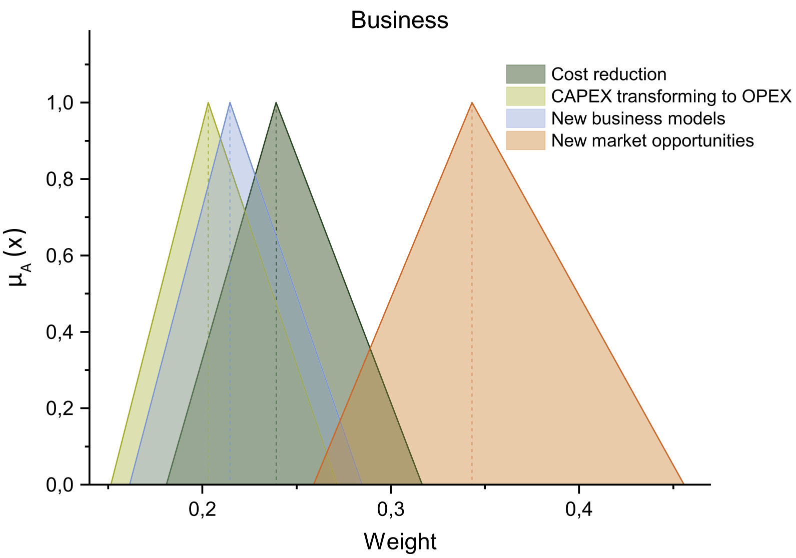

Fig. 9. Fuzzy evaluation of Business Sub-criteria.

Regarding the sub-criteria of the Acceptance criterion, it is clear that security and privacy issues are the most important. This is to be expected for mainly two reasons: On the one hand, the softwarization of networks alongside the use of NFV/SDN technologies make end-to-end security more challenging; On the other hand, the 5G environment is characterized by multi-tenancy, heterogeneity and resource sharing, also leading to security and privacy concerns. This is further enhanced by edge caching functionalities giving the ability to collect and process high volumes of data, as well as by the transformation of end users from pure consumers to mixed content consumers and producers.

Experts seem to have also highly prioritized advanced applications (weight: 0.2) and ease of deployment (weight: 0.22). Innovations in the space of service- and network-level function development in combination with advanced application development are expected, fully capitalizing the increased performance in terms of low latency and high data rates, as well as the flexibility that will be afforded by 5G networks. This is further enhanced by the use of NFV technologies. On the other hand, ease of deployment is a factor that will influence 5G adoption and speed up its evolution. The ease of deployment heavily depends on the ability of 5G systems to allow the reuse, or upgrading, of existing network infrastructures. In addition, features, like plug and play, self-configuration, optimization and healing will play an important role in the deployment and management of 5G networks.

Surprisingly enough, regulatory issues, as well as health issues and impact on environment are deemed of secondary importance compared to other issues. Health and environmental issues are always an important aspect to consider along

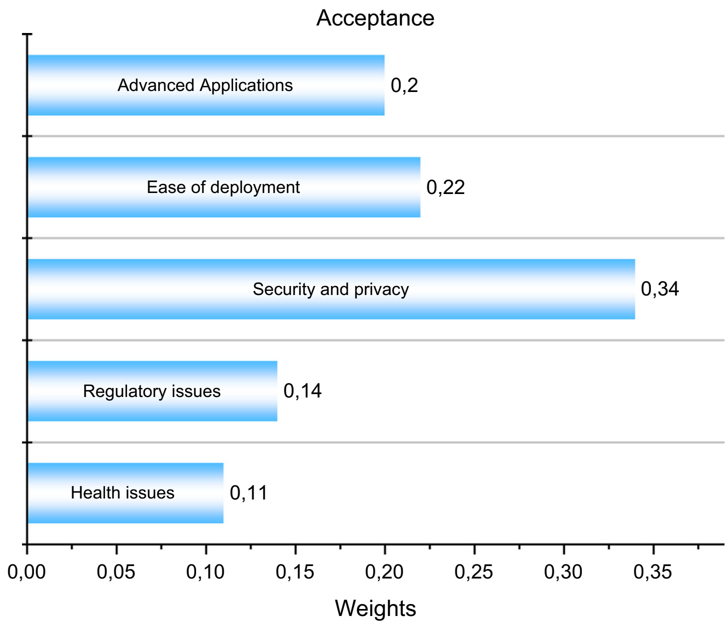

Fig. 10. Relative weights of Acceptance Sub-criteria.

with the measures that should be taken in order to address growing possible public concern. The low weight of health issues and impact on environment can possibly be attributed to the fact that mobile technologies are not new, and as such their impact on both health and environment have already been frequently investigated. Moreover, certain standards addressing the health concerns have been established, such as the IEEE C95.1-2005 (http://emfguide.itu.int/pdfs/C95.1-2005.pdf) which provides recommendations to protect against the possible harmful effects of humans being exposed to electromagnetic fields in the frequency range from 3 kHz to 300 GHz. On the other hand, the low priority of regulatory issues is somehow unexpected and cannot be easily explained. In the new era of 5G where heterogeneous networks will be combined, while resource sharing and open access will enable service provision on top of third party infrastructure, regulation is expected to play a central role. However, previous experience has shown that regulatory decisions are not always desirable from the market players' side and usually lead to market disruption. Thus regulatory issues should be of increased importance regarding the deployment of 5G networks.

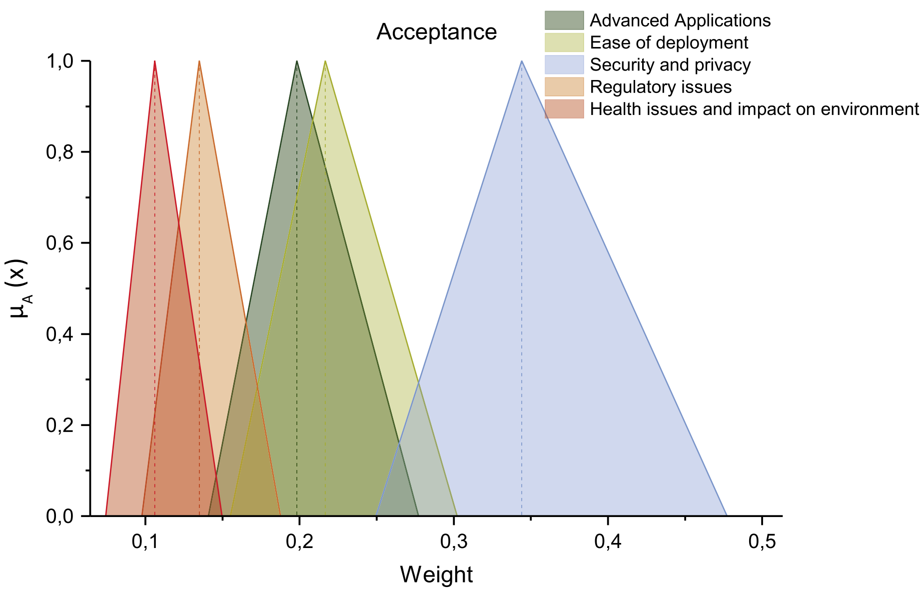

Fig. 11. Fuzzy evaluation of Acceptance Sub-criteria.

Fig. 11 suggests that there is an overlapping between advanced applications and ease of deployment, as well as between the regulatory issues and health/environmental impact sub-criteria, indicating that the ranking of these sub-criteria may possibly change. The overlapping between the security and privacy sub-criterion and the rest is not negligible, also potentially leading to the increased probability of rank reversal. Also note that the security and privacy sub-criterion is more prone to uncertainty-induced perturbations since its shape is wider than the rest.

Regarding the Flexibility criterion, as shown in Table 3 and Fig. 12, optimized and more dynamic usage of all distributed resources, open access and resource/spectrum sharing seem to take precedence over other issues with weights of 0.29, 0.24 and 0.2 respectively. This is consistent with the nature of 5G networking, as well as to the requirement for efficient use of resources. In the 5G networking environment, heterogeneous systems and devices will be connected, while end-users will also act as content and/or resources providers. These new features will necessitate a new framework for resource use/sharing that will be dynamic.

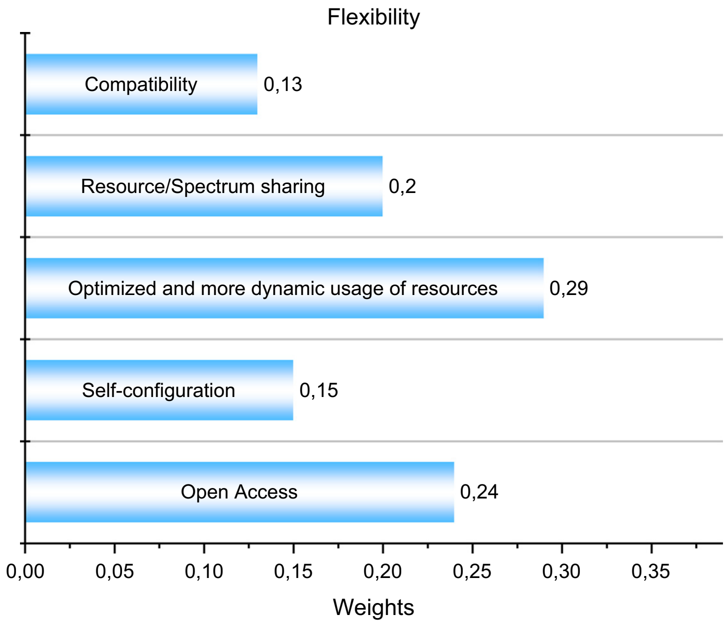

Fig. 12. Relative weights of Flexibility Sub-criteria.

Self-configuration, although a critical factor for ease deployment and cost reduction, receives a relatively low priority. Compatibility with legacy systems also seems to be of secondary concern. This is an indication that the experts tend to think that the adoption of 5G networking will not demand compatibility with previous legacy systems which have already been installed, thus reflecting an expectation trend that envisions the deployment of a new, parallel 5G network.

Contrary to previous cases, as shown in Fig. 13, there is greater overlapping between all the various sub-criteria of the Flexibility criterion, indicating that there is a higher probability that the ranking of these might change. In addition the majority of the sub-criteria have high widths, also revealing the relatively high degree of uncertainty in these expert judgments.

As shown in Fig. 14, SDN and NFV sub-criterion is the first choice among the experts regarding the Technology criterion. Virtualization technologies using SDN and NFV are anticipated to drastically affect the development of next-generation mobile technology standards expected to rollout under the "5G" banner. This is usually stemming from the need for more rapid scalability in order to address the growing demand, as well as for a more efficient network resource provisioning. This is also confirmed by the trend of the telecoms industry that is moving quickly to virtualized and software-controlled solutions (ACG Research, 2015; The Wall Street Journal; Mobile World congress, 2014), as well as by a number of market reports forecasting rapid growth of these technologies (Howard, 2014; http://www.prnewswire.com/news-releases/the-sdn-nfv--network-virtualization-bible-2015--2020--opportunities-challenges-strategies--forecasts-300066574.html; http://www.prnewswire.com/news-releases/network-functions-virtualization-nfv-market-business-case-market-analysis-and-forecasts-2015---2020-nfv-revenues-will-reach--87-billion-300033654.html).

Fixed-mobile and/or access-core convergence, mobile edge computing (MEC) and D2D – ad hoc/mesh networks sub-criteria are shown to be of almost equivalent importance after SDN/NFV. This ranking is fully consistent with the 5G Vision (First Vision and Societal Challenges WG Brochure, 2015) according to which 5G will be driven by software and network functions that will run especially at the edge of the network for meeting performance targets. In addition, D2D and AdHoc networking are expected to be adopted as a means to accommodate the increased traffic (increase the cell capacity) and offer

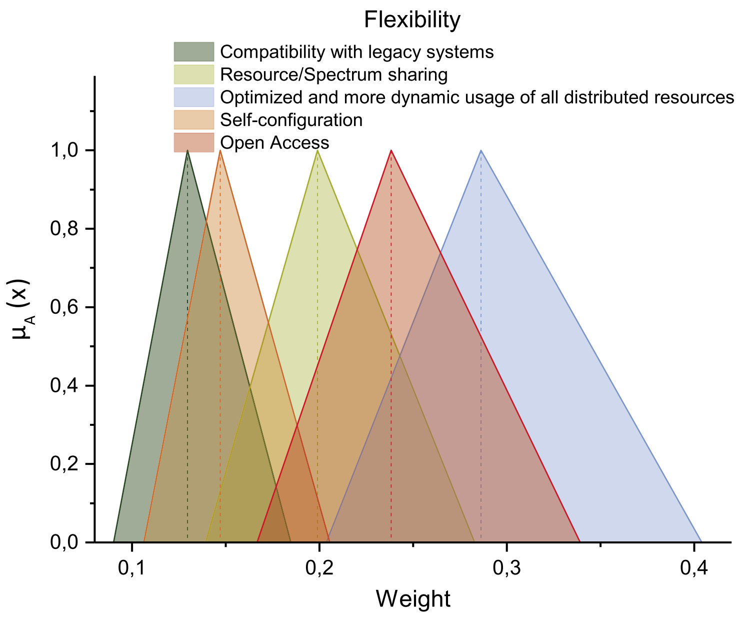

Fig. 13. Fuzzy evaluation of Flexibility Sub-criteria.

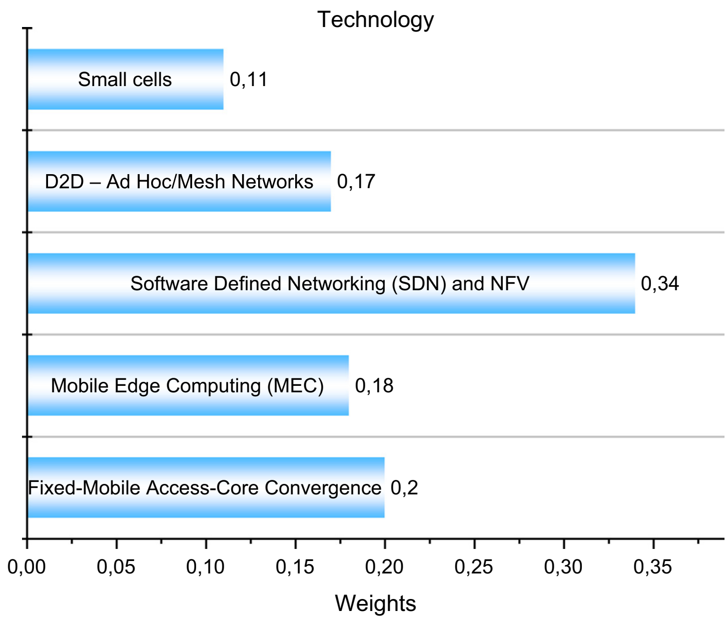

Fig. 14. Relative weights of Technology Sub-criteria.

various proximity services (Mitra and Agrawal, 2015). Finally, the integration of networking, computing and storage resources into one programmable and unified infrastructure will allow fixed-mobile and/or access-core convergence (First Vision and Societal Challenges WG Brochure, 2015) providing the same services in any environment. As a result, 5G will heavily rely on emerging technologies such as MEC, Fog computing (FC) and D2D communications, as well as on fixed-mobile and/or access-core convergence to achieve the required performance, scalability and agility.

In the last position, one can find small cells. We note that small cells represent a technology not being investigated within the CHARISMA project.

Fig. 15 illustrates the fuzzy evaluation of the Technology sub-criteria. It can be seen that the ranking between the last four technologies may possibly change due to the high degree of overlapping between them. SDN and NFV sub-criterion mainly intersects with the fixed-mobile and/or access core convergence sub-criterion, and slightly overlaps with the MEC and D2D – Ad Hoc/Mesh Networks sub-criteria, revealing a small probability of rank reversal. Also note that SDN and NFV sub-criterion is more prone to uncertainty-induced perturbations since its width is also wider than the rest.

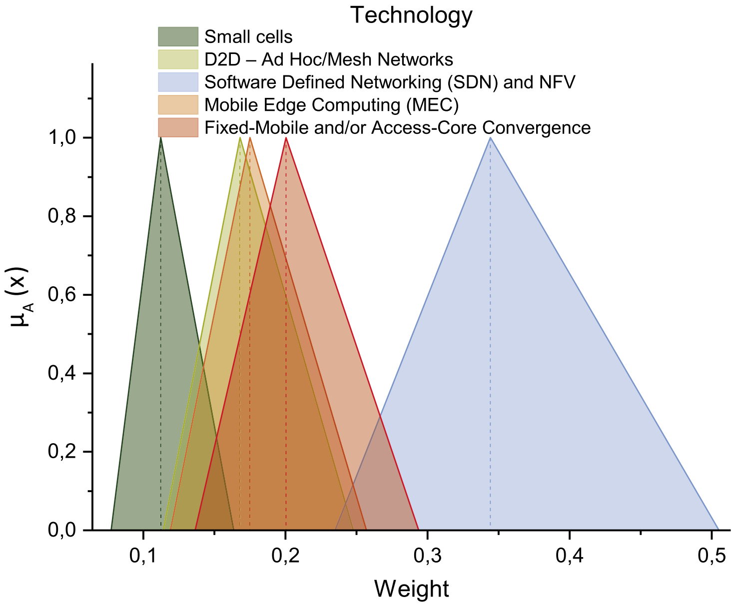

Fig. 15. Fuzzy evaluation of Technology Sub-criteria.

It is interesting to note that fuzzy evaluation of Technology sub-criteria can also be used in order to decide which technologies should be promoted by a government in the long run. The fuzzy numbers could then be taken to guarantee the minimum and maximum amount of subsidies for the future development of selected technologies. As mentioned before, α-cuts can also be considered to define narrower lower and upper limits of the relevant weightings based on risk considerations. The guaranteed interval of grants for the promotion of the evaluated technologies could then be calculated by multiplying the total grants with the derived fuzzy evaluations.

5. Global priorities of sub-criteria and policy implications

In order to capture a global view of the sub-criteria ranking, the global priorities need to be calculated. The global priorities are obtained by multiplying the local priorities (sub-criteria weights) by their parent's priority (weight). The global

Table 4
Global priorities of sub-criteria.

Sub-criteria (SC_{ij})	Global priority
SC_{11}: High data rate	**0.075**
SC_{12}: Low latency	**0.133**
SC_{13}: Low energy consumption	0.041
SC_{14}: High Reliability	**0.078**
SC_{15}: Increased Coverage	0.035
SC_{21}: Cost reduction	0.048
SC_{22}: CAPEX transforming to OPEX	0.041
SC_{23}: New business models	0.043
SC_{24}: New market opportunities	**0.069**
SC_{31}: Advanced Applications	0.036
SC_{32}: Ease of deployment	0.039
SC_{33}: Security and privacy	**0.062**
SC_{34}: Regulatory issues	0.024
SC_{35}: Health issues and impact on environment	0.019
SC_{41}: Compatibility with legacy systems	0.022
SC_{42}: Resource/Spectrum sharing	0.033
SC_{43}: Optimized and more dynamic usage of all distributed resources	0.048
SC_{44}: Self-configuration	0.024
SC_{45}: Open Access	0.04
SC_{51}: Small cells	0.01
SC_{52}: D2D – Ad Hoc/Mesh Networks	0.015
SC_{53}: Software Defined Networking (SDN) and NFV	0.031
SC_{54}: Mobile Edge Computing (MEC)	0.016
SC_{55}: Fixed-Mobile and/or Access-Core Convergence	0.018

Bold values correspond to the sub-criteria with the highest priority.

priorities for all the sub-criteria add up once again to 1. Table 4 presents the global weights for all the sub-criteria considered.

The results presented in both the previous section and Table 4 are a valuable tool for decision and policy makers. In fact, they provide very useful guidelines for the successful deployment as well as for the fast market adoption of 5G networks.

As shown, the most important factors expected to affect the adoption and deployment of CHARISMA and 5G networks in general are low latency, high data rate and high reliability. Essential sub-criteria here include new market opportunities, security and privacy, as well as cost reduction.

Thus, the issues that are expected to significantly affect the deployment of 5G networks are mainly included in the three categories/factors namely: Performance, Business and Acceptance. It is then evident that strategic planning and policy decisions should be mainly focused in two directions – target groups: those who would like to make an investment in 5G networks (e.g., network operators); and those who will use 5G networks (end users).

Regarding the first target group, both government and private enterprise should invest in developing new or upgrading and strengthening existing infrastructures and networks in order to achieve 5G requirements. Furthermore, they should also give incentives to enhance the adoption of 5G networking. On the one hand, government should give subsidies to providers/operators to enable new investments. It should be noted again that due to virtualization and softwarization, 5G networks will reduce the cost of network deployment and lower the barriers to entry. On the other hand, providers/operators should reduce the prices of new technologies/networks in order to attract new customers or and motivate existing ones to migrate to the new technologies and networks. However, such a regulatory exercise can become extremely complex. The assumption that once the investment has taken place, 5G networks will replace the existing networks instantaneously is not true; in fact, the transition from the old networks to the new ones is likely to be a relatively slow process, and hence, there is likely to be a transition phase during which both technologies will coexist.

Although regulatory issues are not among the top preferences of experts, according to the authors' opinion, this aspect should be taken into serious account during the deployment of 5G networks for another reason too: Since open access, spectrum sharing, M2M & D2D communications and OTT have been introduced (and which are becoming dominant themes in future 5G networking) specific regulation is needed in the areas of licensing, spectrum management, switching and roaming, numbering, competition, security and privacy in order to build public confidence, as well as to ensure a competitive market.

Regarding the second target group, there is also the possibility of reduced willingness to use or make a transition to 5G networks due to a perceived lack of need and/or fitting into their lifestyle. However, in this regard, it is not so much an issue of educating the public; rather alternative means to encouraging such a transition should perhaps be adopted. Simply adapting the new network technologies to these people may be sufficient to significantly increase their motivation; in other words, targeted contents/services should be developed to address their needs. For example, regarding elderly people, new tele-medicine and e-healthcare services need to be developed and supported by 5G networks. This will lead to an increase in the perceived usefulness of 5G networking.

High importance should also be attached, especially in the case of the second target group, to support efforts to increase the public awareness of the benefits accruing from 5G networks. Since there are strong concerns regarding the impact of technology on human life, and personal privacy and security, the management of such ethical issues seems to be an important issue, as a means to allay fears and win public support. In addition, campaigns to promote public understanding may also need to be carefully organized in order to inform people about the positive social and economic impacts of 5G networking, such as job creation, better entertainment, improved social inclusion, increased wellbeing, enhanced health care, environmental friendliness, reduced emissions, and fewer accidents.

6. Conclusions, limitations and future work

The EU has an ambitious policy to accelerate research in the area of 5G networking, and has established the 5G-PPP initiative to support 5G through the Horizon 2020 research programme. However, before 5G can become a commercial reality, a wide variety of issues need to be resolved. In this paper, we have provided an initial roadmapping description of the various technologies, techno-economic, standardizations, and regulatory issues that need to be addressed as part of a successful 5G deployment strategy. Based on pairwise comparison surveys conducted among experts within the CHARISMA project consortium, a number of technical, economic and social issues determining the penetration of future 5G networks have been evaluated and prioritized. By applying the Fuzzy AHP methodology, the relative importance of all identified issues has been rated, while also addressing at the same time the inherent uncertainties associated with such a survey.

According to the derived results, the most important criterion that will affect 5G deployment is Performance. It appears that breakthroughs in performance, as stated by the relative 5G PPP KPIs, are expected to be the main drivers behind 5G. This can be encapsulated by the statement that 5G Performance must clearly supersede that of current legacy systems.

After Performance, the next most important criterion is that of Business; this highlights the fact that apart from performance, economic factors will also strongly influence 5G deployment. Acceptance and Flexibility also closely follow together in importance; while Technology is rated as the criterion with the least importance. Taking into account the high priority of performance, it can be deduced that the performance KPIs therefore need to be reached independently of the underlying technology. An overlap between the relative importance of business, acceptance and flexibility has occurred, indicating that there is a possibility of rank reversal; that is the rankings between these specific criteria may change.

The analysis of the sub-criteria related to Performance has revealed that low latency is the most important, followed by high reliability and high data rate. These latter two seem to be almost equivalent in relative importance. New market opportunities as a sub-criterion of Business takes precedence as compared to the other business alternatives; thus new services and new business models are also expected to be critical drivers for a successful 5G deployment.

As expected, security and privacy is the most important sub-criterion of Acceptance; hence important effort needs to be directed towards these requirements. Somewhat surprisingly, regulatory issues as well as health issues and impact on environment are deemed of secondary importance. The optimized and more dynamic usage of the resources followed by multi-tenancy (open access) are the most important sub-criteria related to Flexibility.

Regarding Technology, great importance is being placed on SDN and NFV, while small cells receive the smallest weight. The ranking of the remainder of the sub-criteria is unclear due to their similar weights and high degree of overlap (fuzzy evaluation).

Taken together, CHARISMA's emphasis on low latency, multi-tenancy, and high security, reliability and availability therefore appears to be in line with the results of the expert survey. In combination with the work being performed in the relevant standardizations groups, the challenge is now to ensure appropriate coordination and harmonization between the different activities and emerging 5G-PPP solutions. Although still in the early stages, vendors and telecom operators are starting to test and validate the technical systems that are leading the way towards the next generation of 5G networks.

The authors expect this paper to be a valuable insight for researchers and stakeholders within the 5G ecosystem; indeed this paper can be assumed to act as a framework to identify those factors affecting the adoption and evolution of CHARISMA and 5G solutions. Such a framework is necessary in order to bridge the gap between the technical and socio-economic requirements that will guarantee the business prospects for the large scale deployment of 5G.

However, there are some limitations that need to be taken into account for future work in this area. First of all, the sample population (valid questionnaires) for this research exercise was limited (sixteen experts) and all were within CHARISMA project. Although, literature (Dede et al., 2015) supports the assertion that the participation of more than fifteen experts/questionnaires can lead to accurate results, future research should also be conducted using a more representative sample of the EU population. Fuzzy AHP methodology can also be combined with other methodologies such as cluster analysis in order to obtain an insight into additional contributing factors such as life style.

As mentioned in Section 4, the ranking between the investigated factors may also possibly change; a situation referred to as rank reversal. Therefore, future work should also evaluate the possibility and impact of rank reversal by resorting to either Monte Carlo simulations or closed-form approximations (Dede et al., 2016).

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