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ARTÍCULO DE INVESTIGACIÓN

Fuzzy Systems: An Approach to 5G Networks under the Software Defined Network Paradigm

Sistemas Difusos: Una Aproximación a las redes 5G bajo el Paradigma de Redes Definidas por Software

Sistemas Fuzzy: uma abordagem para redes 5G sob o paradigma de rede definida pelo software

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Recibido: septiembre de 2017 **Aceptado:** noviembre de 2017

Para citar este artículo: Albarracin-Sanchez, L.F., and Puerto-Leguizamón, G.,A. (2018). Fuzzy Systems: An Approach to 5G Networks under the Software Defined Network Paradigm. *Revista Científica*, 31(1), 96-110. **Doi:** https://doi.org/10.14483/23448350.12540

Abstract

The exploitation that has had the fuzzy systems related to advances of 5G networks (Fifth Generation Mobile Networks) and how this development has been framed by the paradigm of SDN (Software Defined Networks) architectures are reviewed in this article. The first part reviewed terms required for understanding the technologies and their evolution; on which different scenarios are evaluated because they have contributed to the development of the definition of 5G networks. Following this, the research and development of the fuzzy systems applied to telecommunications, specifically 5G technology and SDN architectures were described. Finally, the respective conclusions of the fuzzy systems in the 5G networks and SDN architectures have been exposed.

Keywords: 5G Networks, Radio Access Network, Core Network, Software Defined Networks, Fuzzy Systems Type 1, Quasi two and Type two.

Resumen

En este artículo se revisó la utilización que ha tenido los sistemas difusos en torno a los avances de las redes 5G (Redes Móviles de Quinta Generación) y cómo este desarrollo ha sido enmarcado por el paradigma de SDN (Software Defined Networks). La primera parte revisó los términos requeridos para entender las tecnologías planteadas y su evolución; en esta definición se evalúan diferentes escenarios que han contribuido al desarrollo de la definición de las redes 5G. Posteriormente se describió la investigación y desarrollo de los sistemas difusos aplicados a las telecomunicaciones, específicamente la tecnología 5G y las arquitecturas SDN. Finalmente, se expusieron las conclusiones respectivas de los sistemas difusos en las redes 5G y las arquitecturas SDN.

Palabras clave: Redes 5G, Red de Acceso de Radio, Red de Núcleo, Redes Definidas por Software, Sistemas Difusos Tipo I, Cuasi-II y Tipo 2.

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Resumo
A exploração que teve os sistemas difusos relacionados aos avanços das redes 5G (Redes móveis de quinta geração) e como esse desenvolvimento foi enquadrado pelo paradigma das arquiteturas SDN (Software Defined Networks) são revisadas neste artigo. A primeira parte analisou os termos necessários para a compreensão das tecnologias e sua evolução; em que diferentes cenários são avaliados porque contribuíram para o desenvolvimento da definição de redes 5G. Em seguida, foram descritas a pesquisa e desenvolvimento dos sistemas difusos aplicados às telecomunicações, especificamente tecnologia 5G e arquiteturas SDN. Finalmente, as respectiva conclusões dos sistemas difusos nas redes 5G e arquiteturas SDN foram expostas.

Palavras-chaves: Redes 5G, Red de Acesso de Rádio, Red de Núcleo, Redes Definidas por Software, Sistemas Difusos Tipo I, Cuasi-II e Tipo 2.

Introduction

Having in mind that developments in today's telecommunications are focused on obtaining the highest possible transfer rate for users with embedded mobility support (Gupta & Jha, 2015), obtaining an optimal and high-performance cost-benefit ratio for both: the customer, as well as the services provider, is imperative for the telecommunications markets.

This paper will explain specific definitions of fuzzy systems and their applications in telecommunications, which will allow to address the application of these techniques in new technologies, as shown in (Bhandari & Singh, 2016; Demydov, Seliuchenko, Beshley, & Brych, 2015; Dotcenko, Vladyko, & Letenko, 2014; Dubois & Prade, 1997; Xu et al., 2008). In the initial stage of the article, the basic theory of fuzzy systems will be exposed, followed by the advances in the 5G networks including the definition of the SDN paradigm. Afterwards, the integration of the SDN paradigm into the 5G networks will be explained as well by describing the proposals and developments up to date that has been made regarding the diffuse systems in 5G and SDN networks. Finally, we will show as conclusions the possible fields of action for decision making with fuzzy systems in 5G and SDN technologies.

Fuzzy Systems

A. Fuzzy Logic

Fuzzy Logic Systems are compared with probability theories as presented in(Dubois & Prade, 1997) since they comprise architectures for the resolution of problems with uncertainty under a perspective of membership degrees. This means that in essence, a fuzzy system defines that the possible input variables for a system to obtain a specific output do not have deterministic levels of an associated variable.

Different stages define a global description of fuzzy systems: The fuzzifying block, the inference engine, and the defuzzyfier block, as shown in Figure 1.

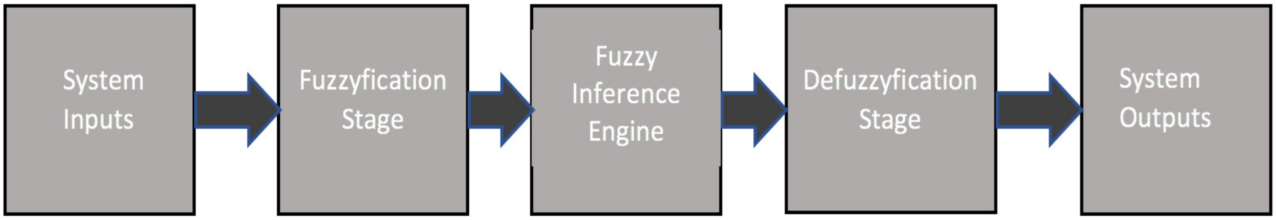

Figure 1. Fuzzy Systems Scheme.

The different blocks of fuzzy systems are explained below:

A. System Inputs: these are defined as the set of variables to be analyzed by the fuzzy system in order to establish the decision to take with an uncertainty problem.
B. Fuzzification Stage: In this stage, the degree of membership of the defined entries are determined in the different sets that establish the universes of the problem to be evaluated.
C. Fuzzy Inference Engine: In this stage are defined the rules that allow to establish and process fuzzy inputs to obtain an output in membership degrees of the system.
D. Defuzzification Stage: In this stage, the outputs of the fuzzy inference engine are converted to a deterministic form.
E. Outputs from the System: This block comprises the results of the system, with the decisions found to solve the initial problem under the lens of a fuzzy system.

The fuzzy systems have presented evolutions regarding the form in their architecture, approaches of the inputs and their methods for the fuzzy inference engines. The next section will show the more representative fuzzy systems for a better understanding of what has been exposed.

B. Type I Fuzzy Systems:

In type I fuzzy systems, two types of fuzzy systems can be emphasized: the Mamdani type fuzzy system and the Sugeno type fuzzy system. The main difference of these types of systems is perceived in the way the outputs of the system are determined (Jantzen, 1998; Mendel, 1995).

The Mamdani type fuzzy system is more recurrent to see in conventional fuzzy architectures. The Mamdani method is based on fuzzifying the input variables, applying a fuzzy operator to these inputs, followed by applying methods of implication and aggregation, in order to defuzzify the outputs (Wang, 2015).

The most common defuzzification method used in Mamdani Fuzzy Systems is the Centroid Method, the expression gives this one:

$$Z_{COA} = \frac{\int_z \mu_A(z).zdz}{\int_z \mu_A(z).} \tag{1}$$

Where z is the output variable, and $\mu A\ (z)$ is the membership function of the aggregated fuzzy set A with respect to z.

The method of a Sugeno fuzzy system was initially proposed by Takagi, Sugeno, and Kang, this type of system aims to develop a systematic method to generate fuzzy rules from an input/output data set. To make an example of this concept, define a Sugeno fuzzy system that will commonly contain a fuzzy rule of the form:

$$\text{If } X \text{ is } A \;\&\; Y \text{ is } B, \text{ then } z = f(x,y) \tag{2}$$

Where *f(x,y)* is generally a polynomial dependent function of the input variables X and Y, however, it can be defined as any function that can properly define the output of the model within the fuzzy region specified by the antecedent of the rule (Adlassnig & Vienna, n.d.; Dimitar, 2006).

In order to better illustrate the above concept, figure 2 shows a membership function of type I fuzzy system. As observed, it is a Gaussian type function that establishes the membership of the input variable in the fuzzy system to a set from the proposed fuzzy system. In this context, x represents possible values of the input data, and *f(x)* shows the value assigned to the membership function depending on the model used, in figure 2 a Gaussian model is used.

C. Interval Type II Fuzzy System:

The interval type II fuzzy systems argue that there is uncertainty even on the degree of membership of an input to a specific set in a fuzzy system. Defining this way that a variable can have a belonging degree to the membership degree associated with a set. This, means that a diffuse set expresses the degree of imprecise non-deterministic truth to which an element belongs to the whole. The characteristic function of a fuzzy set can then take values between 0 and 1, which denotes the membership degree of an element to a given set.

The construction of a fuzzy set depends on the identification of a suitable universe and the specification of a membership function with the appropriate linguistic meaning as discussed in (Yosra JARRAYA, Souhir BOUAZIZ, Adel M. ALIMI, 2016) and (Mendel, 2007). Figure 3 illustrates the conceptualization of the difference between a diffuse set type I and an interval type II. In particular, figure 3(a) shows a type 1 fuzzy sets, where it can be seen that for each value of the input data (x-axis) there is a unique equivalence in the membership function (y-axis). Figure 3(b) shows an interval type 2 fussy system, where it can be seen that for each value of the input data (x-axis) there is a possible range of values in the membership function (y-axis); this is a Type 2 Membership Function.

A Type 2 Fuzzy System, denoted T2FS, is characterized by a Type 2 membership function μ_{T2FS} ,where $x \in X$ and $u \in J_x \sqsubseteq [0,1]$, i.e.,

$$T2FS = \{((x,u), \mu_{T2FS}(x,u)) \mid \forall x \in X, \ \forall u \in J_x \subseteq [0,1]\} \quad (3)$$

in which $0 \leq \mu_{T2FS}(x,u) \leq 1$. T2FS can also be expressed as:

$$\mu_{T2FS} = \int_{x \in X} \int_{u \in J_x} \mu_{T2FS}(x,u)/(x,u) \qquad J_x \subseteq [0,1] \quad (4)$$

Where $\iint$ denotes union over all admissible $x \text{ and } u$.

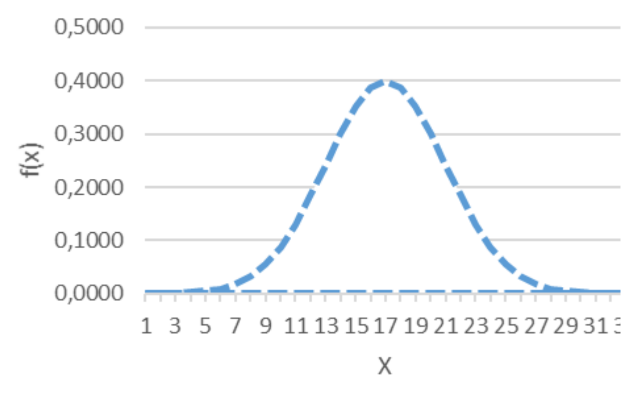

Figure 2. Gaussian Membership Function.

D. Quasi II Fuzzy Systems:

Taking into account the evolution of type II fuzzy systems, some possible approaches are proposed for the next step in their advancement as presented in (Coupland, 2007; Coupland & John, 2007; Starczewski, 2006).

In this context, the Quasi-II systems proposed by Mendel (Mendel & Liu, 2008), are an alternative used in telecommunications as manifested in (Albarracin & Melgarejo, 2010). These quasi-II type fuzzy systems can be defined as:

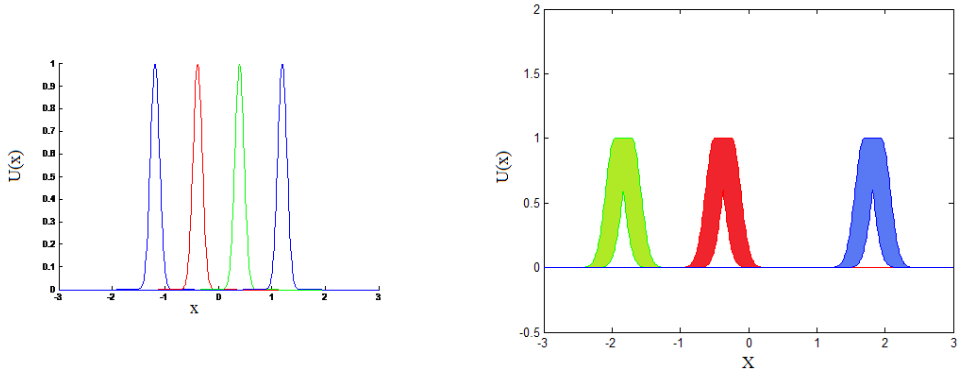

Figure 3. (a) Type I Fuzzy Set (b) Interval Type 2 Fuzzy Set.

A. An interval type II fuzzy system in parallel with a type I fuzzy system. On which we have a common defuzzification process, using the triangle's centroid method (a common method for defuzzification) formed by the three values delivered by the inference engine.
B. Two type II fuzzy systems executed in parallel, on which their respective type reduction is carried out, and to which the respective defuzzification is applied with the centroid method, using the four values obtained from the inference engine (Mendel & Liu, 2008).

These models, proposed by Mendel, are based on the approaches presented in (Mendel & Liu, 2008), which explain how after a complete understanding of the type II fuzzy reduction through representations of an alpha level (Mendel & Wu, 2007) of the type II fuzzy systems and the understanding of the geometry of type reduction sets, the logical stages to be followed in fuzzy systems are the formulation of fuzzy systems quasi II, through the interconnections of type I systems with interval type II fuzzy systems, or by means of the interconnections of only interval type II fuzzy systems.

5G Networks

Taking into account the approaches of 4G mobile networks (4th Generation Mobile Networks) regarding their speed capabilities (with LTE Advanced speeds up to 1 Gbps), the basic definitions of the required reach in the networks 5G (Fifth Generation of Mobile Networks) is being approached. Among these definitions and as the main objective the support of capacities of up to 10 Gbps for mobile users (Dubois & Prade, 1997) is established. The following is a brief explanation of some key points that have been found relevant in the context of 5G systems development.

A. Beam Multiple Access Division (BDMA) and Spatial Division Multiple Access (SDMA): As explained in (Amaya et al., 2014; Gupta & Jha, 2015; Irnich, Kronander, Selen, & Li, 2013; Roy, n.d.; C. Sun et al., 2015) among the medium access methods that are proposed to improve speeds within the 5G network are BDMA and SDMA, which provide access to the medium of mobile users through electromagnetic signal bundles dedicated to users. The concept, in essence, is the ability of electromagnetic systems to deliver information to the user in a dedicated manner using a specific signal (electromagnetic beam). This means that a dedicated signal is required in the physical space for each user and in this way, they can share the electromagnetic medium.

In (Roy, n.d.) different technologies are defined to achieve the spatial separation in the medium access, to have a better understanding of these subjects it will be exposed the one that is considered as a better acceptance in the understanding of the concept:

> **Switched Beam Technology:** This technology seeks to develop intelligent hardware and software that allows defining which electromagnetic beam is used for communication with each specific user, during a specific time instant. The complications associated with this technique lay within the definitions of temporality and assignment of communication beams to the user, especially for moving users (Roy, n.d.).

B. Massive MIMO: The use of multiple antennas to transfer more information to users is the beginning of the current MIMO scheme. The Massive MIMO scheme, proposes the use of a high number of antennas (around hundreds (Gupta & Jha, 2015)), this creates a great difference to the current architectures, which allow maximum 4X4 schemes (4 antennas to transmit and 4 to receive simultaneously (Mohandas & Bhaskar, 2013; Werner, Furuskog, Riback, & Hagerman, 2010). Figure 4 illustrates Massive MMO deployment proposal.

As shown in figure 4, MIMO requires the existence of more than one antenna for transmission and more than one antenna for reception. Massive MIMO (also shown in figure 4) uses hundreds of antennas for transmission and reception. In figure 4 it is shown how multiple antennas use spatial diversity to achieve the delivery of the information on the RF (Radio Frequency) channels. The idea is that each antenna has communication with directivity and when the signals overlap they create constructive additions to the signals. Likewise, challenges arise to achieve the efficient transmission in systems of high antenna density, obtaining the minimum interference and destructive signals between them. In (Agiwal et al., 2016; Gupta & Jha, 2015; Olwal, Djouani, & Kurien, 2016; C. Sun et al., 2015; S. Sun, Rong, Hu, & Qian, 2015), are mentioned the different challenges that are addressed to achieve efficient systems with Massive MIMO.

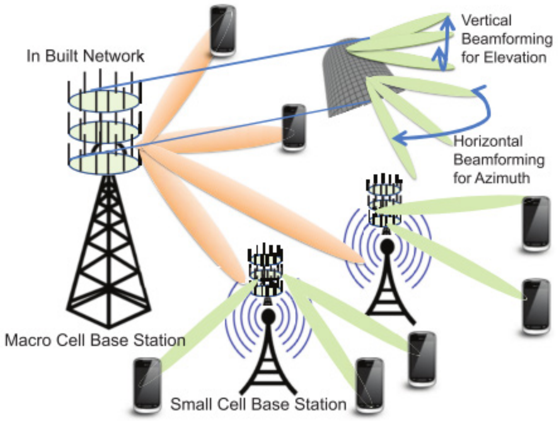

Figure 4. Massive MIMO (Agiwal, Roy, & Saxena, 2016).

C. Spectrum Sharing: Taking into account that the bit rates that are targeted in 5G are quite high compared to the current ones, the efficient use of large blocks of spectrum for 5G can be seen in the development horizon. Within the postulates for the new generation of mobile networks, it is defined that 5G networks will use the existing mobile networks allowing through the simultaneous communication of all the technologies to achieve a greater transfer of data. This means that unlike today's mobile network technologies, in which there is a single connection to a specific technology (LTE, HSPA, UMTS, EDGE or GPRS) in 5G, it is proposed to have a simultaneous connection with all available technologies to achieve parallel communications and connections with all the available technologies.

Under this precept, it can then be thought about the administration of the spectrum that must perform 5G in order to deliver the spectrum resource efficiently and without obstructing existing communication technologies. It is then when the techniques of Spectrum Sharing are defined on which the allocation of spectrum resources to the communication nodes are defined (Chatzikokolakis, Spapis, Kaloxylos, & Alonistioti, 2015; Gupta & Jha, 2015; Irnich et al., 2013). The best approach to define Spectrum Sharing techniques is through the definition of the spectrum sharing technologies scope. According to what is exposed in (Irnich et al., 2013), there are three basic scenarios to share the spectrum:

1. Sharing in just one Technology: It refers to sharing spectrum resources only under a defined technology, i.e., between 3G technology sectors.
2. Sharing between Well-Defined Technologies: In this scenario, the spectrum between standardized regulated technologies is shared, i.e., the spectrum is shared between UMTS and LTE technologies).
3. Spectrum Free Sharing: In this scenario, only the band of the spectrum to be used is reviewed, regardless of whether any (even unregulated) technologies are being used, i.e., spectrum that can be shared in amateur radio bands.

Now given the scenarios, the definition of the general techniques for Spectrum Sharing are defined in two:

1. Distributed Spectrum Sharing Technique: In this solution, each communications node makes use of the spectrum autonomously and reviews the availability of the spectrum and coordinates with the adjacent nodes the possible use using signaling. An example of this application is the current use of WIFI networks, which choose the best channel to transmit by detecting the use of the spectrum around them in the possible bands to use.
2. Centralized Spectrum Sharing Technique: In this technique, a centralized entity manages the information regarding the available resources in a specific location in a specific time, and according to this information, the decisions of spectrum utilization are made. An example of this is observed in geolocation databases for the use of unused TV bands.

D. Slicing: The concept of Slicing as defined in (Da Silva et al., 2016; Yoo, 2016), it is shown in this paper the ability of the 5G technology to divide the network into independent network piece that can serve different services in a dedicated way. Under this concept, each network piece is composed of network functions that are selected for a specific service, and this piece is called "Network Slice."

With this idea in mind, the challenges for an adequate implementation of Slicing in 5G networks can be addressed according to what is stated in (Da Silva et al., 2016; Sama, An, Wei, & Beker, 2016; Yoo, 2016):

A. To achieve an architecture that supports divided functionalities for the network traffic and for the roaming services in the 5G systems that arise.
B. To achieve the proper separation between the different network instances (NSI-Network Slice Instance).
C. Sharing resources appropriately among different NSIs.
D. Define which network functions should be shared and which should be managed centrally in the network.
E. Define the procedures to define the appropriate NSI for a user.
F. Define how the appropriate support will be provided to third parties through Network Slicing.
G. To make a clear definition of the scope, mechanisms, and functionalities when implementing Network Access Slicing (Radio Access Network Slicing).

In (Sama et al., 2016) a proposal is presented to address the problem of Slicing focused mainly on the Evolved Packet Core (EPC) network that can be considered as a starting point on the research carried out regarding slicing.

E. SDN: The definitions that compose the Software Defined Network paradigm (SDN) will be explained in detail in section IV, but it is exposed in this section the applications that have been defined for 5G networks.

According to what can be seen in (Abdurrehman, Sadique, & Shah, 2016; Cho, Lai, Shih, & Chao, 2014; Costa-requena et al., 2014; Ksentini, Bagaa, & Taleb, 2016; Sama et al., 2016; Yazici, Kozat, & Sunay, 2014; Zhang, Xie, & Yang, 2015), among the main characteristics defined as 5G technology stands the deployment of SDN (Software Defined Networks) and NFV (Network Functions Virtualization) for the management of 5G technology resources. In (Yazici et al., 2014) it is shown how the SDN paradigm allows to separate the control functions of the elements of the core of the mobile network (PGW - Packet Gateway and SGW-Serving Gateway) and that this development can be extended even to the RAN Network and the communications between devices (D2D - Device to Device). Figure 5 illustrates the proposed architecture for a 5G network under the SDN paradigm with the definition set forth.

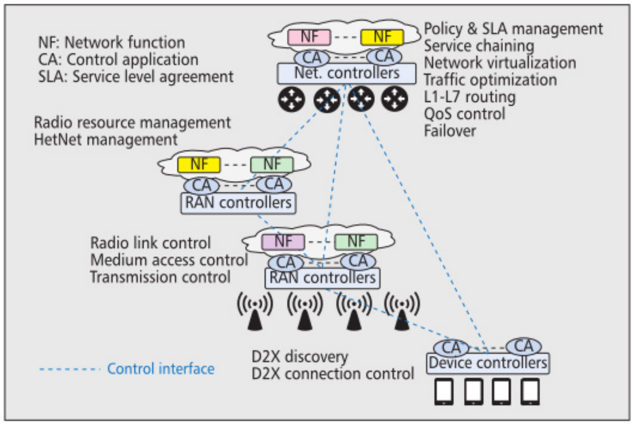

Figure 5. 5G Network Architecture under SDN Paradigm (Yazici et al., 2014).

In figure 5, the different layers of a mobile network are shown:

- **A. The Core Layer:** This layer is shown in the upper part of figure 5. The Net. Controllers are defined in this layer where policies, concatenation of services, traffic optimization, routing and other functionalities are stated.
- **B. The Heterogeneous Network and Radio Resource Management Layer (HetNet):** The central part depicted in figure 5 represents the layer where the Radio Resource management (Hetnet management) is defined. The elements that allow the traffic of information in the air interface are managed in this layer.
- **C. The Media Access Layer**: This layer is also depicted in the central part of figure 5 where the Radio Link Control, Medium Access Control, and Transmission Control are performed. This layer defines how the different users are connected to the network through the air interface.
- **D. The Device Controller Layer:** The lower part of figure 5 represents the Device Controllers. In the framework of the SDN architecture, the user's devices and the possible connections between them are located in this layer.

As shown in Figure 5, each network layer is separated regarding its network functions and control applications, as defined in the SDN paradigm.

In (Sama et al., 2016) the concept of implementing the SDN paradigm is further extended in the core of the mobile network, starting from the current architecture of the LTE network with the same core elements for a 5G network proposal, it is noteworthy that the proposed approach interconnects the Network Slicing with the SDN architecture, indicating that different network services are assigned different control and switching resources. The definition given in (Sama et al., 2016) states that the different current functions of the Evolved Packet Core (EPC) in general can be decomposed into metafunctions and that these are distributed under SDN in the control plane and user plane.

Similarly, to have a more global conception regarding the application of SDN in the 5G networks in (Abdurrehman et al., 2016; Cho et al., 2014; Ksentini et al., 2016; Zhang et al., 2015) different SDN architectures are defined as proposals for 5G networks. These architectures highlight the following aspects:

- A. The definition of programmable networks under SDN allows 5G architectures to take advantage of the resources and programmable optimizations for their services.
- B. Additional services are offered because of SDN for 5G, such as Interconnection between Data Centers (DCI), load minimization and relocation of SGWs and caching in the Radio Access Network (RAN).
- C. Different functionalities and common benefits are established for network services through SDN, such as Management of higher traffic volumes, lower latency compared to current networks, decreases in operating costs (mainly associated with consumption Energetic), flexible routing and network virtualization.
- D. Likewise, a technology similar to SDN is proposed for the management of radio - SDR; this technology focuses on managing the RF interface resources in the access layer so that the users can review the different frequency bands so they can connect to different technologies through a single interface.

SDN Architecture

The SDN paradigm is proposed by the ONF organization (Open Networking Foundation) as an alternative to traditional network structures, in which each node of the telecommunications system individually processes traffic decisions and does the forwarding actions according to the inner algorithms. In the SDN paradigm, a network architecture is proposed, where the control of the network is separated from the traffic forwarding, and it is directly programmable. As discussed in (Xia, Wen, Foh, Niyato, & Xie, 2015), the inherent protocol for the SDN architecture is OpenFlow; which communicates the data plane with the control plane. This is accomplished through the abstraction of the data plane with flow tables, where each flow is a combination of "n" possible headers from layer 2 to layer 4 (in the OSI model).

Figure 6 shows the clear difference between traditional traffic forwarding architectures in telecommunication systems and the approach established by the SDN paradigm. In this way, the SDN architecture has evolved regarding its definition and contemplates even to support circuits switching networks (Xia et al., 2015) through circuits switching flow tables, thus allowing a macro definition of the scope of the paradigm to all telecommunications systems. There are also projects that establish the approximation for the transition of the current networks to an SDN scheme, as shown in (Gerola et al., 2013) a definition of the SDN environment known as OFELIA (OpenFlow in Europe Linking Infrastructure and Applications) and VeRTIGO (Virtual Topologies Generalization in OpenFlow Networks) which allow the experimentation required for different environments (islands) of SDN networks. From this test environment, the generation of "OpenFlow Agents" can be denoted, since they allow the linking of Open Flow Hardware to an SDN architecture (intermediaries for traditional Hardware and SDN architecture). Figure 6 shows how conventional networks operate, in which each node make the routing decisions independently and how SDN networks operate, in which an SDN controller takes all the routing decisions including learning at the link layer level, security issues and quality of service policies. Under the SDN parading the nodes just forward the traffic according to what the SDN controller establishes.

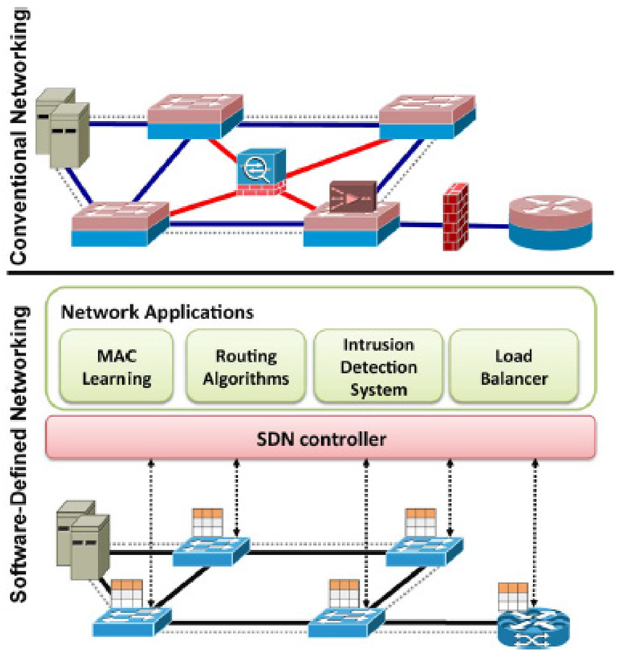

Figure 6. Legacy Network Vs. SDN (Kreutz et al., 2015).

As discussed earlier in this article, the SDN architecture is a fundamental pillar in the different definitions of the scope of 5G networks, this is due to the fact that for the different functionalities presented by 5G systems, independent nodes may not be defined to take decisions by their own, for example, the core network will need the flexibility of assigning resources of the whole network to the users or applications (Network Slicing) or otherwise the end users will be able to share resources of different nodes with autonomous decisions (D2D environments) by decisions made in the core network. In addition to this, the SDN architecture has allowed the integration of the different layers of the mobile networks for a unified management, as discussed in (Sama et al., 2016) (for the definition of the core services of the network), and also illustrated in (Nguyen, Bonnet, & Harri, 2016; S. Sun et al., 2015) where SDN architecture applications are defined for mobile network access (specific to SDM, Massive MIMO and mobility management). However, the significance of the SDN architecture goes further into service definitions and even integrates transport layers.

As shown in (Costa-requena et al., 2014; Iovanna & Ubaldi, 2015; Sarmiento et al., 2016; Yamashita et al., 2016), the application of the SDN architecture covers the allocation of resources in the backhaul of mobile networks, especially over optical transmission systems, where the resources of the radio access network and the resources of the optical networks are interrelated to guarantee the services of the users. In addition to this scheme, there are contemplated SDN-based hardware schemes (optical nodes and transducers) to achieve the requirements of the high traffic demands and separation of services required in 5G (Sarmiento et al., 2016; Yamashita et al., 2016).

Finally, it is possible to show that there are already proposals for the harmonization of the SDN schemes for the access and transport interfaces in the mobile networks for the 5G technologies, in (Vilalta et al., 2016) a proposal is shown on how to orchestrate the different control layers of the SDN architecture (radio resource control layer and transport resources control layer) through a principal/secondary topology, which allows a demonstrative evaluation of the hierarchy to achieve the provisioning and recovery of resources and services in End-To-End systems under the SDN architecture.

Fuzzy systems in 5G networks and SDN architectures

At present of this paper, there are few applications of fuzzy systems in telecommunication systems. It is possible to denote works such as those shown in (Albarracin & Melgarejo, 2010) where the fuzzy systems are applied to communication channels; but specifically for the development of 5G technologies, the presented proposals focused mainly on the handling of the air interface, such as that found in (Aryal, Dhungana, & Paudyal, 2012), which defines the use of fuzzy systems for the management of interference in RF systems, seeking to identify an "α" term and its variations according to different parameters from the radio frequency interface (e.g. amount of connected users, mobility, synchronization, available spectrum, etc.), which can determine the variation of the interference in the system.

In (Peng, Wang, Li, Xiang, & Lau, 2015), advances and new mechanisms are shown for heterogeneous networks (HetNets) and also the coexistence of high-power and low-power nodes is proposed, as well as spectral efficiency, energy efficiency and reuse of space resources. However, it is considered that the management of the interference generated between different types of nodes becomes a challenge, and in this scenario, a controller based on the fuzzy logic that modifies the handover margins dynamically supports the whole concept of robust mobility optimization.

Also in (Demydov et al., 2015), the use of fuzzy systems for handover algorithms is used, specifically to support Vertical Handover in HetNet networks. In this scenario, fuzzy systems are used to determine the decision criterion regarding the performance of the handover (change of the server node for one user to another, given its mobility). In this model, the different current mobile network systems (LTE, UMTS, and GSM) and their associated load are presented as inputs, and through the fuzzy system, it is established if the handover should be performed.

Similarly, in (Wu, Liu, Huang, & Zheng, 2015) fuzzy systems are used for the parameter optimization in a handover process. In this research, an algorithm based on a Q-Learning is proposed on the fuzzy systems for mobility management in small cell networks. In the proposed algorithm, the Call Dropping Ratio (CDR) and HandOvers Rate (HOR) are used as the initial inputs to dynamically adapt the Handover Margin (HOM) and thus regulate the number of handovers and signaling transmitted over the network.

As a final example of the application of fuzzy systems in the approaches for 5G networks, the use of fuzzy systems for the best choice of radio access technology for users is also defined (Vertical Handover) is presented in (Kaloxylos, Barmpounakis, Spapis, & Alonistioti, n.d.). In this proposal, unlike (Demydov et al., 2015), more variables are taken at the input of the fuzzy system to define what is the Radio Access Technology (RAT) to be used by the user. In this model, the use of the variables of mobility, RAT load, backhaul network load, Reference Signal Received Quality (RSRQ) and the sensitivity to the latency by the service used by the user is proposed. As seen, more variables are included than those proposed in (Demydov et al., 2015) (RAT and load) to determine the best technology to be used by the user and thus to establish if it is consistent to perform the user's handover to another technology.

However, regarding the development of fuzzy systems applied to SDN architectures, there are developments such as those described in (Bhandari & Singh, 2016), where it is proposed to use fuzzy systems for the provisioning of traffic in an SDN architecture. In this model, the fuzzy system is applied in the control plane to decide the route that should be assigned to the traffic that reaches the network. In this scenario the use of two fuzzy systems are taken into account to make the decision, the first fuzzy system is focused on measuring and assessing the traffic behavior regarding the network KPIs (load and delay) for this specific traffic; the second fuzzy system evaluates the capacity of the links through which the traffic will be sent. In this application, the combination of several fuzzy systems is observed to achieve decision-making and to determine the best paths for traffic flows. It is important to denote that this architecture, still manages a scheme based on type I fuzzy systems.

In (Dotcenko et al., 2014) it is shown how fuzzy systems can be used to implement security algorithms in the traffic flows of SDN networks. In this model, the fuzzy system inputs are the anomalies of the flows that can be considered as malicious traffic, and then the fuzzy system processes the information, and with recurrent training, it defines which flows are malicious, and it also allows to decide isolation or to block the malicious traffic.

Conclusions

According to what is presented in the different sections of this paper, it is evident that the 5G technology has not yet been defined regarding how it will offer telecommunications services; however, there are great definitions focusing on the architectures and functionalities that are considered crucial in the development of this technology. It is also observed that SDN architectures are more advanced regarding deployments, compared to 5G technologies; and that this same development has allowed the SDN architecture to become a mainstay of 5G technology.

In this matter, it is also noted that the implementation of fuzzy systems for decision making in the various telecommunication systems has not been very exploited; and that only type I fuzzy systems have been applied in the developments (except (Albarracin & Melgarejo, 2010)) on systems architectures that include fuzzy systems. This current picture of technology development provides a broad spectrum of opportunities for the development and integration of fuzzy systems in emerging mobile telecommunication systems.

Regarding this, some possible fields of investigation are presented:

A. Integration of the decision-making techniques through fuzzy systems in different network layers over an SDN architecture, where all decisions in the control layer are validated through type I, type II and quasi-II fuzzy systems.
B. Application of type II and quasi-II fuzzy systems for decision making in the access layer of mobile systems, such as handover processes (both Intra-System and IRAT) and allocation of air interface resources to the users.

C. Decision making through fuzzy systems for Network Slicing scenarios, where different network resources are evaluated in all layers (Access, Transport, and Core) and depending on the need of the user, the quantity and capacity of resources will be allocated for a specific service dynamically.
D. Evaluation of the integration of type II and quasi-II fuzzy systems in the current control plane processing in the SDN architecture and its coupling with the current transport protocol for SDN (Open Flow).
E. Application of fuzzy systems in the decision making of the resource allocation in scenarios of Massive MIMO to different users, taking into account the environment variables and the type of service that the users require.
F. Application of type I, type II and quasi-II fuzzy systems for the decision making in the allocation of the air interface resources for the BDMA and SDMA medium access schemes.

References

Abdurrehman, S., Sadique, M., & Shah, P. N. (2016). To Use Software Defined Networking Technology In Telecommunication For 5-G Network. *International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT)*, 1046–1049.

Adlassnig, K., & Vienna, A. (n.d.). Fuzzy Set Theory and Fuzzy Logic (pp. 103–125).

Agiwal, M., Roy, A., & Saxena, N. (2016). Next generation 5G wireless networks: A comprehensive survey. *IEEE Communications Surveys and Tutorials*. https://doi.org/10.1109/COMST.2016.2532458

Albarracin, L. F., & Melgarejo, M. A. (2010). An approach for channel equalization using quasi type-2 fuzzy systems. *2010 Annual Meeting of the North American Fuzzy Information Processing Society*, (1), 1–5. https://doi.org/10.1109/NAFIPS.2010.5548203

Amaya, N., Yan, S., Channegowda, M., Rofoee, B. R., Shu, Y., Rashidi, M., … Wada, N. (2014). First Demonstration of Software Defined Networking (SDN) over Space Division Multiplexing (SDM) Optical Networks. *Optics Express*, *22*(3), 3638. https://doi.org/10.1364/OE.22.003638

Aryal, S. R., Dhungana, H., & Paudyal, K. (2012). Novel approach for Interference Management in cognitive radio. *2012 Third Asian Himalayas International Conference on Internet*, 1–5. https://doi.org/10.1109/AHICI.2012.6408448

Bhandari, A., & Singh, V. P. (2016). Design of Fuzzy-Based Traffic Provisioning in Software Defined Network. *I.J. Information Technology and Computer Science*, (9), 49–61. https://doi.org/10.5815/ijitcs.2016.09.07

Chatzikokolakis, K., Spapis, P., Kaloxylos, A., & Alonistioti, N. (2015). Toward spectrum sharing: opportunities and technical enablers. *IEEE Communications Magazine*, *53*(7), 26–33. https://doi.org/10.1109/MCOM.2015.7158262

Cho, H. H., Lai, C. F., Shih, T. K., & Chao, H. C. (2014). Integration of SDR and SDN for 5G. *IEEE Access*, *2*, 1209–1217. https://doi.org/10.1109/ACCESS.2014.2357435

Costa-Requena, J., Kantola, R., Llorente, J., Ferrer, V., Manner, J., Ding, A. Y., … Tarkoma, S. (2014). Software Defined 5G Mobile Backhaul. *1st International Conference on 5G for Ubiquitous Connectivity (5GU)*, 258–263. https://doi.org/10.4108/icst.5gu.2014.258054

Coupland, S. (2007). Type-2 fuzzy sets: Geometric defuzzification and type-reduction. *Proceedings of the 2007 IEEE Symposium on Foundations of Computational Intelligence, FOCI 2007*, (Foci), 622–629. https://doi.org/10.1109/FOCI.2007.371537

Coupland, S., & John, R. (2007). Geometric Type-1 and Type-2 Fuzzy Logic Systems. *IEEE Transactions on Fuzzy Systems*, *15*(1), 3–15. https://doi.org/10.1109/TFUZZ.2006.889764

Da Silva, I., Mildh, G., Kaloxylos, A., Spapis, P., Buracchini, E., Trogolo, A., … Bayer, N.

(2016). Impact of network slicing on 5G Radio Access Networks. *EUCNC 2016 - European Conference on Networks and Communications*, 153–157. https://doi.org/10.1109/EuCNC.2016.7561023

Demydov, I., Seliuchenko, M., Beshley, M., & Brych, M. (2015). Mobility management and vertical handover decision in an always best connected heterogeneous network. *Proceedings of 13th International Conference: The Experience of Designing and Application of CAD Systems in Microelectronics, CADSM 2015*, 103–105. https://doi.org/10.1109/CADSM.2015.7230808

Dimitar, R. (2006). *Introduction to Fuzzy Control and Modeling*. *Control Engineering*.

Dotcenko, S., Vladyko, A., & Letenko, I. (2014). A Fuzzy Logic-Based Information Security Management for Software-Defined Networks. *Advanced Communication Technology (ICACT), 2014 16th International Conference on*, (February), 167–171. https://doi.org/10.1109/ICACT.2014.6778942

Dubois, D., & Prade, H. (1997). The three semantics of fuzzy sets. *Fuzzy Sets and Systems*, *90*(2), 141–150. https://doi.org/10.1016/S0165-0114(97)00080-8

Gerola, M., Doriguzzi Corin, R., Riggio, R., De Pellegrini, F., Salvadori, E., Woesner, H., … Bergesio, L. (2013). Demonstrating inter-testbed network virtualization in OFELIA SDN experimental facility. *ACM SIGCOMM Comput. Commun. Rev.*, 39–40.

Gupta, A., & Jha, R. K. (2015). A Survey of 5G Network: Architecture and Emerging Technologies. *IEEE Access*, *3*, 1206–1232. https://doi.org/10.1109/ACCESS.2015.2461602

Iovanna, P., & Ubaldi, F. (2015). SDN solutions for 5G transport networks. *2015 International Conference on Photonics in Switching, PS 2015*, 297–299. https://doi.org/10.1109/PS.2015.7329032

Irnich, T., Kronander, J., Selen, Y., & Li, G. (2013). Spectrum sharing scenarios and resulting technical requirements for 5G systems. *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC*, 127–132. https://doi.org/10.1109/PIMRCW.2013.6707850

Jantzen, J. (1998). *Tutorial on fuzzy logic*.

Kaloxylos, A., Barmpounakis, S., Spapis, P., & Alonistioti, N. (n.d.). An efficient RAT selection mechanism for 5G cellular networks.

Kreutz, D., RAmos, F. M. ., Veríssimo, P. E., Rothenberg, C. E., Azodolmolky, S., & Uhlig, S. (2015). Software-Defined Networking : A Comprehensive Survey. *Proceedings of the IEEE*, *103*(1), 14–76. https://doi.org/10.1109/JPROC.2014.2371999

Ksentini, A., Bagaa, M., & Taleb, T. (2016). On using SDN in 5G : the controller placement problem. https://doi.org/10.1109/GLOCOM.2016.7842066

Mendel, J. M. (1995). Fuzzy logic systems for engineering: a tutorial. *Proceedings of the IEEE*, *83*(3), 345–377. https://doi.org/10.1109/5.364485

Mendel, J. M. (2007). Type-2 Fuzzy Sets and Systems: An Overview. *IEEE COMPUTATIONAL INTELLIGENCE MAGAZINE*, (February), 4–8. https://doi.org/10.1007/s10979-011-9268-2

Mendel, J. M., & Liu, F. (2008). On New Quasi-Type-2 Fuzzy Logic Systems. *International Conference on Fuzzy Systems (FUZZ 2008)*, 354–360. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1681901

Mendel, J. M., & Wu, H. (2007). Type-2 fuzzistics for nonsymmetric interval type-2 fuzzy sets: Forward problems. *IEEE Transactions on Fuzzy Systems*, *15*(5), 916–930. https://doi.org/10.1109/TFUZZ.2006.889959

Mohandas, L., & Bhaskar, V. (2013). Performance analysis of mimo transmission modes in an lte system. *Chennai Fourth International Conference on Sustainable Energy and Intelligent Systems*, 1–6.

Nguyen, T.-T., Bonnet, C., & Harri, J. (2016). SDN-based distributed mobility management for 5G Networks. *International Conference on Information Networking*, (Wcnc), 337–342. https://doi.org/10.1109/ICOIN.2016.7427127

Olwal, T. O., Djouani, K., & Kurien, A. M. (2016). A Survey of Resource Management Toward 5G Radio Access Networks. *IEEE Communications Surveys and Tutorials*. https://doi.org/10.1109/COMST.2016.2550765

Peng, M., Wang, C., Li, J., Xiang, H., & Lau, V. (2015). Recent Advances in Underlay Heterogeneous Networks : Interference Control , Resource Allocation , and Self-Organization. *IEEE COMMUNICATION SURVEYS & TUTORIALS*, *17*(2), 700–729.

Roy, R. H. (n.d.). Spatial Division Multiple Access Technology and Its Application t o Wireless Communication Systems.

Sama, M. R., An, X., Wei, Q., & Beker, S. (2016). Reshaping the Mobile core network via function decomposition and network slicing for the 5G era. *IEEE Wireless Communications and Networking Conference Workshops, WCNCW 2016*, 90–96. https://doi.org/10.1109/WCNCW.2016.7552681

Sarmiento, S., Montero, R., Altabas, J. A., Izquierdo, D., Agraz, F., Pages, A., … Lazaro, J. A. (2016). SDN-enabled flexible optical node designs and transceivers for sustainable metro-access networks convergence. *International Conference on Transparent Optical Networks*, *2016*, 2–5. https://doi.org/10.1109/ICTON.2016.7550659

Starczewski, J. T. (2006). A triangular type-2 fuzzy logic system. *IEEE International Conference on Fuzzy Systems*, 1460–1467. https://doi.org/10.1109/FUZZY.2006.1681901

Sun, C., Gao, X., Jin, S., Matthaiou, M., Ding, Z., & Xiao, C. (2015). Beam Division Multiple Access Transmission for Massive MIMO Communications. *IEEE Transactions on Communications*, *63*(6), 2170–2184. https://doi.org/10.1109/TCOMM.2015.2425882

Sun, S., Rong, B., Hu, R. Q., & Qian, Y. (2015). Spatial Domain Management and Massive MIMO Coordination in 5G SDN. *IEEE Access*, *3*, 2238–2251. https://doi.org/10.1109/ACCESS.2015.2498609

Vilalta, R., Mayoral, A., Baranda, J., Nuñez, J., Casellas, R., Martínez, R., … Muñoz, R. (2016). Hierarchical SDN Orchestration of Wireless and Optical Networks with E2E Provisioning and Recovery for Future 5G Networks. *Optical Fiber Communication Conference 2016*, 2–4.

Wang, C. (2015). *A Study of Membership Functions on Mamdani-Type Fuzzy Inference System for Industrial Decision-Making*. Lehigh University.

Werner, K., Furuskog, J., Riback, M., & Hagerman, B. (2010). Antenna configurations for 4x4 MIMO in LTE - Field measurements. *IEEE Vehicular Technology Conference*. https://doi.org/10.1109/VETECS.2010.5493762

Wu, J., Liu, J., Huang, Z., & Zheng, S. (2015). Dynamic fuzzy Q-learning for handover parameters optimization in 5G multi-tier networks. *International Conference on Wireless Communications and Signal Processing, WCSP 2015*. https://doi.org/10.1109/WCSP.2015.7341220

Xia, W., Wen, Y., Foh, C. H., Niyato, D., & Xie, H. (2015). A survey on software-defined networking. *IEEE COMMUNICATION SURVEYS & TUTORIALS*, *17*(1), 115–124. https://doi.org/10.1007/978-3-319-28430-9_9

Xu, W., Pang, Y., Ma, J., Wang, S.-Y., Hao, G., Zeng, S., & Quian, Y.-H. (2008). FRAUD DETECTION IN TELECOMMUNICATION : A ROUGH FUZZY SET BASED APPROACH. *Proceedings of the Seventh International Conference on Machine Learning and Cybernetics*, (July), 1249–1253.

Yamashita, S., Yamada, A., Nakatsugawa, K., Soumiya, T., Miyabe, M., & Katagiri, T. (2016). Extension of OpenFlow protocol to support optical transport network, and its implementation. *IEEE Conference on Standards for Communications and Networking, CSCN 2015*, 263–268. https://doi.org/10.1109/CSCN.2015.7390455

Yazici, V., Kozat, U. C., & Sunay, M. O. (2014). A new control plane for 5G network architecture with a case study on unified handoff, mobility, and routing management. *IEEE Communications Magazine*, *52*(11), 76–85. https://doi.org/10.1109/MCOM.2014.6957146

Yoo, T. (2016). Network slicing architecture for 5G network. *International Conference on Information and Communication Technology Convergence (ICTC)*, 1010–1014. https://doi.org/10.1109/ICTC.2016.7763354

Yosra JARRAYA, Souhir BOUAZIZ, Adel M. ALIMI, A. A. (2016). Evolutionary Hierarchical Fuzzy modeling of Interval Type-2 Beta Fuzzy Systems. *IEEE International Conference on Systems, Man, and Cybernetics*, 3481–3486.

Zhang, J., Xie, W., & Yang, F. (2015). An Architecture for 5G Mobile Network Based on SDN and NFV. *ICWMMN2015 Proceedings*, 87–92.