Notes on Intuitionistic Fuzzy Sets
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QoS characterization of some service compositions based on intuitionistic fuzzy pairs

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Abstract: In recent years, a new approach to the estimation of uncertainty in service systems has been developed. It is based on a causal characterization of the traffic in virtual service devices and makes use of the notion of an intuitionistic fuzzy pair. In a series of papers, this approach has been used to obtain quality of service estimations of various compositions of services. In the present paper, an overview of the main results related to the estimation of uncertainty in service compositions is presented.
Keywords: Intuitionistic fuzzy pairs, Service composition, Quality of service.
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1 Introduction

In recent years, the computing paradigm has moved from centralized service providing to distributed computing paradigms [4]. Distributed computing paradigms such as Internet of Things (IoT), Fog (Edge) mobile computing and cloud computing allow for building enterprise architectures through service composition and recomposition. Often, a software application can benefit from services with the same functionality but different Quality of Service (QoS) values [13]. QoS in service compositions is an important criterion for the selection of services in the process flow in order to maintain a certain level of quality. The QoS of a composition of services can be considered as a complex service provision scheme where the service cost varies depending on its partnership with another [6].

The composition of several services represents a new service. The embedded services may share similar functionality but different QoS. Therefore, it is important to define and derive QoS of the various compositions of services. Web service composition issues are considered a significant area of research for selecting the appropriate web services that provide the expected QoS and attain the clients' Service Level Agreement (SLA, see [14]). Service Quality Agreement (SQA) is a program aimed at satisfying both — costumers and service providers. In the standardization SQA documents of ITU-T and ETSI, in force, the uncertain service results are not discussed, but service compositions are foreseen [15]. On the other hand, service termination due to an uncertainty reason and/or uncertainty service result is not rare (e.g., 'abandoned service'). The problem regarding the representation of uncertainty in the service of requests is studied in [9] where the apparatus of the Intuitionistic Fuzzy Sets (IFSs, see [2]) is proposed as an approach aimed at quantifying the uncertainty. The problem is further studied in [10], where three intuitionistic characterizations of uncertainty of the service of requests are proposed: intuitionistic fuzzy flow, intuitionistic fuzzy traffic and intuitionistic fuzzy time characterizations. The advantages of using Intuitionistic Fuzzy Pairs (IFPs, see [3]) are illustrated in the case of a serial composition of two services for which analytical expressions of the degrees of membership, non-membership and uncertainty of the intuitionistic fuzzy traffic, flow and time characterizations are obtained. In [11], inuitiotionistic fuzzy estimation of the uncertainty of parallel composition of services is studied. Finally, in [1] intuitionistic fuzzy estimation of uncertainty of a composition consisting of serial and parallel services is studied.

In the present paper, we shall summarize the results related to the estimation of uncertainty in service compositions. More specifically, we shall focus on the analytical expressions for the degrees of membership, non-membership and uncertainty of some of the intuitionistic fuzzy characterizations of the compositions and their relation to the corresponding degrees of the embedded services.

2 Preliminaries

2.1 Base virtual devices

The basic elements of the conceptual models of service systems are the base virtual devices [7]. A general graphical representation of a base virtual service device (such as server, buffer, switch, etc.) is shown in Figure 1.

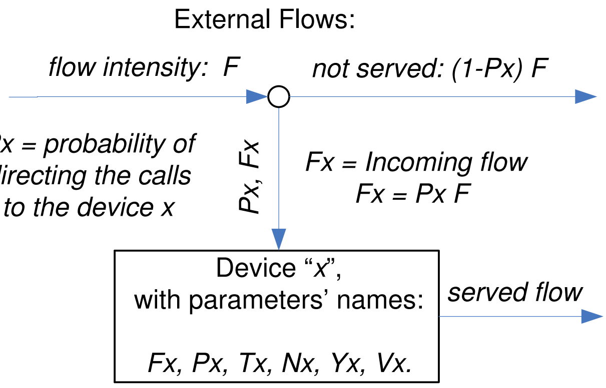

Figure 1. Graphical representation of a base virtual device.

Every base virtual service device is characterized by six parameters. If x is the name of the service device, then its parameters are the following:

- Fx – Intensity or incoming rate (frequency) of the flow of requests (i.e., the number of requests per time unit) to device x;
- Px – Probability of directing the requests towards device x;
- Tx – Service time (duration of servicing of a request) in device x;
- Yx – Traffic intensity [Erlang];
- Vx – Traffic volume [Erlang - time unit];
- Nx – Number of lines (service resources, positions, capacity) of device x.

Base virtual devices of different types are used in the conceptual models (see [7]). The ones used in the present paper together with their graphical representations are shown in Figure 2.

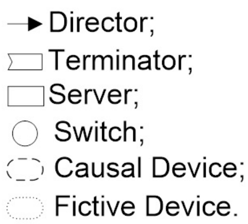

Figure 2. Base virtual device types and their graphical representations.

Each type of base virtual device has a specific function (see [7]):

- Director – points unconditionally to the next device which the request shall enter but without transferring, changing or delaying it.
- Terminator – eliminates every request that enters it (so it leaves the model without any traces).
- Server – models the delay (service time, holding time) of requests in the corresponding device without their generation or elimination. It models also traffic and time characteristics of the requests processing.
- Switch (Transition) – selects one of its possible exits for each request that enters, thus determining the next device where this request shall go to.
- Causal device – virtual device defined for presentation of causes of service ending, e.g., successful (carried) or not (interrupted, abandoned, etc.).
- Fictive device – presents fictive traffic which is necessary for engineering. For example, not carried traffic is fictive, but it is used for calculating of the offered traffic, which is necessary for real device dimensioning.

The base virtual devices do not contain other devices. Comprise virtual devices are also used in the conceptual models of service systems. The base virtual devices can be embedded on several levels in the comprise devices.

2.2 Causal decomposition of the traffic in virtual devices

Following the papers [8, 9], the causes of service ending and the corresponding causal devices, are grouped in generalized comprising causal devices. Three causal traffic qualifiers are enough for representation of the service in a device: "parasitic", "carried" and "served" (see [5]). Their meanining is justified below (see [9]).

The *parasitic traffic* in a pool of resources is the traffic which was unsuccessfully served in the pool. The parasitic traffic occupies real resources but not for a useful service execution. In this paper, we use the qualifier "uncertain" as more adequate to the user's point of view.

The *carried traffic* in a pool of resources is the traffic which was successfully served in the pool (and carried to the next service device). We distinguish between two types of carried traffic:

- 'zero service', e.g., zero waiting in a buffer if the buffer is empty and there is free requested place for the service in the following device. The requests are receiving zero service in the causal 'zero service device' and may be served without delay.
- 'genuine service' – successful and real service of requests in the pool. The service time is noticeable.

The *served traffic* in a pool of resources is any traffic occupying (using) resources in the pool. The served traffic is a sum of the carried and the parasitic traffic.

Apart from that, the notion *not served traffic* and *offered traffic* should be specified.

The *not served traffic* is the traffic not occupying the recourses in the pool, due to any reason, e. g., 'blocking' [5], in the case of lack of service places in the pool. The intensity of the not served traffic is a multiplication of the not served requests' flow intensity and mean service time of the served requests.

The *offered traffic* is a sum of the served and not served traffic intensities in the pool.

A naming system for the parameters of the devices is also proposed (see [9]). Every parameter's name is a concatenation of one or two qualifiers, parameter's symbol and the device name:

Causal name $=$ ⟨qualifier⟩⟨qualifier⟩.⟨Parameter's Symbol⟩.⟨Device Name⟩.

Some of the qualifiers used for characterization of the traffic are (see [8]):

- crr. = carried;
- nsr. = not served;
- ofr. = offered;
- prs. = parasitic;
- srv. = served.

'Parameter's symbol' is one of the letters P, F, T, Y, V, N (see Section 2.1). Qualifiers are used to characterize the parameters of the devices [7]. The qualifiers may be two, one or none. In case that the parameter's symbol is omitted, the causal name is a name of a device (see Fig. 3). The names of the devices are in small or subscript letters. For example, $crr.Fx$ is the intensity of the carried flow of requests of the device x, $prs.Fx$ is the intensity of the parasitic flow of requests of the device x (see Fig. 3). In the figures, only the names of causal devices may be present. The names of the device parameters are implicit.

A general presentation of a service network portion 'x' is shown in Fig. 3. The virtual device $srv.x$ embedded in it has a limited capacity. Because of the limited capacity, requests rejection due to lack of service places (call attempts blocking) may occur.

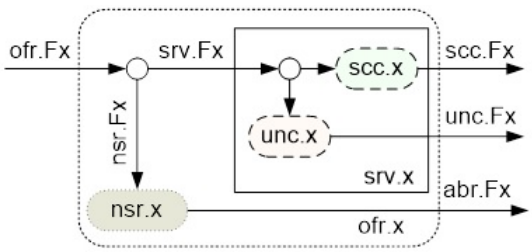

Figure 3. Causal decomposition of the traffic inside a virtual service device x (see [9]).

The device $nsr.x$ is not a part of the service device.It is a part of the comprise fictive device $ofr.x$ which is necessary for dimensioning and traffic estimation.

The service of requests in a system can be classified into:

- successful – the service belongs to a fully completed target service (qualifier $scc.$);
- unsuccessful (abortive) – the service has either received a random denial or has not finished (without final result) all stages of service (qualifiers $nsr.$, $abr.$).;
- uncertain – all required stages of service are passed but the result of the service is unclear, partial, etc., or shortly – non-determined (qualifier $unc.$).

The qualifier $unc.$ is used to characterize the traffic for which the reasons for the parasitic load cannot be determined explicitly. There might be several reasons as to why it cannot be determined explicitly. Some of them are:

- Abandoning/Failure by the users.
- Unsatisfying terms of service according to the users' opinion.
- Technical (objective) reasons – electricity failure, equipment failure, etc.
- Preempted – overtaken by higher priority request.

An important assumption must be stated about the device $unc.x$. It is assumed that in the case of uncertain service the service of the requests is terminated.

3 Intuitionistic fuzzy service characterizations

In order to quantify the uncertainty in the service of requests, the notion of Intuitionistic Fuzzy Pair (IFP) is used (see [3]). An IFP is an ordered couple of real numbers $\langle a, b \rangle$ such that $a, b \in [0, 1]$ and $0 \le a + b \le 1$ which is used as an evaluation of some object or process. The real numbers a and b are referred to as degrees of validity and non-validity or degrees of membership and non-membership, respectively. The real number $c = 1 - a - b$ is the degree of uncertainty.

Let x be a service device with causal decomposition of the traffic as shown in Figure 3. Let us define an IFP $\langle \mu_x^y, \nu_x^y \rangle$, where

$$\mu_x^y = \frac{scc.Yx}{ofr.Yx} \tag{1}$$

$$\nu_x^y = \frac{abr.Yx}{ofr.Yx}\,. \tag{2}$$

From Fig. 3 it is clear that the so defined $\langle \mu_x^y, \nu_x^y \rangle$ is indeed an IFP. The degree of uncertainty is defined as

$$\pi_x^y = \frac{unc.Yx}{ofr.Yx}\,. \tag{3}$$

We shall refer to the above IFP as *intuitionistic fuzzy traffic characterization* of the service.

Let us define an IFP $\langle \mu_x^f, \nu_x^f \rangle$, where

$$\mu_x^f = \frac{scc.Fx}{ofr.Fx} \tag{4}$$

$$\nu_x^f = \frac{abr.Fx}{ofr.Fx}\,. \tag{5}$$

From Figure 3 it is clear that the so defined pair is indeed an IFP. The degree of uncertainty of this pair is given by

$$\pi_x^f = \frac{unc.Fx}{ofr.Fx}\,. \tag{6}$$

We shall refer to the so defined IFP as *intuitionistic fuzzy flow characterization* of the service.

Before we define the thrid intuitionistic fuzzy characterization, the notion of *partial time* should be introduced. Let us consider k subdevices of a service device x which are not exclusively encompassing the service device g. Let the parameters of each such subdevice be Y_i, F_i, T_i. We have

$$Fg = \sum_{i=1}^{k} F_i \,. \tag{7}$$

Obviously, $Fg \leq Fx$ and $Fg = Fx$ only when the subdevices encompass the service device x.

$$Yg = \sum_{i=1}^{k} F_i \, T_i \,. \tag{8}$$

Now, since $Yg = Fg\,Tg$, we have

$$Tg = \frac{Yg}{Fg} = \frac{\sum_{i=1}^{k} F_i T_i}{\sum_{i=1}^{k} F_i} \,. \tag{9}$$

The partial service time Tg is defined by

$$prt.Tg = \frac{Yg}{Fx} = \frac{\sum_{i=1}^{k} F_i \, T_i}{Fx} \,. \tag{10}$$

$prt.Tg$ shows what part of the mean occupation time of the device x belongs the device g. In the special case when the two device x and g are the same, we have

$$prt.Tg = \frac{Yx}{Fx} = Tx \,. \tag{11}$$

The notion of partial time is suitable for the definition of intuitionistic fuzzy time characterization of the real time occupation of service systems. The third (intuitionistic fuzzy time) characterization is given by the pair $\langle \mu_x^t, \nu_x^t \rangle$, where

$$\mu_x^t = \frac{prt.scc.Tx}{srv.Tx} \,, \tag{12}$$

$$\nu_x^t = \frac{prt.abr.Tx}{srv.Tx} \tag{13}$$

and the respective degree of uncertainty is given by

$$\pi_x^t = \frac{prt.unc.Tx}{srv.Tx} \,. \tag{14}$$

We shall refer to the pair $\langle \mu_x^t, \nu_x^t \rangle$ as *intuitionistic fuzzy time characterization* of the service.

4 Intuitionistic fuzzy estimations of the uncertainty of a serial composition of services

In [10], a conceptual model of a serial composition of two services is proposed. It consists of two embedded service devices denoted by 1 and 2. For each of the embedded devices a causal decomposition of the traffic is considered. Using the graphical representation of the serial composition (see Figure 4), analytical expressions for the for the degrees of membership, non-membership and uncertainty of the intuitionistic fuzzy traffic, flow and time characterizations are obtained in [10] characterization.

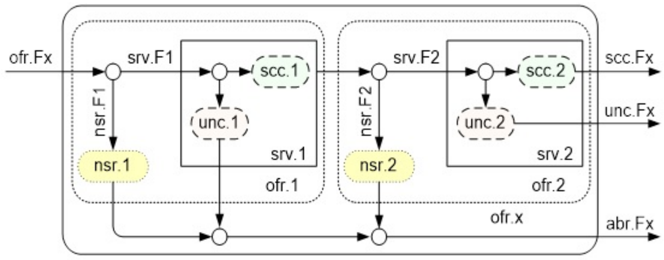

Figure 4. Serial composition of two services inside a virtual service device x (see [9]).

The degree of membership of the intuitionistic fuzzy traffic characterization is given by:

$$\mu_x^y = \frac{(1 - nsr.P_1)(1 - unc.P_1)(1 - nsr.P_2)(1 - unc.P_2)}{unc.P_1\, unc.T_1 + (1 - unc.P_1)[scc.T_1 + unc.P_2\, unc.T_2 + (1 - unc.P_2)scc.T_2]}\,. \tag{15}$$

For the degree of non-membership of the intuitionistic traffic characterization we have

$$\nu_x^y = \frac{nsr.F_1\, srv.T_1 + unc.F_1\, unc.T_1 + nsr.F_2(scc.T_1 + srv.T_2)}{A}\,, \tag{16}$$

where

$$A = ofr.Fx[unc.P_1\, unc.T_1 + (1 - unc.P_1)[scc.T_1 + unc.P_2\, unc.T_2 + (1 - unc.P_2)scc.T_2]] \tag{17}$$

Taking into account that the uncertain traffic and flow intensities of the comprise device are equal to those of the second embedded device, for the degree of uncertainty π_x^y we have

$$\pi_x^y = \frac{(1 - nsr.P_1)(1 - unc.P_1)(1 - nsr.P_2)unc.P_2\, unc.T_2}{unc.P_1\, unc.T_1 + (1 - unc.P_1)[scc.T_1 + unc.P_2\, unc.T_2 + (1 - unc.P_2)scc.T_2]} \tag{18}$$

Now, we shall present the degrees of membership, non-membership and uncertainty of the intuitionistic fuzzy flow characterization of the comprise device. The degree of membership of the intuitionistic fuzzy flow characterization is given by:

$$\mu_x^f = (1 - nsr.P_1)(1 - unc.P_1)(1 - nsr.P_2)(1 - unc.P_2)\,. \tag{19}$$

For the degree of non-membership of the intuitionistic fuzzy flow characterization we have

$$\nu_x^f = nsr.P_1 + (1 - nsr.P_1)[unc.P_1 + (1 - unc.P_1)nsr.P_2]\,. \tag{20}$$

The degree of uncertainty of the intuitionistic fuzzy flow characterization is given by:

$$\pi_x^f = (1 - nsr.P_1)(1 - unc.P_1)(1 - nsr.P_2)unc.P_2 \tag{21}$$

Finally, we shall present the degrees of membership, non-membership and uncertainty of the intuitionistic fuzzy time characterization for the comprise service device. The degree of membership is given by

$$\mu_x^t = \frac{(1 - unc.P_1)(1 - unc.P_2)(scc.T_1 + scc.T_2)}{unc.P_1 + (1 - unc.P_1)} \cdot \frac{1}{B}\,, \tag{22}$$

where

$$B = unc.P_1\, unc.T_1 + (1 - unc.P_1)[scc.T_1 + (1 - nsr.P_2)[unc.P_2\, unc.T_2 + (1 - unc.P_2)scc.T_2]] \,. \quad (23)$$

The degree of non-membership of the intuitionistic fuzzy time characterization is given by:

$$\nu_x^t = \frac{unc.P_1\, unc.T_1 + (1 - unc.P_1)nsr.P_2\, scc.T_1}{C} \,, \quad (24)$$

where

$$C = (1 - nsr.P_1)[unc.P_1\, unc.T_1 + (1 - unc.P_1)[scc.T_1 + (1 - nsr.P_2)[unc.P_2\, unc.T_2 + (1 - unc.P_2)scc.T_2]]] \,. \quad (25)$$

Finally, the degree of uncertainty of the intuitionistic fuzzy time characterization is given by:

$$\pi_x^t = \frac{(1 - unc.P_1)(1 - nsr.P_2)unc.P_2\, unc.T_2}{D} \,, \quad (26)$$

where

$$D = (1 - nsr.P_1)[unc.P_1\, unc.T_1 + (1 - unc.P_1)[scc.T_1 + (1 - nsr.P_2)[unc.P_2\, unc.T_2 + (1 - unc.P_2)scc.T_2]]] \,. \quad (27)$$

5 Intuitionistic fuzzy estimations of the uncertainty of a parallel composition of services

A conceptual model of a parallel composition of two services inside a comprise virtual service x is shown in Fig. 5. The model is described in detail in [11]. The composition of the two embeded service devices 1 and 2 is parallel alternative, i.e., every request is serviced by only one of the two devices. The type of service ending of the embeded devices is preserved (remains the same) for the comprise device. An example of a parallel alternative service is an office with two service places of the same type.

On the basis of the conceptual model shown in Figure 5 analytical expressions for the intuitionistic fuzzy flow characterization of the comprise device through the intuitionistic fuzzy flow charcterizations of the embeded devices are derived in [11].

For the degree of membership of the intuitionistic fuzzy flow characterization of the comprise service device x we have:

$$\mu_x^f = P_1\mu_1^f + P_2\mu_2^f. \quad (28)$$

The degree of non-membership of the intuitionistic fuzzy flow characterization of the comprise virtual service device x is given by:

$$\nu_x^f = P_1\nu_1^f + P_2\nu_2^f. \quad (29)$$

Finally, the degree of uncertainty of the intuitionistic fuzzy flow characterization of the comprise service device x is given by:

$$\pi_x^f = P_1\pi_1^f + P_2\pi_2^f. \quad (30)$$

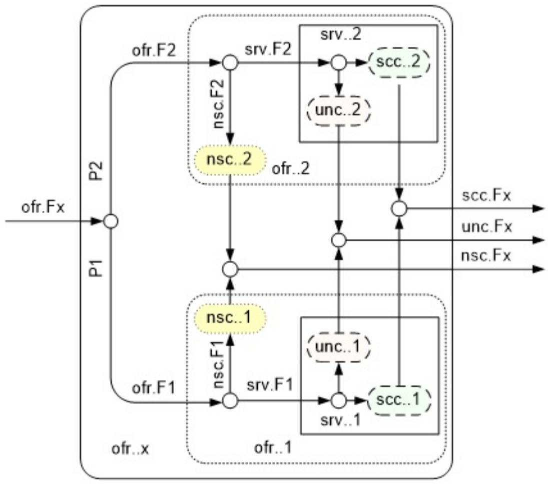

Figure 5. Conceptual model of a parallel composition of two services within a comprise virtual service device x.

6 Intuitionistic fuzzy estimation of the uncertainty of a composition consisting of serial and parallel services

For the first time, in [1], a conceptual model of a complex composition consisting of serial and parallel services is studied. The serial and parallel compositions are represented as comprise servce devices (see Figure 6). Each one of them consists of two embedded service devices.

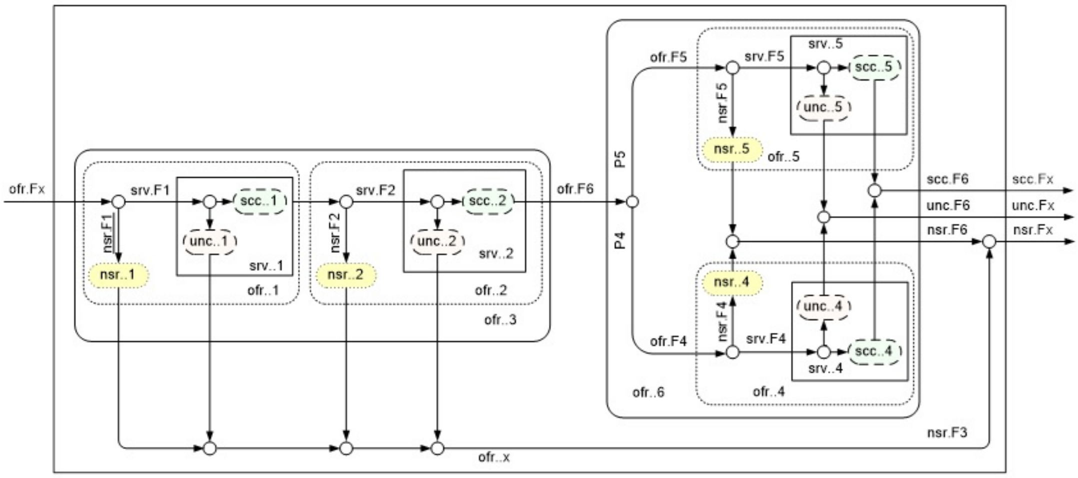

Figure 6. Conceptual model of a composition of two serial and two parallel service devices inside a comprise service device x.

In the comprise service device x, two comprise service devices are embedded. One — denoted by 3 — is a serial composition of two service device denoted by 1 and 2, respectively. The second comprise service device denoted by 6 is a parallel alternative composition of two service devices denoted by 4 and 5, respectively. For each of the service devices $1, 2, 4$ and 5, a causal decomposition of the traffic is considered.

Based on this conceptual model analytical expressions for the degrees of membership, non-membership and uncertainty of the intuitionistic fuzzy flow characterization are derived in [1]. The corresponding degrees for the intuitionistic fuzzy traffic characterization can be obtained in a similar way using the approach presented in [11].

From Fig. 3 and the definitions of the intuitionistic fuzzy flow and probability characterizations in [10, 12] for every service device x we have:

$$\mu_x^f = \mu_x^p = \frac{scc.Fx}{ofr.Fx} = (1 - nsr.Px)(1 - unc.Px)\,, \tag{31}$$

$$\nu_x^f = \nu_x^p = \frac{nsr.Fx}{ofr.Fx} = nsr.Px\,, \tag{32}$$

$$\pi_x^f = \pi_x^p = \frac{unc.Fx}{ofr.Fx} = (1 - nsr.Px)unc.Px\,. \tag{33}$$

Here, we should point out that the composition of the two service devices 1 and 2 in Fig. 6 is different from that in [10]. This is so because it is assumed that the requests which are not served or which are served with uncertainty by device 3 (containing devices 1 and 2) are not served in the next device (device 6). This assumption corresponds to some real life cases. In this way, the flows $nsr.F1$, $unc.F1$, $nsr.F2$ and $unc.F2$ are unified in Fig. 6 as not served.

For the degree of membership of the intuitionistic fuzzy flow characterization of the comprise service device x we have:

$$\mu_x^f = \mu_1^f \mu_2^f (P_4 \mu_4^f + P_5 \mu_5^f)\,. \tag{34}$$

The degree of non-membership of the intuitionistic fuzzy flow characterization of the comprise service device x is given by:

$$\nu_x^f = \mu_1^f \mu_2^f (P_4 \nu_4^f + P_5 \mu_5^f) + \nu_1^f + \pi_1^f + \mu_1^f(\nu_1^f + \pi_2^f)\,. \tag{35}$$

Finally, for the degree of uncertainty of the intuitionistic fuzzy flow characterization of the comprise service device x we have:

$$\pi_x^f = \mu_1^f \mu_2^f (P_4 \pi_4^f + P_5 \pi_5^f)\,. \tag{36}$$

7 Conclusion and future work

We have outlined the existing results about the characterization of the uncertainty in the service of requests in compositions of services based on the notion of an IFP. The importance of the obtained results is that they allow for the QoS of the comprise service to be represented as a composition of the QoS of the embedded services. Further research on the estimation of the uncertainty of service compositions requires conceptual models of other types of service compositions such as concomitant composition, cyclic composition and complex compositions consisting of two or more simple compositions to be constructed and analytical expressions for the degrees of membership, non-membership and uncertainty of the comprise service to be derived.

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