Distributed Systems Ontology

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***Abstract*—Applications in distributed systems, have increased their complexity and demands of new requirements, since the TCP/IP design, e.g. requirements for mobility, security, QoS and throughput. The access technologies also have a history of continuous development, with the increase of its capacity and new transmission medium. This evolution in applications and new access technologies have not been followed by significant development in the main protocols of the layers 3 and 4 in the Internet architecture, as the IP, TCP and UDP. This study shows ontological deficiencies in the Internet architecture in supporting new applications requirements and proposes improvements for the next generation Internet, based on the applications needs.**

Keywords-Distributed Systems; New Internet; Ontology; Post TCP/IP Architecture

I. Introduction

THE TCP/IP architecture in facto is a standard for distributed systems. It's structure is based on the OSI Reference Model from ISO (without the session and presentation layers) and its major protocols appeared about three decades ago. Examples are IP, TCP and UDP, published in the IETF, respectively, in the RFCs 760, 761 and 768 [1]-[3].

This architecture has supported the expansion of computer networks such as the Internet, NGN/IMS, Sensor Networks and Cloud Computing. This expansion has been driven largely by meeting needs of communication between people, which reflects in needs of the computer systems to support this communication.

Despite the computational evolution, there weren't significant improvements in layers 3 and 4 of this architecture in the last three decades, and new application requirements were met through new specifications or adjustments in existing protocols. Thus, this work aims to show ontological deficiencies of the Internet architecture in meeting the new requirements demanded by applications and proposes improvements to the new generation Internet to support such requirements.

It is important to note that the links at the time of specification of the protocols of the layers 3 and 4 of this architecture supported bandwidths that ranged from 1200 to 2400bps and networks with throughput of 64Kbps were considered high speed networks. Meanwhile, the physical connections evoluted to bandwidths with tens of Gbps in a single link.

The interest in studying this area was raised by the limited development of intermediate layers of the TCP/IP architecture, which did not evoluted to support the new applications requirements nor the development of physical links, creating gaps in meeting the needs and, therefore, creating some problems for distributed systems.

In this paper, section 2 presents the ontological foundations in distributed systems and section 3 identifies problems and limitations of Internet architecture in applications that demand quality of service. Section 4 presents the ontology of this architecture and problems for the post IP discussion, and section 5 shows the conclusions and suggestions for future work in this area of research.

II. Ontological Foundations in Distributed Systems

The name "ontology" comes from the Greek, where "on" means "to be" and "ta onta" means "a being." However, Johannes Clauberg was the first to use the term ontology. He defined the terms ontology and ontosofy as "The research about the being, in general." This definition was made in [4] and is based on the original definitions of Aristotle [5].

To the Greeks, according to the definitions of Aristotle, the knowledge about the reality of beings was formed by the Metaphysics and Theology, although Aristotle did not use the term ontology [6]. Also in the 17th century, as Clauberg did, Jacobus Thomasius used the name ontology for the terms First Philosophy or Metaphysics [7]. The same definition was used for the name transcendentia as "common determinations to all beings" [6]. Clauberg's definition of the ontology should absorb the tradiotional knowledge of metaphysics, but in a more formal way. Thus, several scholastics adopted the name ontology as the definition for "general Metaphysics" [4]-[6].

The term ontology has been widely used by Wolff, in a similar way as Clauberg did [6]. However, Kant wanted to change the sense of use, so that it determined "the system of all concepts and principles of understanding" [5] [8]. This attempt to change the sense by Kant, was not adopted and currently the name ontology is used to designate the Substantialist Metaphysics, which deals with things in themselves, so

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opposed to the Critical-sense Metaphysics, which object is all the knowledge in each one of its orders [6].

Other philosophers such as Herbart and Rosmini also used the name ontology for the sciences of reasoning and not as an intuitive science, and Husserl separated this term in "formal" or "material", considering the material ontology subject to the formal ontology. The material, according to Husserl, is a science of facts, and the formal is the foundation of all sciences which makes the material being based on the formal [5].

Heidegger, on the other hand, considered, that the ontology is not just a formal entity and that it deals only and exclusively with the issues regarding the being as such and what makes the existence possible. Otherwise, to Nicolai Hartmann, the ontology is not intended to solve all problems and has a more general character than the rational metaphysics theories due to its coverage on all areas of the real [5]. A distinct sense for the name ontology was given by Stanislaw Leśniewski [5] [9] that called it his logic when presenting his system of calculus of names, with the separation of:

Protothetic	propositional calculus;
Mereology	algebra of classes, except the null class;
Ontology	theory of classes and relations.

In the sense given by Leśniewski, the ontology would be the basis for the formalization of logic, with little relation to classical ontology. However Kotarbiński and Leon Chwistek indicated that the calculus of Leśniewski has very close relation with the formal logic of Aristotle and, therefore, have the same traditional bases. Leśniewski confirmed that position with his axiomatic ontology, taking it as a basis for the process of formalization [5].

The birth of logic, as well as the ontology, have foundations in Parmênides, who influenced Socrates and Platô in the inquiries about the Being and, consequently, in the thinking about ontology itself. The definition of being, by Parmênides, limited the philosophy, as it considered the Being to be regarded as immutable, eternal and identical to itself (unique). Plato, following Socrates, broke the unity of the Being cited by Parmênides, and distinguished the sense of the word Being in three: one as a noun and two as a verb. As a noun, it means the existing reality. As a verb, the first meaning is to exist. The second is the verb connecting a subject to its predicate [7].

Despite having basis on the considerations of Parmênides, Socrates and Plato, ontology's beginning is attributed to Aristotle, since he clearly formulated a discipline for the study of the Being in Metaphysics. The current use of this term to determine things in itself, is similar to the original meaning of the definition of Aristotle, as the area of philosophy that investigates "the being as such".

A. Ontological Establishments

The term ontology has been used in the area of technology in the past years, especially in the areas of databases, information systems, software engineering, artificial intelligence and semantic web. Its use was applied for the first time in computing by [10] and has since been adopted by several authors with different meanings.

One of the most used definitions of the name ontology in computer systems, is credited to Tom Gruber, who defines it as: "An ontology is an explicit representation of a conceptualization" [11].

Despite its extensive use in the area of technology as a representation of a conceptualization, there are still some evident gaps in the formal representation of conceptual models for computer systems and their interoperability. In this field of studies Giancarlo Guizzardi presents significant contributions in establishing ontology concepts over conceptual models. For interoperation of conceptual models, he proposes first the use of a adequate modeling language for the conceptual representation and then use a computational efficient language to represent the results of this conceptual modeling [12].

He also proposes an extension of the Unified Modeling Language (UML), and not OWL (Ontology Web Language), to analyze and integrate ontologies in semantic web and describes the formal representation of the real world in a conceptual modeling language, proposed to categories of ontological endurants (objects) and endurants universals. For the integration of distributed applications, particularly, there are complementary studies for models and standardization of abstract platforms, as discussed in the next sub-section.

B. Distributed Systems Modeling

There is a constant and growing interest for modeling distributed systems capable of abstracting details of operating systems, network protocols, and even certain application protocols. The basis of this interest is in the standardization and simplicity when integrating such systems, even though, in some cases, the abstraction implies a higher computer processing.

This standardized modeling gives the benefit of facilitating the reuse of technologies, but also facilitates the decoupling between systems. In this area, middleware technologies were developed, such as CORBA, J2EE (EJB and JMS) and Web Services. Another example, with greater specificity for the management of networks is the SNMP (Simple Network Management Protocol).

In the area of modeling for distributed applications, Almeida proposes a methodology for the design of these systems. Among his contributions, he introduced the notions of abstract platform and platform independence. He also discusses the quality of design, the process of design, modeling languages in abstract platforms and a design framework for independent platforms [13].

In modeling for distributed systems, the concept of abstract platform has similarities with the concept of SOA (Service Oriented Architecture), which also seeks to standardize the integration and promote the reuse and component modeling of distributed systems [14]. From a philosophical analysis, these components may represent parts of a distributed system, being subject to both ontological theory of classes and relations, as well as mereological issues regarding the parts, all of which presents a certain behavior of the system as a whole.

The interactions between components of distributed systems and the relations between the parts, the whole and its behavior are discussed by Guizzardi, Dijkman, Almeida e Costa [15]. They also discuss the "U" behavior in the architectural design of systems, whose behavior was also observed in layers of communication in networks, Internet architecture and the OSI reference model of ISO. The behavior in "U" in a distributed system implies the communication, starting at the application layer, down to the intermetiate and lower layers and returning to the application layer.

The Internet architecture in its design, did not predict all the new components that would arise over the years, which brought new needs, new requirements and hence changes in the behavior of the distributed system. This resulted in limitations in this architecture – like mereological impacts over relations between the parts that form distributed systems.

III. Limitations of the Internet Architecture

A brief review over the evolution of the Internet architecture shows that there are lots of protocol specifications for new applications and services that consequently demanded new requirements for distributed systems. On the other hand, little was done to the evolution of intermediate layers of this architecture. An evidence of this is the analysis on the evolution of RFC 760, 761 and 768, summarized in Fig. 1.

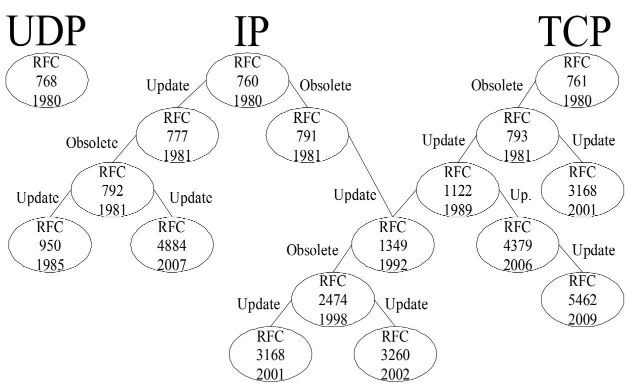

Figure 1. Evolutional Review of RFC 760, 761 and 768.

Substantial changes have occurred in both RFC 760 and 761 still in 1981, reflecting respectively in RFC 791 and 793. For the RFC 760, replaced by RFC 791 in 1981, the updates through RFC 1349 and 2474 were related to the field ToS (Type of Service), which since RFC 2474 brought the definition of the the DS Field (Differentiated Services Field) with the use of DSCP (Differentiated Services Code Point), formed by the 6 inital bits of the DS Field. The 2 remaining bits of the original ToS from RFC 760 and 791 had no longer been used in RFC 2474 [16]-[18].

A curiosity about the use of the ToS, related to the limitations and problems in the TCP/IP architecture, is the fact that this field had not been used anymore in the 1990s and was later redefined as the DS Field to meet requirements such as QoS (Quality of Service), which had its need increased due to the expansion of real time communication services, as the VoIP (Voice over IP), sensor, and management networks. A statement on this ToS disuse in the 1990s, is found in [19], where Tanenbaum informs that it was deprecated, but he does not keep this position anymore in his later work in the area of distributed systems, as in 1998 the ToS was used as DSCP [20].

In 1995, the specification of Ipv6 for the network layer was done by the RFC 1883 [21]. This protocol is similar to the IPv4 in the Internet architecture, but makes changes in some fields of the IP header, such as removal of the IHL (IP Header Length), the inclusion of the Flow Label and increases the amount of bits address, which changed from 32 in version 4 to 128 in version 6.

About the transport layer of this architecture, there is the publication in of the SCTP (Stream Control Transmission Protocol) in RFC 2960, in October, 2000 [22]-[23]. This RFC seeks to improve the processing of media streams, though it has not become a standard used for the most of NGN networks, which remain with the use of RTP (Real Time Protocol) on UDP, for the media transport [24]-[25].

The RTP sends media with the support of RTCP (Real-Time Transport Control Protocol) and uses the timestamp so that the destination receives the information corresponding to the instant of time given by the source. At this point, it becomes clear that the applications that need to communicate in real time, make use of a structure that increases the network cost, in matter of bytes, since the RTP, as a transport protocol, uses another transport protocol, the UDP, in its communication. Evidently, this problem occurs just in applications that require low network cost to better support the real time requirement.

A structured solution for this problem would be rethinking and redefining the intermediate layers to meet the real-time communication, as a requirement of applications. Nevertheless, the attempts to improve the RTP / RTCP remain, e.g. the replacement of RFC 1889 by 3550 in 2003, the update of 3550, by 5506, in 2009, the specification of RFC 3711 in 2004 to SRTP (Secure Real-time Transport Protocol) and the extension of the RTP profile for RTCP in 2006 by RFC 4585 [24]-[28].

Improvements like the mentioned above, and others also in the intermediate layers, were hampered by the expansion of the network and its users that expanded to commercial use, beyond the military. Thus, the increase of its use resulted in a downturn of its evolution. One of the criticisms about this conflict between scientific evolution and commercial interests, is discussed by Douglas Comer at [29].

"By the summer of 1989, both the TCP/IP technology and the Internet had grown beyond the initial research project into production facilities on which thousands of people depended for daily business. It was no longer possible to introduce new ideas by changing a few installations overnight. To a large extent, the literally hundreds of commercial companies that offer TCP/IP products determined whether products would inter operate by deciding when to incorporate changes in their software. Researchers who drafted specifications and tested new ideas in laboratories could no longer expect instant acceptance and use of the ideas. It was ironic that the researchers who designed and watched TCP/IP develop found themselves overcome by the commercial success of their brainchild".

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In an attempt to by-pass the architectural problem of improving the intermediate layers, are performed adjustments and specifications of new protocols, which often work as a workaround, but not directly attack the root cause of the problem. The cause is a question of architectural technology that was created for the needs of the applications of the 1970s and met the existing requirements of that period. With the rise of new requirements it is necessary to rethink the layers of distributed systems and find an alternative to make the change while maintaining compatibility with legacy systems.

It is clear that the specification of IPv6 was an attempt focused on the network layer as a part, and not thinking of the structure of all layers as a whole. Another fact is that the specification of this protocol does not meet in a structured way, the new application requirements. It was specified 14 years ago [21], and its significant changes occurred only in 1998, more than 1 decade ago [30].

Today, the deployment of IPv6 in large scale would happen mostly by the driven of commercial interests, and not by needs or scientific reasons to improve the distributed systems, or even to investigate, propose and develop the Internet architecture. For a significant improvement in distributed communication technology it will be necessary to rethink these systems and defend their evolution in a persistent and scientifically courageous way, as well as finding a way to do so. Also, to justify the IPv6 by the use of all IPv4 number of classes is a weak allegation.

IV. Internet Architecture's Ontology

The philosophical meaning of the term ontology refers to the study of the "being, while being", and addresses the issues of metaphysics, which regards the discussions beyond the traditional physics. The word meta means beyond, above, in the sense of superior or condition of something [7].

The use of ontology (such as explicit representation of a conceptualization) in the lower and middle layers of Internet architecture hasn't kept up with its use by the application layers, as it is possible to see its use in the areas of computer systems as databases management, information systems, software engineering, artificial intelligence and semantic Web, as discussed in section 2.

These computational areas, when using the Internet architecture for distributed communication, usually make use of protocols and structures of the layers 3 and 4, discussed in section 3. When there is a new need requested by applications, if this architecture does not support it, an adjustment is made in current protocols, or specification of new ones. This is done to minimize the impacts on the installed base, however this has been prevailing over the importance to maximize technology efficiency.

As it happened with RTP, which added a transport protocol over another, in the same layer, and RTSP to add security. It is fact that the RTP did not solve the issues regarding the quality of the delivery of media, being necessary to have another attempt to add QoS mechanisms in networks, using for example the DSCP, which also presents great difficulty for its use, since it needs to be explicitly configured in the network elements of the upper and intermediate layers, to make the quality of service possible from the provider to the link, and between endpoints in a distributed system. Summarizing, the QoS is not implicitly recognized and self-configured since it was not a requirement of the architectural design of the TCP/IP. This issue reinforces the need for discussion to revise the current architecture.

Another relevant question in this particular example is the analyses on the real necessity of the transport layer in TCP/IP architecture. A preliminary analysis based on its protocols indicates that it can serve mainly to:

1. Sort the packets;
2. Address processes by the use of ports;
3. Guarantee the delivery of packets in a connection less medium (e.g. TCP's acknowledgement);
4. Establishing connections;
5. Informing the packet's size (also in IP at net. layer).

The sort of packets is possible with TCP, since this protocol has the field "sequence number". However, usually this field is used for confirming the sending of packages to meet the requirement of guaranteed delivery. On the other hand, using this sequence number in TCP with a field of only 32 bits, limits the size of the window to confirm the sending of packets, generating a problem in high speed networks and high performance systems, due to the little time to fill the TCP window.

Another problem, is that in some cases, the application itself creates mechanisms to sort the information, considering the difficulties presented here as to their treatment by the transport layer. For example, at the H.248/MEGACO protocol, which can be transported via UDP, TCP or SCTP, the establishment of connection between terminations is timed. In this case, as well as to SIP, the confirmation of the TCP is not used to guarantee delivery of packets, since the application controls the retransmission through its own timers [31]-[32].

The package size information also occurs redundantly between the IP and TCP/UDP protocols. This fact doesn't come to be a serious problem, although it increases the overhead on the network. The field length in such transport protocols, typically carries the value of the length of the IP plus the header size (20 bytes for TCP and 8 for UDP).

As for the network layer used to address packets, there is also a conflict within the concept of mobility of applications. A brief example is the communication applications, as VoIP and Instant Messaging. In this type of application, the packets need to be addressed to the destination user, but are addressed to the destination host IP. In such situation, there's a coflict in the conceptual issue, because in certain mobile applications, in which the user uses login, for example, the real need is to send data to the user and not to his/her host IP. Although they are actually sent to the latter, and not to the former. The result is a series of collateral problems, like those faced by NAT (Network Address Translation) in networks.

It would be possibly better in this matter, to rethink the roles and responsibilities of layers 2 and 5, together with 3 and 4, for the new generationa Internet architecture. A coherent architectural vision can meet these requirements without redundance and overlapping responsibilities. For this, it is important to do a diagnosis of the real world needs to create a conceptual model with formal representation, to ontologically satisfy the distributed systems requiremens.

V. Conclusion

The use of the term ontology in computer systems has been expanded in the last years, and in this area, it is used for the representation of a conceptualization. When used in distributed systems it is usually applied to the application layer and not to the intermediate or lower layers of the TCP/IP architecture.

Due to a large installed base in the Internet architecture, there are lots of difficulties in its evolution. However, it is possible to have a Post IP technology in a hybrid form with the current technologies in order to meet, in a better way, the new application requirements.

This paper presents some deficiencies in the Internet architecture regarding the requirements demanded by applications, which emerged after the specification of the intermediate layer protocols of this architecture, such as IP, TCP and UDP. The rise of new requirements has been met in a case-based manner and not architectural, due to be easier to accomplish a specific setting than rethinking a layer or set of them, in an architecture.

For this reason, this work proposes further extensive discussion for the new generation Internet, with focus on supporting the new applications requirements. Thus, it is suggested for future work the continuity and expansion of this ontological construction, for the conceptual mapping of requirements to be met by the networks. After this map it is suggested a representation of this conceptualization in a formal way, with its design, validation and implementation using efficient computing systems.

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