

Leveraging P2P Architecture and Semantic Web for Enhanced Resource Discovery

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ARTICLE INFO

Article History:

Accepted: 10 May 2024

Published: 18 May 2024

Publication Issue :

Volume 11, Issue 3

May-June-2024

Page Number :

64-73

ABSTRACT

Web 4.0, also known as the next generation, intelligent internet, possesses the potential to become a widely and universally used communication medium for various types of information. However, its decentralized architecture lacks strong semantic support, resulting in an internet that is disorganized. The current system lacks the capacity to facilitate users' effective information discovery, extraction, and integration from multiple sources. Additionally, it fails to give consumers efficient tools for manipulating and turning acquired data into knowledge that is useful. Peer-to-peer (P2P) overlay technologies have recently come to light as a way to improve resource discovery on the internet. In dynamic and large-scale situations, these technologies provide a scalable framework for allocating, sharing, and gaining access to resources. The purpose of this research is to discuss on semantically enabled web architecture that makes use of P2P overlay technology. This architecture aims to facilitate structured and precise access to internet resources and promote knowledge sharing among community members who share similar interests. The paper examines the core elements of the semantic web architecture, which encompass the services and protocols responsible for resource advertising, discovery, and management, methods and material. It then delve into the hybrid peer-to-peer (P2P) overlay structure, specifically focusing on indexing and resource location, and explores the mechanisms necessary to facilitate scalable routing within a distributed environment.

Keywords : Semantic Web, Peer-to-Peer (P2P), Ontology, Scalable, JXTA overlay, Interoperable

I. INTRODUCTION

In the past ten years, the Internet has granted access to an extensive array of resources, spanning various types of content, including interactive dialogues, network services, text, audio, and video files, scientific data,

retail products, and video files. However, despite this wide range of capabilities, the full potential of the internet as a comprehensive and widely accessible technology has yet to be fully realized.

The decentralized nature of the internet, coupled with its inherent limitations in terms of semantic understanding and security, has presented challenges in facilitating expressive services and resource discovery tools that effectively align with the user's interests while mitigating information overload [15]. Previous resource discovery tools were primarily designed to assist in accessing information on the Internet.

These tools have been utilized with different degrees of success in accomplishing the indexing and discovery of internet resources. The effectiveness of these tools in the context of indexing and discovery can vary based on several factors. These factors may include the specific algorithms and techniques employed, the scalability and efficiency of the indexing process, the quality and comprehensiveness of the metadata used for resource description, and the overall adoption and integration of these tools within the internet infrastructure. However, it has become evident that they fall short in catering to the specific requirements of individual users. The fact that many of these tools offer uniform and equal access to all internet resources is the cause of this restriction. Although more current methods use sophisticated algorithms to give web pages weights, these weights are largely used for page ranking and may not correctly reflect the individual users' preferences [21].

As a result, when users submit queries, they frequently obtain an excessive amount of replies that frequently contain irrelevant data while leaving out more pertinent information. Additionally, these Internet tools in their current form offer scant assistance for the development of knowledge communities based on common practices, interests, or objectives. P2P overlay technologies have recently emerged as a remedy to this gap by facilitating resource discovery on the internet. These tools allow peers to create large-scale, ad-hoc self-evolving infrastructures without the requirement for centralized management or control [1].

The simplicity of deploying peer-to-peer (P2P) overlay infrastructure creates a favourable environment for the emergence of inventive applications that can deliver services over the internet in a highly effective and strategic manner. This streamlined deployment process facilitates the creation of a new wave of applications that can leverage the capabilities of P2P networks to provide services efficiently and with strategic intent. The accessibility and ease of setting up P2P overlay infrastructure enable the development of innovative applications that can harness the power of these networks, leading to more efficient and purposeful service delivery over the internet [1]. These applications leverage the distributed nature of P2P overlays to optimize resource utilization, enhance scalability, and improve overall performance, resulting in a more robust and dynamic internet service ecosystem.

These applications achieve this by autonomously creating and maintaining local ontologies, as well as advertising and searching for local ontologies. The main aim of the paper is to overcome the limitations presented by current Internet tools, particularly the challenge of "information overload." The goal is to facilitate successful resource discovery, service deployment, and information sharing among community members who share shared interests. By addressing information overload, the study aims to improve the efficiency of locating appropriate resources, ease seamless service deployment, and promote knowledge exchange within these communities. The ultimate goal is to provide a solution that empowers community members to efficiently discover and leverage resources, ultimately improving their overall experience and collaboration.

A. SEMANTIC WEB SERVICE

The emergence of Semantic Web service, as discussed in reference [9], has propelled the evolution of the Web to a more advanced stage, considering its distributed and diverse characteristics. There are two

distinct visions for the future development of the Web. The first vision focuses on enhancing its usability as a platform for collaboration among users, while the second vision aims to enable machines to comprehend its contents. The provision of annotation data plays a crucial role in achieving this second objective [7]; [20]. As mentioned in reference [4], Berners-Lee, the creator of the World Wide Web (WWW) and others highlights that the Semantic Web can be viewed as an expansion of the current web infrastructure. Today's web (the "syntactic" web) is about documents whereas the semantic web is about "things" - concepts we are interested in (people, places, events etc.), and the relationships between these concepts [28]. In this extension, information is represented in a more meaningful manner that is comprehensible to both humans and computers [4].

The Semantic Web enables the representation of content and services in a format that can be effectively understood by machines in an intelligent way. This capability fosters automation in various tasks, including annotation, discovery, publishing, advertising, and composition of services. By leveraging semantic representations, the Semantic Web empowers automated processes and enhances the interoperability and efficiency of information exchange and service utilization on the web. The Semantic Web is built upon the foundation of ontology, which is considered as the fundamental structure supporting its functioning [5]. In essence, the Semantic Web makes the current web machine-understandable rather than just machine-readable.

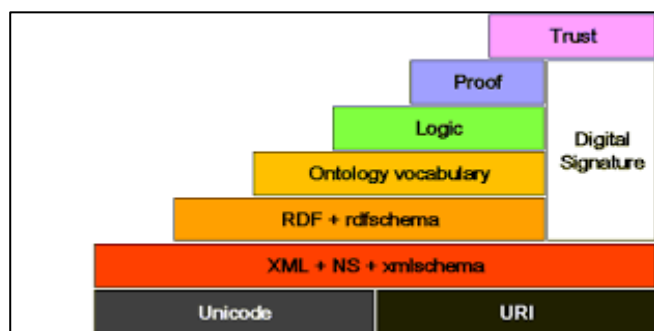


Figure 1: Semantic Web Architecture

The layers of architecture represented in Fig.1, [4]; [7]; [8]; [9]; [11] are briefly described below:

URIs (Uniform Resource Identifiers) are utilized to identify and locate resources or any other entities on the Web. They provide a uniform system of naming for each resource, forming the foundation of the Web's addressing system. Unicode serves as the standard for representing characters in computer systems, ensuring consistent character representation across different platforms.

XML (Extensible Markup Language) is a markup language specifically designed for machine readability and has its own distinct format. It is widely recognized within the World Wide Web community due to its flexible text-based structure. XML (eXtensible Markup Language) was created with the purpose of describing data and addressing the challenges related to large-scale e-business and electronic publishing. It serves as the basis for a rising number of software development projects because it is essential in facilitating the exchange of various data kinds on the web. Each document begins with an XML Namespace definition.

The Resource Description Framework (RDF) constitutes the foundational layer of the Semantic Web. The framework acts as a mechanism for utilizing and representing metadata, enabling the description of resource semantics in a format that can be understood by machines. RDF (Resource Description Framework) is employed in this framework, utilizing URIs (Uniform Resource Identifiers) to identify web resources and establish connections or relationships between them. RDF follows a graph-based model, allowing for flexible and interconnected data representation.

In addition to RDF, there is RDF Schema, which serves as a simple modeling language. It is used to describe classes of resources and their properties. RDF Schema also provides a basic reasoning framework that allows for the deduction of resource types based on the defined relationships and properties. This inference mechanism enables the framework to make logical

deductions and enhance the understanding of resource types within the data. Overall, RDF enables the machine-accessible description of information about web resources, fostering a semantic understanding of data on the web.

Ontology vocabulary serves as a language that establishes a shared vocabulary and grammar for publishing data while also providing a semantic description of the data. This semantic description helps preserve ontologies and ensures their readiness for inference. Ontology, in this context, refers to describing the meaning and semantics of the data, creating a standardized way for different parties to communicate and understand each other.

In the Semantic Web, system development follows a logical approach that takes into account the structure of ontologies. A reasoner can be employed to check and resolve consistency issues and identify redundant concept translations. Reasoning systems are used to generate new inferences based on the available information. In the realm of proof, digital signatures play a significant role. By signing their statements, sources can enable agents to verify the authenticity and origin of the information. Moreover, security technologies like encryption and access control can be utilized to ensure the confidentiality of information. Trust forms the ultimate layer of the Semantic Web, representing the assurance and reliability of the information available on the web. This component revolves around the credibility and dependability of the data, ensuring its quality and integrity. By relying on trusted knowledge, information can be inferred and extracted, fostering a sense of confidence in the data presented on the web.

B. Peer-to- Peer Network Architecture

Peer-to-peer (P2P) networks are decentralized network architectures that enable nodes to directly share and access resources without relying on a central authority. In a P2P network, each node performs the same functions, acting as both a server and a client [26].

This network architecture has been established within the computer networking ecosystem, where each workstation shares equal responsibilities, but fewer devices are connected to the central server. P2P network models have become increasingly popular for sharing information and exchanging data. By sharing the capacity and burden across all of the peers in the network, these approaches offer considerable benefits of decentralization and scalability. Consequently, P2P networks have emerged as viable alternatives to conventional client/server infrastructures in a wide range of domains [12].

Peer-to-peer networks can be categorized into two main types based on the way sections within the network are connected: unstructured and structured networks. Unstructured networks are created when overlay links are established in a random manner. These networks can be easily constructed by new peers, who can copy existing links from other nodes and gradually build their own connections over time [1]. When a peer wants to find a certain piece of data in an unstructured network, the query must be broadcast around the network to find as many peers as possible who have the desired data [3]. However, there is no assurance that flooding the network will find a peer with the requested data because there is no linkage between a peer and the content it controls. Additionally, search inefficiency is brought on by the increased signaling traffic that flooding causes. Examples of unstructured P2P networks include Gnutella, Napster, and Kazaa [27].

Structured P2P networks aim to overcome the limitations of unstructured networks by employing a Distributed Hash Table (DHT) and allocating specific responsibilities to individual peers for particular segments of the network's content. Hash functions are used in structured networks to give the peers and the content that they contain values [27].

Based on these assigned values, a global protocol is followed to establish which peer is responsible for which material. By implementing this approach,

structured networks enhance the efficiency and effectiveness of data retrieval and sharing within the network. As a result, when a peer needs to find specific data, it uses the global protocol to find the peer or peers that are in charge of that data. The search is subsequently directed toward the identified responsible peers. By leveraging the global protocol, the peer ensures an efficient and targeted search process, enabling the retrieval of the desired data from the appropriate sources. This structured approach improves search efficiency and ensures that the desired data can be located more reliably within the network.

II. METHODS AND MATERIAL

The study used content analysis research design approach and used a qualitative research methodology. This entails searching through pertinent secondary text sources, papers, websites and journals for pertinent information to the topic. Data gathered was analyzed using the content analysis method. A qualitative textual description of the analysis technique was used for data presentation.

A. Semantic Web and P2P-Style Architecture

As mentioned in reference [2], a closer examination of the current World Wide Web reveals a combination of architectures, consisting of both client/server-based and peer-to-peer (P2P) elements. On one hand, each node in the network can directly communicate with any other node within a single, global address space, resembling the structure often seen in P2P networks. In practice, there is a notable disparity between nodes serving as content servers and those operating as clients.

According to estimates, there are over 150 million customers compared to around 50 million web servers. Any type of centralization would result in immediate limitations in terms of network throughput and server capacity given the enormous scope of the World Wide Web. This highlights the need for decentralized approaches to ensure efficient utilization of resources

and prevent overburdening of servers in such a large-scale network [2]. Therefore, the mixed architecture of the web, combining client/server and P2P elements, helps to address these scalability challenges and maintain efficient network operations.

The necessity for a flat, non-server-centered design becomes even more critical in the context of the Semantic Web. While the physical load-balancing considerations remain similar to those of the existing web, the Semantic Web introduces an additional aspect that favors a peer-to-peer (P2P) approach [2]. A server-centered architecture not only creates physical bottlenecks but also imposes semantic limitations on the Semantic Web.

By adopting a P2P-style strategy, the Semantic Web can overcome these limitations and enhance its capabilities. A flat, non-server-centered architecture allows for distributed and decentralized management of semantic data and resources. This approach promotes scalability, fault-tolerance, and flexibility in the Semantic Web infrastructure. It enables efficient resource discovery, knowledge sharing, and collaboration among peers without imposing rigid semantic constraints or relying solely on centralized servers.

Therefore, embracing a P2P-style strategy addresses both the physical bottlenecks and semantic limitations, empowering the Semantic Web to realize its full potential as a dynamic and decentralized information space. Any single server in a server-centered design would impose a certain semantic perspective on all of its clients because the Semantic Web seeks to make information semantics explicit. This may have unfavorable effects, such as reducing the variety of information that is accessible and adding to the workload of information servers in maintaining vast ontologies [14].

By adopting a P2P-style architecture, the Semantic Web can avoid these issues. In a decentralized network, no single server dictates the semantic view for all clients. Instead, each peer can contribute its own

semantic interpretations and perspectives, fostering a more diverse and flexible information ecosystem. This distributed approach helps to alleviate both physical and semantic bottlenecks, enabling a more scalable and pluriformity Semantic Web.

A P2P-style architecture offers a solution to overcome both the physical and semantic bottlenecks. In this architecture, a flat network of peers enables the provision of diverse semantic perspectives using different ontologies. Each peer within the network employs its own localized and compact ontology. An important aspect of successfully combining Peer-to-Peer solutions with Semantic Web technologies is the utilization of emergent semantics. This approach relies on the utilization of lightweight and/or heavyweight ontologies created by various individuals, departments, or organizations [14].

III. RESULTS AND DISCUSSION

A. Semantic Overlay Approach and P2P "Interest Groups" routing.

In a P2P network, Nodes often know little about their colleagues, and what little they do know ages quickly. Therefore, a node must decide which node(s) should be searched before considering how to answer to a query. Peer discovery systems are now necessary because of this, and they frequently have to deal with semantic heterogeneity. Each node may promote itself using its own local ontology or vocabulary, resulting in variations in the representation of information. [6].

A potential solution has been proposed, as shown in Fig. 2, which suggests the use of "Interest Groups" to gather peers with knowledge about similar or related topics. This approach also involves a "locally centralized" mechanism to manage these groups effectively [17]. Each peer within the P2P network possesses a unique semantic characterization based on the services it offers. This semantic characterization, in turn, influences the semantic characterization of the group(s) to which the peer belongs. By organizing peers into

Interest Groups that share semantic similarities, the process of information sharing and query resolution within the P2P network becomes more streamlined and efficient. This grouping based on semantic similarities enhances the overall effectiveness of the network by facilitating better matching and relevance in information exchange among peers. The term Expertise has been used to reflect the semantic categorization of services, peers, and groups in our discussion in this work.

We contend that the ideal solution for meeting the specified needs is a semantically enabled P2P hybrid infrastructure that facilitates the creation and management of peer groups. Peers within this infrastructure are grouped into clusters according to how semantically similar they are. However, a small group of peers known as super peers are given responsibility for inter-group communication. According to reference [17], in semantic overlays, peers are grouped based on their proficiency in the semantic domain, specifically their ability to respond to specific semantic queries. Consequently, the super peers are solely responsible for directing the semantic queries to the group of peers who possess expertise in the same semantic domain required by the queries. Fig.2, illustrates semantic groups, overlays and routing.

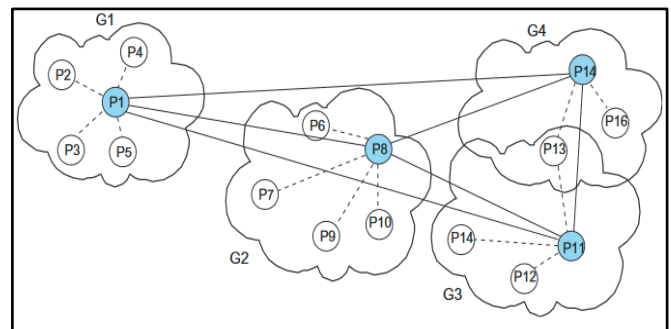


Figure 2: Illustration of Overlay Approach and Semantic Groups

Based on Fig. 2, the peers within the system have a dual role as both service providers and service requesters. They are organized into groups based on their semantic characteristics. The semantic overlay is managed via the Semantic Affinity (SA) function, which compares the similarity of services, peers, groups, and queries.

The SA function is crucial to this process. To join a group G , a peer P must meet a certain requirement known as the Membership Threshold (MT). The membership decision is based on the semantic affinity between the peer P and the group G , denoted as (G, P) , which needs to exceed the specified threshold value [17]. This threshold acts as a criterion for determining the suitability of a peer to become a member of a particular group.

Each cloud depicted in the figure represents a specific semantic domain in which the peers contained within are considered experts, as indicated by reference [17]. It is also possible for clouds to overlap, meaning that a Peer Expert (PE) who possesses expertise in multiple semantic domains spans across several clouds. This overlap is exemplified by Peer P13 in Figure 2, where clouds G3 and G4 intersect.

Peers in a semantic overlay infrastructure can create queries and enhance them with semantic tags. These requests are then routed to the semantic group(s) deemed most likely to produce successful matches for the query. If none of the peers within a particular group can adequately respond to the inquiry, the inquiry is passed to other groups that are relevant. The query is then broadcasted to all peers linked with the group(s) to whom it was routed, broadening the search scope [17]. This select-and-flood routing approach avoids flooding the entire network every time a query is sent, thereby optimizing the query routing process [2].

JXTA, Edutella, and Morpheus are examples of super-peer networks that embody these qualities. These networks possess the ability to combine the advantages of centralized search, such as effectiveness and efficiency, with the benefits of distributed search, such as autonomy, load balancing, assault resistance, and semantic interoperability. They accomplish this by combining elements from both pure and hybrid systems.

By leveraging the strengths of both approaches, super-peer networks offer a flexible and robust solution for

information retrieval and resource discovery in decentralized environments. These networks enable efficient and scalable search capabilities while maintaining the autonomy and resilience associated with distributed systems. This fusion of centralized and distributed search mechanisms results in a versatile framework that enhances the overall performance and effectiveness of information retrieval and resource discovery processes in decentralized settings.[10] [18] [19] [22]

How Semantic Overlay is managed

The Juxtaposition (JXTA) layer serves as the foundational functionality for managing the hybrid P2P network, upon which the remaining components rely in the semantic overlay. JXTA technology, consisting of a set of six Extensible Markup Language (XML)-based protocols, enables communication and collaboration among diverse types of peers using pipes as an abstraction for peer-to-peer communication [23] [24]. In the JXTA framework, other peers can act as intermediaries when direct communication is impeded by network partitioning, restrictions such as firewalls or network address translations (NATs), or when different communication protocols are employed [25]. This flexibility in the JXTA framework allows for enhanced connectivity and communication within the P2P network, overcoming various network limitations and ensuring effective collaboration among peers.

In the case of the semantic overlay depicted in Fig. 2, the architecture incorporates the JXTA API as the underlying protocol for tasks such as creating, joining, and leaving groups, as well as publishing and discovering resource advertisements. Fig. 3 illustrates the peer system architecture. The pieces that directly connect with the JXTA framework are the Group Manager, Membership Manager, and Query Manager. These elements carry out their respective tasks within the semantic overlay system by utilizing the capabilities of the JXTA API. Fig. 3 illustrates Peer system architecture.

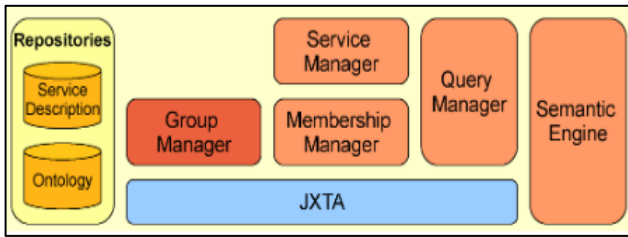


Figure 3: Peer System Architecture

The architecture's API, provided by the Service Manager and Query Manager, allows user applications like file sharing to interact with the system. The Semantic Engine plays a crucial role in processing semantic information and provides tools that are accessible to all components within the peer system architecture. The Repositories are responsible for storing the semantic data persistently, enabling peers to participate in the distributed process of semantic overlay management. These repositories hold the necessary information for effective operation within the semantic overlay network.

The main role of the Service Manager (SM) is to aid users in managing web service descriptions. When a new web service becomes available, the SM takes responsibility for its semantic description by storing it in the Service Description Repository. It analyzes the service description to identify the semantic concepts it contains and then updates the Peer Expertise (PE) based on this information. If any changes or modifications occur in the PE, the SM promptly notifies the Membership Manager to ensure that the membership information remains current and accurate [17].

This collaborative interaction between the SM, Service Description Repository, PE, and Membership Manager ensures the accurate representation of web services and the corresponding expertise of peers within the system.

The Membership Manager (MM) is responsible for evaluating the affinity of a peer to the semantic groups present in the network. It assesses the compatibility between the peer's expertise (PE) and the groups' expertise (GE). If there is a change in the peer's

expertise or if the group expertise that the peer currently belongs to has changed, the MM triggers an operation to either join or leave the group. In the case of a group expertise modification, the Rendezvous (RDV) of the group performs the necessary changes and notifies the peer through the JXTA API. This process ensures that peers are dynamically aligned with the most suitable semantic groups based on their expertise and facilitates effective participation within the semantic overlay network.

The Group Manager (GM) component is instantiated specifically when a peer takes on the role of the Rendezvous (RDV) for a group. During this time, the GM is solely responsible for network-related management operations and does not allow any interaction with user applications. Its key responsibilities include maintaining the Group Expertise (GE), routing queries between the group's peers, and facilitating the escalation of the GE to other groups as needed.

The Repositories, namely the Ontology Repository and the Semantic Description Repository plays a vital role in storing persistent information that is essential for various overlay management tasks. It is responsible for housing important ontology resources, including relationships, concepts, attributes, and axioms. These resources serve as models for the domain ontology referenced by the web services published by peers. The Ontology Repository acts as a repository for these crucial components, enabling effective management and utilization of the domain ontology. On the other hand, the Semantic Description Repository stores the semantic descriptions of web services and promotes language flexibility by adopting interoperable languages such as Web Ontology Languages (OWL). These repositories ensure the availability and accessibility of essential semantic information for efficient operation within the semantic overlay network.

The Query Manager (QM) fulfills two main roles. Firstly, from the perspective of the user application, it

provides tools for creating and submitting semantic queries. These queries are generated using the QM's functionalities and submitted for processing. Secondly, from the network side, the QM actively listens for incoming queries that are specifically directed towards the peer. It assesses the Query Expertise (QE) and conducts searches within its local web services to identify matches that meet the criteria specified in the query. By performing these functions, the QM facilitates effective query handling and retrieval of relevant information.

The Semantic Engine (SEN) plays a supporting role for the architecture's components whenever there is a requirement for semantic operations. It provides tools for extracting semantic concepts from web service descriptions and implements algorithms for calculating semantic affinity. The SEN facilitates the processing and interpretation of semantic information within the system, enabling accurate query evaluation and effective matching of services based on semantic criteria.

IV. CONCLUSION

The initial resource discovery tools utilized on the internet have been employed with different levels of achievement. Nevertheless, they have demonstrated their inability to effectively address the unique requirements of individual users. These tools primarily rely on keyword-based searches and are ill-suited for semantic-based searches. Consequently, they struggle to comprehend the true intent behind a query, often leading to a lack of comprehensive exploration within the domain of candidate services. Furthermore, the services discovered through these tools occasionally fail to fully satisfy the original search criteria, necessitating additional time and effort to filter and refine the initial set of results.

The integration of P2P architectures and semantic technologies offers a promising solution to the

aforementioned challenges. By leveraging P2P systems, decentralization, scalability, and fault tolerance can be ensured. By organizing peers into Interest Groups that share semantic similarities, the process of information sharing and query resolution within the P2P network becomes more streamlined and efficient. Simultaneously, the publication of services described with semantic annotations can enhance and automate the discovery process. The ability to semantically annotate services coupled with recent trends and advances as well standards being added to the semantic layer cake allows for a more precise characterization of the relationships between peers and the services they provide. This, in turn, significantly improves the service discovery process by enabling a more accurate matching of user requirements with available services.

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