

Survey of Model and Architectures for a Restricted and Local Mobile Access to the Web of Data

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Abstract. Mobile Access to the Web of Data is currently a real challenge in developing countries, mainly characterized by limited Internet connectivity and high penetration of mobile devices with the limited resources (cache, memory, etc.). In this paper, we survey and compare proposed solutions (models, architectures, etc.) that could contribute to solve this problem of mobile access to the Web of Data with intermittent Internet access. These solutions are discussed in relation to the underlying network architectures and data models considered. We present a conceptual study of peer-to-peer solutions based on gossip protocols dedicated to design the connected overlay networks. In addition, we provide a detailed analysis of data replication systems generally designed to ensure the local availability of data on the system. We conclude with some recommendations to achieve a connected architecture that provides mobile contributors with local access to the Web of data.

Keywords: Web of Data, Gossip protocol, graph replication, limited connectivity, semantic overlay, mobile contributor

1. Introduction

The Web (or Web of Documents) is originally seen as a software architecture for making documents available, and for linking and sharing them over a network of connected machines[1]. This vision evolved very quickly. Indeed, in [2], the author shows how the vision of hypertext, i.e. the linking of documents by hypertext links, must be overcome to allow machines to automatically link Web data to real world-elements, which would at the same time allow intelligent agents

to add and manipulate Web contents. In 2006, Tim Berners Lee[3] clarified his semantic web vision by emphasizing that its sole aim was not to publish information on the Web, but to link them in order to allow a machine or a human to browse the Web of data. He then presented a collection of guidelines for delivering and linking structured data on the Web: the Linked Data Principles. These principles offer directions on the application of semantic web standards technologies (RDF, URI, SPARQL, etc.) to link data from different sources. By analogy to traditional Web (of documents) that can be explored via hyperlinks, applications that adopt the principles of linked data can browse the Web

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1 of Data made up of different data sources by following
2 the RDF (Resource Description Framework) links to
3 provide more relevant responses to users needs [4].
4

5 In a number of the distributed systems such as Web
6 applications, search engines, e-learning platforms, etc.,
7 some network nodes provide services, and others con-
8 sume these services. Internet is the common commu-
9 nication channel that allows the nodes that constitute
10 data sources and services (server nodes) and consumer
11 nodes of these services (client nodes) to be connected
12 and interacting. However, the availability and particu-
13 larly the quality of the Internet is not always ensured in
14 certain areas such as the African continent. Indeed, de-
15 spite the significant progress made in recent years, In-
16 ternet access remains a major constraint in developing
17 countries in general and Africa in particular. Accord-
18 ing to Internet Words Stats data [5] of June 2018, the
19 penetration rate was estimated at 36.1% in Africa com-
20 pared to 95% in North America and 85.2% in Europe.
21 Furthermore even when Internet access is provided, the
22 distributed systems must cope with the dynamics of
23 their environments. Distributed systems have to mainly
24 consider the eventual nodes failure and the popular
25 client/server model is then revealing its limitations. In
26 such model, the server is the only node that provides
27 the service and in case of unavailability, it becomes the
28 single failure point for the entire distributed system.
29 Moreover, this centralized architecture, apart from the
30 significant costs that may be incurred to keep it op-
31 erational, does not efficiently exploit the available re-
32 sources (storage memory, processor, etc.) of the client
33 nodes, which participate passively to the architecture
34 and benefit from the provided service. Nevertheless,
35 these client nodes have the particularity of being in-
36 creasingly mobile, numerous and constitute a privi-
37 leged means of access and consumption of Web's ser-
38 vices. In the African continent, for example, the num-
39 ber of the smartphone holders is expected to almost
40 double between 2016 (336 million) and 2020 (660 mil-
41 lion), for a penetration rate of 55%, according to De-
42 loitte's forecasts [6].
43

44 In recent years, peer-to-peer (P2P) model positioned
45 itself to be an efficient solution to meet the dynamism
46 and scalability requirements of the distributed systems
47 [7]. Nodes act both as clients and servers, contributing
48 to the services in which they participate. Regardless of
49 the specific type of application, p2p systems can be de-
50 fined according to the topology connecting the nodes
51 to each other to form the underlying network usually

1 called overlay [7]. There are two main classes of the
2 superposed networks [7]: structured overlay networks
3 well represented by distributed hash tables (DHT) and
4 unstructured overlay networks. The former link their
5 peers according to their identifiers in order to allow
6 efficient routing between them. The identifier of each
7 node determines its position on the network. For the
8 unstructured overlay networks, links between nodes
9 are created randomly or based on proximity measure-
10 ments. Networks based on gossip protocols are good
11 illustrations [8–11]. These protocols aim to build and
12 maintain an unstructured topology with random graph
13 properties [12]. They also provide load balancing be-
14 tween nodes and are used as building blocks in net-
15 work management applications, in particular for very
16 dynamic environments [10].
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19 In this paper, we aim to survey the existing solutions
20 (models, architectures,...) that can contribute to solv-
21 ing the problem of the intermittent access to the Web of
22 Data by mobile contributors. These solutions are dis-
23 cussed here in relation to the network architectures and
24 data models. We firstly present a conceptual study of
25 P2P solutions based on gossip protocol dedicated to
26 the design and management of the connected overlay
27 networks. And secondly, we give a detailed analysis of
28 the technical approaches to ensure local data availabil-
29 ity on such a peer-to-peer architecture.
30
31

32 Our contributions in this paper are: 1) a comparison
33 of the functional approaches of gossip protocols based
34 on the underlying adhesion mechanism. 2) A classifi-
35 cation of approaches dedicated to designing data shar-
36 ing systems adopting an RDF data model. For each of
37 these approaches we also identify a set of the exist-
38 ing applications and the future research trends that we
39 consider relevant.
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41

42 The document is organized as follows: In Section 2,
43 we present a motivating application scenario. Section
44 3 discusses logical structure of unstructured architec-
45 tures based on gossip protocols and the system evo-
46 lution model generated by contributors. Section 4 de-
47 scribes the approaches taken from these architectures
48 to access the Web of Data despite connectivity and
49 hardware resource constraints. Section 5 presents the
50 conclusion with an overview of the evaluation param-
51 eters and future research directions.

2. Motivation: Example of scenario

We target a scenario where users form a P2P network such that anyone can generate information and make it available to everyone else on the network. To illustrate this scenario, let us consider the real case of the International Jazz Festival of Saint-Louis in Senegal. It is an annual event during which thousands of people are meeting in different locations around the city to celebrate Jazz music and enjoy the various concerts and cultural activities held for this purpose. During this event, the constant need to access and share information related to the schedule and their contents is an important point for improving the quality of the festival.

Mobile access to the Web of Data: Khadim, Thierno and Guirane are friends who came to attend the festival. Khadim is interested in concerts at Abdoulaye Wade Square and festivities held mainly on the edge of the Senegal River that borders the city. Thierno and Guirane came specially for different quintets' show on Faidherbe Square. Their smartphones are assumed to be equipped with the application dedicated to this event. When they arrive at the Saint-louis bus station, they detect the wifi network in the area dedicated to the festival and got connected to it. Thierno and Guirane are then automatically integrated into clusters located in the area in relation to their points of interest. As for Khadim, being the only one interested in African Jazz, he is integrated in an empty cluster for this point of interest and in another cluster related to the river. Everyone wants to have information about their interests, so they query their applications. Thierno and Guirane receive identical information since they belong to the same clusters. Khadim receives information about festivities held near the river. He also receives information on concert planning. This information originates from a cluster located at Abdoulaye Wade Square. Their friend Samuel who lives in Saint Louis has also been integrated into this cluster.

Local access and collaborative modification: Samuel has set up his profile by specifying his interest for concerts at Abdoulaye Wade Square. By visualizing the schedule of these concerts, he notices that the name of one of the artists was incorrectly written on the system, he decides to modify this information. A local band decides to informally join the festival by playing at the entrance of the bridge (of the city) and they add their event to the shared data. Khadim decides a few minutes later to refresh the data presented to him and finds

that the artist's name has indeed changed and that a new event was added.

3. Peer-to-peer and semantic data exchange

Research on RDF data exchange on peer-to-peer networks has made great progress. Many of these solutions, particularly those dedicated to dynamic architectures, are based on gossip based (or epidemic) protocols. These protocols have an interesting approach in the sense that they are very resistant (having an intrinsic redundancy degree allowing to mask network and node failures) and scalable (load distribution across all system nodes) [13]. The operating principle is conceptually as follows: when a node (contributor) needs to send information via the network, it randomly selects t nodes among its neighbors and transmits them the message (t is a parameter named *fanout*). Each node repeats this process once it first receives the message.

Challenges and operating principles of these protocols are very diverse. They are very suitable for designing peer-to-peer communication systems because of their scalability, ease of deployment, but above all their resistance to network and process failures. They have been successfully applied in several areas: aggregate calculation (mean, variance, minimum, maximum, etc.) [8–10], load balancing [11], network management [12]. The shared characteristic of such protocols is that each node periodically or reactively exchanges information with certain of its peers. A gossip protocol assumes the existence of an underlying membership mechanism, a fundamental component, which provides each node a complete or partial system knowledge. This consists of a list of node identifiers or profiles commonly called a *view*.

The costs in terms of memory and network traffic to ensure overall system knowledge are generally elevated for dynamic networks where nodes continuously leave and join. These constraints lead us to mechanisms that provide partial knowledge of the system. These mechanisms are more adapted to the dynamic characteristics of the system and are less constraining in terms of resources. Several gossip protocols were then implemented on top of these mechanisms. The latter can be classified into two families [13]: basic membership mechanisms and two-layer membership mechanisms.

3.1. Gossip protocols with basic membership mechanisms

With this type of mechanism, the view owned by each node is composed of peers dispersed across the network. No characteristics are considered on a node to integrate it into another node's view. Two system models can be identified among these protocols[13]: centralized systems that use a set of central servers whose main task is to provide each node with a random view, and decentralized systems whose main characteristic is self-organization. We will focus here on protocols that adopt decentralized architectures that avoid in particular problems related to storage memory size and central server failures (Figure 1: On each node, the outgoing arrows indicate the neighboring nodes that make up its local view. The incoming arrows represent the views of the neighboring nodes in which the node is integrated). These protocols can be divided into two groups: (1) protocols using a random selection of peers at runtime and (2) those using deterministic selection.

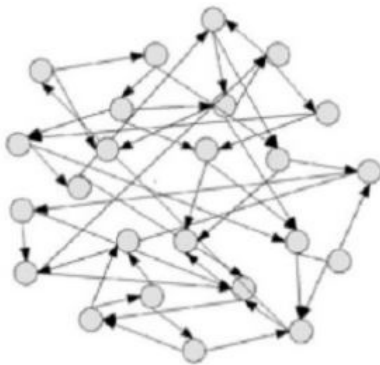


Fig. 1. Example of a basic membership mechanism [13].

3.1.1. Random peer selection

These gossip protocols have the particularity of being totally based on random choices. More precisely, at runtime, the peers selection for information dissemination is done randomly among the peers composing the node view. All the nodes composing the view have in principle the same probability of being requested for the exchange. This keeps the architecture connected and close to the random graph properties. The challenge is therefore to build and maintain the connected graph even with node failures. Choosing the *fanout* parameter to be applied to the protocol is decisive in the sense that it has a particular impact on the speed of message propagation. Hence the importance of find-

ing a good value for the *fanout*. The following work is based on this principle.

Ganesh et al. [14] presents SCAMP, a peer-to-peer membership service that operates in a completely decentralized manner, where no node has any overall knowledge of members. The system is totally self-organized, the size of local views naturally converges to the "right" value for gossips to succeed. This value depends on the size of the system.

Jelasy et al. [11] introduces a generic scheme, generalizing gossip protocol based on sampling services. Sampling services aim to give each node a set of peers with which to exchange information. Authors show that unstructured dynamic overlay networks based on gossip protocols are natural candidates for the implementation of sampling services for their reliability and scalability. Two methods are presented in the Peer Sampling Service API: `Init()` and `GetPeer()`. `Init()` starts the service for a given node if it was not previously done. `GetPeer()` retrieves a peer address when the group includes several nodes.

Jelasy et al. [15] introduces a generic framework implementing decentralised peer-sampling service by building and maintaining unstructured dynamic architectures based on information about peer contributors. The basic principle underlying the proposed framework for designing the peer sampling service itself relies on gossip paradigm. In fact, each node manages a local small table providing a partial view on the entire set of nodes and periodically updating it by a gossip process.

Leitao et al. [16] presents HyParView, a membership protocol to support gossip broadcasting that ensures elevated reliability levels, despite high node failure rate. HyParView is based on an approach based on the use of two distinct partial views: small active view, and a bigger passive one. All nodes' active views build together an architecture used for message transmission. The purpose of the passive view is to maintain a list of nodes that can be used to substitute active view's failed nodes.

Bortnikov et al. [17] presents Brahms, a random peer sampling algorithm for large dynamic systems that are pruned to malicious behaviour. Brahms provides a view to each and also overcomes Byzantine attacks (e.g. attacks where adversaries have full control to certain authentic nodes from which they disrupt the network).

3.1.2. Deterministic peer selection

These protocols differ from random selection protocols in the deterministic nature of their peer selection procedures during data exchange. In previous protocols, although the architecture remains effectively connected despite its dynamic nature, peer-to-peer links are by default meaningless. In the case of a deterministic choice, the selection is guided by the application of mechanisms based on characteristics such as peer "age" (time spent in the view), metric distance, similarity (shared interests, semantic proximity, profile, etc.), scheduling (Round Robin), etc. This allows to have virtual but relevant links between peers in the architecture, thus improving the quality of the views. In this category, the following related works have attracted our attention.

Voulgaris et al. [12] describes CYCLON, a low-cost, full membership management framework. CYCLON improves on the basic shuffling protocol [18]. Shuffling operation is a swapping process of a neighbour subset among a couple of nodes. It originates from any of these two nodes. The basic shuffle protocol guarantees that overlay connectivity remain intact until membership changes. CYCLON uses a similar design like the basic shuffle. However, nodes do not randomly select the neighbour with whom to exchange informations, they choose the oldest neighbor.

Nedelec et al. [19] proposes a random peer sampling protocol called Spray, based on Scamp and Cyclon. The protocol is designed to avoid the constraints introduced by WebRTC framework. WebRTC allows communication channels between browsers to be established. However, it does not manage addressing and routing. Browsers connect by exchanging offers and receipts using a shared mediator like couriers, specialised signalling services, available WebRTC links, etc. Spray avoid these constraints through its three-part connection establishment procedure, by using only neighbor-to-neighbor interactions. Spray: 1- adapts dynamically each peer's neighborhood. So, connection volume logarithmically increases with network size; 2- only uses interactions between neighbours to establish connections. Thus, connections are established in constant time; 3-quickly converges towards a topology with similar properties as a random graph. As a result, the network gains robustness against large-scale failures and efficiently disseminates information.

In [20], **Alromih et al.** proposes EEGossip, an Energy-Efficient Gossiping protocol to route data towards sink. Using a selection procedure, the protocol determines

the best path for each neighbor. The selection function uses the next node residual energy, next node distance (the distance between the current node and its neighbor) and the sink distance (the distance between the sink and the next node). For the calculation of the distance, EEGossip uses the Chebyshev distance [21] which overcomes the Euclidean distance regarding both processing complexity and execution time [22].

3.1.3. Synthesis on basic membership mechanism

In summary, gossip protocols adopting a basic membership mechanism have several advantages for the decentralized peer-to-peer systems. They make it possible to maintain the architecture connected despite the mobility (arrival/departure) of the nodes. The failure resistance of nodes and network is ensured in particular by the level of data redundancy. The amount of information passing through the architecture can be controlled by choosing the size of the views, the *fanout* parameter, the type of protocol execution (cyclic or reactive) and also the type of message propagation (push/pull). WebRTC also has an important advantage for these protocols through its signalling and connection services. It enables gossip protocols to be deployed on mobile phone or tablet web browsers, enabling direct/indirect connections between mobile users. Table 1 provides a summary of the different gossip protocols surveyed in this section. The following criteria were used to compact their comparison in one table:

- **Push-propagation**: the protocol is based on a push stream. In this type of propagation, nodes transmit data to randomly selected neighbors without expecting responses from them. The mechanism is very suitable for disseminating information as it is unnecessary to have receivers responding to originators.
- **Pull-propagation**: the protocol is based on a pull stream. Pull propagation guarantees data is sent when required. This allows to reduce network load whenever data size is important.
- **Cyclic Execution**: the protocol is executed in a cyclic manner at the level of each peer.
- **Biased peer selection**: the choice of a peer when executing the protocol is made in a deterministic way. A selection mechanism is applied to select the most suitable node (oldest (age), closest (metric distance), similarity metric, etc.)

- Defense mechanism: the protocol integrates one or more security mechanisms to maintain the architecture connected and/or preserve the anonymity of each peer.
- WebRTC: the protocol is based on the WebRTC framework which allows communication channels between browsers to be established.

3.2. Gossip protocols with two overlay membership mechanisms

A second family of protocols is designed on top of the membership protocols described in Section 3.1 by adding clustering mechanisms to form two-level architectures (Figure 2). Here, the role of basic gossip protocols is to build and maintain a connected architecture on top of which an appropriate clustering mechanism is then applied to build even more efficient overlay networks.

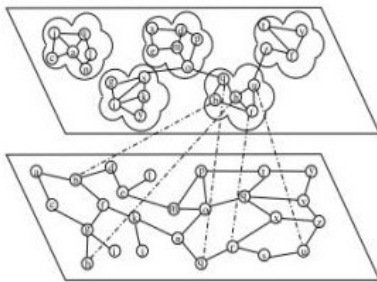


Fig. 2. Example of two overlay membership mechanisms [23].

The common objective of these architectures is to cluster nodes according to a geographical, semantic, profile or network proximity criteria and take this proximity into account in order to provide participants with local neighbor lists exclusively made of members of same cluster. Some models offer mechanisms that allow a few selected nodes in the cluster to be equipped with a remote view composed of nodes from other clusters in order to keep the entire system connected (Figure 2). Kermarrec et al.[13] show this connectivity is achieved through a limited set of links among clusters.

Several models of two overlay protocols have been proposed. These protocols have the particularity of being completely autonomous, in a way that all the nodes have the same roles. The architecture adhesion procedure for a newly arrived node does not require contact

with a particular node (contact server). Each node can be used as a contact for a new one. The membership mechanisms differ from one protocol to another. The aim is to find a first peer who responds favourably to the membership request. The latter peer will transfer the information relating to his view according to the type of flow (push and/or pull) adopted by the protocol. This information will allow the node that initiated the request to initialize its view. On a number of these protocols, clusters are also formed by adopting the operating principle of the basic gossip protocols. This is the case of Gossple, Vicinity and Behave[23–25]. To form the second overlay, exchanges between peers are performed according to the gossip model guided by the clustering metric considered. In Gossple, Behave, and Cyclades for example, the cluster is represented by a second view held by each node. This second view is made up of the best neighbours selected on the metric basis. Clusters are improved as they are updated by reactive or cyclical update operations.

A number of these solutions also include caching mechanisms to speed up data access[24–26]. This type of mechanism allows relevant content to be temporarily stored on the architecture. Thus, all local caches form a common cache accessible to system contributors. A partial/total caching of the data passing through the system is performed by these contributors in order to process a large part of the requests from the local cache or from the caches of neighboring peers.

3.2.1. Overlay approaches

Voulgaris et al. [27] proposes a proactive approach to build epidemic protocol-based semantic overlay gathering same content peers. Each peer manages a semantic neighbor list and first queries its semantic neighbors to find a file. The model assumes a semantic proximity function that provides numeric semantic proximity metrics among peers regarding their lists of files.

Jelasy et al. [28] proposes T-MAN gossip protocol which allows to build a variety of network architectures. T-MAN is based on a peer sampling service [15] generating a starting network architecture of random links. T-Man primarily depends on three parameters: message size m , sampling parameter w and ranking method *RANK*. Nodes rank their descriptor set (composed of descriptors from random links) with the ranking method and pick first k as neighbours. This results on a structure named *the target graph*.

Mordacchini et al. [29] proposes a general system

Table 1

Summary of basic gossip protocols. The total support of a characteristic is indicated by the sign \checkmark , the partial support by the sign \circ

	Scamp[14]	Cyclon[12]	HyParView[16]	Brahms[17]	Spray[19]	EEGossip[20]
Push-propagation	\checkmark	\checkmark	\circ	\checkmark	\checkmark	
Pull-propagation			\circ	\checkmark	\checkmark	\checkmark
Cyclic execution		\checkmark	\circ	\checkmark	\checkmark	
Biased peer selection		\checkmark			\checkmark	\checkmark
Defensive mechanism				\checkmark		
WebRTC		\checkmark			\checkmark	

architecture dedicated to take advantage of collaborative peer-to-peer information exchange. The idea is to gather similar users and disseminate relevant recommendations across them. The protocol uses a clustering mechanism to group similar users. Each peer firstly independently determines which peers they are linked to. These individual connections are selected based on interest-based metric distance, among the encountered peers. Each time it meets a new peer, it learns from and communicates with potential new neighbours (i.e. similar users). When this process is stabilized, a peer may consider his neighbourhood as a representation of a community of common interest.

Bertier et al. [23] describes the construction of an anonymous social knowledge network using a gossip protocol called Gossple. Periodically, Gossple nodes exchange on their interest and calculate their interest-related distances. They propose to improve navigation in Web 2.0 systems through implicit personalization: an anonymous network of knowledge interested by similar topics is associated with each user, independently from the way they expressed their interests. There is an implied use of this knowledge by users in order to drive and refine searching actions.

Voulgaris et al. [24] presents a self-organizing, generic overlay management framework, VICINITY. Given the node descriptor p and a set of node descriptors D , a select function $SELECT(p, D, k)$ is applied, to return the set of k descriptors that are most closely related to the outgoing links from p in the target structure. Such function is often built on a proximity-specific measurement globally defined. The protocol relies on two layers. The base layer is the peer sampling service. It is in charge of keeping the architecture connected and of periodically providing the upper layer with candidate nodes. Candidates are randomly and uniformly sampled throughout the system. The upper layer protocol, named VICINITY, determines which nodes to foster by use of the selection function.

Frey et al. [25] presents Behave, a decentralized

caching architecture based on behavioral positions and using gossip protocols to construct superposed clusters with similar interest peers. Behave nodes adopt a gossip protocol based on the similarities between their navigation histories to form an interest-based topology. Each node thus has a set of neighbours whose browsing history is closest to their own. From this topology, Behave's behavioral cache appears as the merging of a node's neighbors' local caches.

Boutet et al. [30] presents HyRec, a scalable and cost-effective online system dedicated to customizing user-centric collaborative filtering. HyRec loads recommendation tasks on users' web browsers, while the process is driven by a server which also controls user profile relationships. Each user receives from the HyRec server a set of candidate profiles. Each browser then calculates the KNN (k-nearest-neighbor (KNN) or k-best neighbors,) of its user and the most relevant elements based on this sample. Using a sampling approach, both KNN selection and article recommendation are delegated to users' web browsers. The sampling approach follows the same principle as gossip protocols.

Carvajal et al. [31] introduces a WebRTC-based library called WEbGC. WEbGC enables web browsers to communicate using gossip protocol and to interact with node-JS applications.. WEbGC is also based on the SimplePeer framework, which operates as a JavaScript library and serves as a layer for WebRTC facilitating peer-to-peer data connections.

Folz et al. [26] presents CyCLaDEs, a network architecture based on LDF (Linked Data Fragment) similarities. Using LDF client similarities, CyCLaDEs intends to provide a decentralized behavioral cache for LDF query processing. A predefined number of best customers is identified for each customer and a one-to-one link is established with each one. In case of a given user's process, first the local cache is checked for each sub-request triplet, followed by its neighbors' cache, and if necessary, the LDF server. The network

architecture relies on random peer sampling model for member composition management and a clustered architecture to handle the k-best neighbors.

Nedelec et al. [32] presents CRATE, a real-time decentralised collaborative editor. CRATE directly operates on web navigators using WebRTC. By using an optimistic replication process, CRATE ensures documents accessibility and responsiveness. For the browser network construction, CRATE uses SPRAY random peer sampling protocol with WebRTC technology. With SPRAY, a locally based neighborhood table is provided to editors allowing communication within a subset of editors. CRATE uses SPRAY protocol to evolutively broadcast any replicated sequence operations to all co-workers.

Pilet et al. [33] introduces a peer-to-peer protocol enabling user privacy protection during decentralized averaging. Many limitations of existing solutions, such as eavesdropping attacks, restrict peer exchange coordination, or use of expensive cryptographic primitives such as homomorphic encryption, are overcome by the protocol. The protocol relies on a attack-resilient Random Peer Sampling (RPS) service: Brahms. Each pair is provided with a sample of remaining network peers by the RPS. During several rounds, the protocol exchanges noise before starting to transmit actual data. This makes it hard for an honest but curious attacker to know whether a user is transmitting noise or actual data.

Meiklejohn et al. [34] presents PARTISAN, an actor's application operating platform that enhances evolutivity and decreases latency. In [35], an actor is defined as a computational entity that, in response to a message it receives, can concurrently: send a finite number of messages to other actors, create a finite number of new actors, designate the behavior to be used for the next message it receives. Actor application is one in which actors have the option to stay on a variety of nodes and be able to seamlessly interact with other nodes' actors. PARTISAN offers greater evolutivity by giving developers the ability to define the used network tier at execution point while not modifying application semantics. PARTISAN offers four overlays to developers, including a peer-to-peer overlay based on HyParView [16] and Plumtree broadcast protocol [36]. The peer-to-peer protocol allows PARTISAN to provide both membership processes used to add/delete members from cluster and sending processes for asynchronous messaging.

Leonardi et al. [37] presents NAPA-WINE a P2P television system (P2P-TV) architecture. P2P-TV is

defined as a system in with a source dividing video stream in pieces of data, exchanged with nodes and then distributed to all network members. The goal of NAPA-WINE is to push chunks into layer where peers collaborate to broadcast them, with no requirement for huge resources and bandwidth to sustain the service. Gossip protocols such as Newscast [11] or Cyclon [12] are used for the underlying topology management. This allows peers discovery in overlay topologies mapped on over the network.

3.2.2. Synthesis on overlay approaches

These two-overlay protocols benefit from the advantages offered by the basic protocols on top of which they are built. Therefore the architecture is connected and resistant to failures. The second overlay is particularly useful for creating links between nodes that make sense in relation to the context. It therefore reduces latency time during search scenarios. On certain solutions, the clustering algorithm is executed at the execution of the underlying base protocol. This limits the amount of information transiting on the architecture. Table 2 provides a summary of the different solutions presented in this section. The following characteristics allowed us to compare these different models:

- *Similarity metric* : the model uses a similarity metric to estimate the distance (in terms of interest, metric, semantics or content) between peers;
- *Clustering by gossip* : the clustering algorithm used is based on the same mechanism as a gossip protocol at runtime;
- *Compression of exchanged data* : a compression strategy is applied on data to maintain fluid exchanges in the system;
- *Caching* : the model integrates one or more caching techniques for data storage and thus ensures availability and local access;
- *Semantic clustering* : the clustering algorithm is based on semantic criteria; more precisely, the similarity metric used estimates the semantic distance between peers;
- *Membership Management Protocol (MMP)* : this is the base protocol (gossip protocol) used in the model to build and maintain the architecture's connectivity;
- *Contact server* : the arrival of a new peer in the architecture is done through a contact server whose main role is to store all or a part of each peer's information and to provide each newcomer

with the necessary data for its integration (view, IP address, identifier, etc.).

4. RDF graph sharing and collaborative modification

In this section we focus on collaborative data sharing systems. In the following sub-sections, we do not look at approaches related to the semantic web in general, but more specifically at work related to collaborative sharing and modification.

4.1. RDF Graph

The Resource Description Framework (RDF) is a framework for representing information about resources. Resources can be anything, including documents, people, physical objects, and abstract concepts. RDF 1.1 Concepts and Abstract Syntax [38] defines an abstract syntax (a data model) which serves to link all RDF based languages and specifications. The core structure of RDF data model consists of entities, represented by unique identifiers, and binary relationships, or statements, between those entities. In the graph-based representation of an RDF statement, a triple subject-predicate-object element is the atom of knowledge. It is a relationship in which the source is called the subject, the labeled arc is the predicate (also called property), and the destination is the object. Given two disjoint and infinite sets I , L and B denoting the IRIs, literals and blank nodes respectively, an RDF triple is any element of the set $(I \cup B) \times I \times (I \cup L \cup B)$. Therefore a RDF graph G can be formally said to be a set of RDF triples.

4.1.1. RDF Data Structure

In an RDF graph, different entities are vertexes in the graph and relationships between them are represented as edges (Example: Figure 3). Information about an entity is represented by directed edges emanating from the vertex of that entity (labeled by the property type), where the edge connects the vertex to other entities, or to special literal vertexes that contain the value of a particular attribute for that entity. The core feature of RDF of extensibility relies on a minimal vocabulary with predefined semantics identified by the RDF namespace and ready to be extended.

RDF Schema is a special vocabulary (rdfs namespace), a meta-ontology, that supports the declaration of lightweight vocabularies by providing some ele-

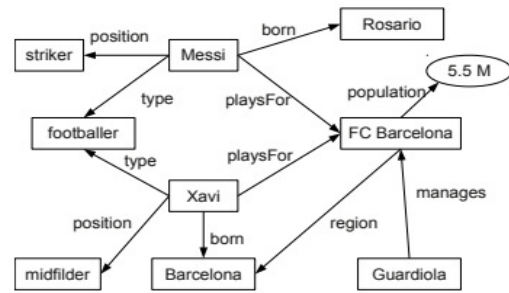


Fig. 3. Example RDF Graph Data from DBpedia [39]. Edges in the graph indicate that the entity ("Messi") is of type "footballer", was born in Rosario, and plays striker for FC Barcelona. Each of the entities that "Messi" is connected to in this graph can have their own set of connections; for example, FC Barcelona is shown to be connected to the Barcelona entity through the region relation.

mentary bases. The relationship of the data to an RDF specification's schema-defining part is particularly relevant[40]. It is common practice to distinguish an RDF Graph into a data part and a schema part. When looking at the storage [41] and querying [42] in databases, a natural distinction is made from schema definition and data statements. As an example, [40] defines a data subgraph of an RDF Graph G as a maximal subgraph G' satisfying $(\text{subj}(G') \cup \text{obj}(G')) \cap \text{pred}(G') = \emptyset$. The schema subgraph associated to G' is $G \setminus G'$.

4.1.2. RDF Graph Storage in collaborative sharing systems

We only address here storage solutions known in collaborative sharing and modification approaches [43–45]. Regarding RDF triples, three common ways to store RDF data have been proposed: the standard XML serialization RDF/XML [43] to store data on documents, the storage systems Jena [44] and Sesame [45].

RDF/XML [43] is a syntax to serialize an RDF Graph into XML. A graph-like data structure as RDF can be mapped onto a tree-model as offered by XML, but can not be truly represented by it: an XML encoding of RDF does not properly represent the connectivity of the RDF Graph, and is thus, as a data structure, unsuitable for querying. Another issue is that RDF/XML is ambiguous in the sense that many XML serializations of the same RDF Graph can be obtained.

Jena [44] is a Semantic Web Framework, offering a Java programming interface, a database subsystem, and a query language (RDQL) [46, 47]. Jena's original design (Jena-1) used two alternative approaches to store an RDF Graph: (1) Three tables: one for statements, one for literals and one for resources. Here the

Table 2

Summary of the two overlay membership protocols. Full support for a feature is indicated by the sign \checkmark .

	Vougaris[27]	T-man[28]	Mordacchini[29]	Gospole[23]	Vicinity[24]	Behave[25]	HyRec[30]	Webgc[31]	Cyclades[26]	Crate[32]
Similarity metric	\checkmark		\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	\checkmark	
Gossip clustering			\checkmark	\checkmark	\checkmark	\checkmark		\checkmark	\checkmark	
Double view	\checkmark			\checkmark	\checkmark	\checkmark		\checkmark	\checkmark	
Data compression				\checkmark		\checkmark				
Caching	\checkmark					\checkmark			\checkmark	
Semantic clustering	\checkmark	\checkmark						\checkmark		
Used MMP	Cyclon[12]	Jelasy[15]	Cyclon[12]	Brahms[17]	Cyclon[12]	Brahms[17]		Cyclon[12]	Brahms[17]	Spray[19]
Contact server							\checkmark		\checkmark	\checkmark

main problem was the heavy use of joins to answer queries. (2) One statement table, with indexes by subject, by predicate and by object.

Sesame [45] is an architecture for efficient storage and expressive querying of large quantities of metadata in RDF and RDF Schema. The main feature of Sesame is that it provides query languages, and a subset of RQL which incorporate the RDF Schema semantics. The concrete data storage is implemented differently according to the underlying database system [45]: PostgreSQL and MySQL.

4.1.3. RDF Graph Querying in collaborative sharing systems

For approaches related to collaborative sharing systems, RDF data and RDF schemas can be considered at three different levels of abstraction [45]: at the syntactic level (they are XML documents), structure level (they consist of a set of triples) and semantic level (they constitute one or more graphs with partially predefined semantics).

Clearly, the requirement is for methods to query on the semantic level (i.e: querying the full knowledge and not only explicitly stated assertions). Two options exist to achieve this goal: (1) Calculate and store as the query base the given graph closure, (2) Enable inference of new statements via the query processor as required.

Much work has been done to build infrastructures consisting of centralized nodes, dedicated to data sharing and capable of ensuring the availability and consistency of these data. These client-server infrastructures of the Web of Data allow the implementation of light clients for users, thus transferring processing and calculation loads to the servers. They are also very suitable (compared to decentralized infrastructures) in terms of speed when searching for information on large amounts of data. Central nodes can cooperate to share knowledge. But the major difficulty in this method is that query results may change over time,

depending on node availability. If a node becomes unavailable, it is not relayed by any other node in the network. Thus, any node can be a point of failure for the system[48].

To overcome these centralized constraints, several approaches in the literature consider distributed scenarios based on peer-to-peer networks. The network provides high resistance to technical failures of nodes. These peer-to-peer systems offer many advantages of decentralized distributed systems but suffer from problems related to the availability and reliability of sources and data. To overcome these constraints, decentralized peer-to-peer systems rely on mechanisms to mitigate the impact of disconnection scenarios on data availability, but also to balance the system's processing loads on all peers. In the case of decentralized RDF data sharing systems, these mechanisms allow a graph to be partially or totally replicated, shared and modified in a collaborative way through the peers involved in the architecture. To this end, several solutions have been proposed in the literature adopting each of the following principles, which are conceptually different:

- Graph replication: the graph is stored on all peers in the network that can modify and/or delete portions of it independently. These addition or deletion operations will then be propagated through the architecture using variable techniques to ensure the consistency of the different copies.
- Distributed graph and structured peer-to-peer system (case of DHTs): the graph is distributed across all peers on a structured peer-to-peer environment (a DHT). In this case, requests are routed directly to peers holding the requested data.
- Distributed graph and semantic overlay: the graph is distributed over all participants by adopting a semantic peer-to-peer net-

work architecture. Also here, requests are routed to neighboring nodes and nodes belonging to other clusters if necessary. For having described the general conception of this approach in section 3.2, we will not treat it in this chapter.

- Cloud and fog computing: the graph is hosted on the cloud. A collaborative cache on browsers is then set up on the architecture to overcome disconnection scenarios.

Next, we will focus on solutions based on following approaches: Graph Replication and Cloud/Fog Computing.

4.2. Graph replication

Data replication methods are gaining popularity in peer-to-peer computer systems as a way to achieve high availability and reliability. Data replication is now a relevant design principle to ensure reliability, load balancing, but mainly the high availability of data and services in distributed systems. It improves the performance and availability of information sharing in a large-scale network[49]. Data replication consists precisely of storing in separate sites several data object copies. The graph is stored on all (or part of) the peers of the network which can modify and/or delete portions of it autonomously. These addition or deletion operations will then be propagated across the architecture to ensure the consistency of the different replicas. This ensures a high availability of locally relevant data, especially in peer-to-peer architectures where data storage and processing is distributed among peers which may have dynamic behaviours.

4.2.1. Replication criteria

Replica control mechanisms can be classified according to three criteria[49]: where updates take place (single-master or multi-master), when updates are propagated to replicates (synchronous vs asynchronous) and how replicas are distributed over the network (full or partial replication).

- Update placement: For Single-master method, each reproduced object has only one primary copy. With this method, only one site is given reading and writing access whereas only reading authorization is granted to others[49]. This is often referred as the master-slave method for master nodes interaction with other "slave" nodes hosting a copy[49]. Centralizing updates on a single

point make it easier to manage concurrent access. However, centralization introduces potential bottleneck and point of failure. Multi-master method allows several sites to hold a primary replica of a single object. These copies are all simultaneously updatable. Each site is allowed to update its copies. Multi-master provides more agility over single-master, as in case of a master crash, another one may handle replicas[49].

- Distribution of replicas: For replicas placement, there are two basic approaches: full replication and partial replication[50]. With full replication, a shared object is copied to each member's site. It provides load balancing simplicity as all sites offer equal capacity. It also offers maximum availability since any site can replace any other site in case of failure. With partial replication, each site holds a copy of a subset of shared objects, so that the replicated objects may be different from one site to another. This approach requires less storage space on the sites and updates only spread to the sites concerned. Thus, these updates produce a reduced load for the network and sites compared to full replication[50].

- Update propagation: Updates can be propagated on a replica control system using a synchronous or asynchronous approach[51]. The synchronous update propagation approach applies changes across replicas within the update producing operations context. Therefore, once operation performed, all replicas have the same state[49]. The source node of the transaction (set of update operations) propagates the update operations in the context of the transaction to all other replicas before executing this transaction. There are several algorithms and protocols to carry out this process[52, 53]. Thus, synchronous propagation requires possible consistency between replicas. With the asynchronous approach, the transaction is first executed at the local site and then updates spread to remote sites. Asynchronous propagation has the advantage that replica unavailability will not interrupt updating processes, thus improving availability. It is possible to classify asynchronous replication solutions as optimistic or pessimistic based on their assumptions about conflicting updates[54, 55]. Pessimistic asynchronous replication is based on predictions that updating conflicts will occur and introduce propagation methods to prevent it. In contrast, optimistic asynchronous replication is based on

the positive hypothesis that conflicting updates arise rarely, if at all. Updates are therefore propagated in the background. Conflicting updates will be processed at the next stage, accepting a certain degree of divergences between sites. Most of these optimistic replication systems ensure possible consistency between replicas[54, 56].

The degree of replication (complete or partial), as well as the source (single or multi Master) and propagation mode (synchronous or asynchronous) of updates in the system are fundamental characteristics for data replication systems.

4.2.2. Selected Graph Replication approaches

BAYOU [57] is a mobile data search solution allowing to reproduce a database on a computer, edit it offline and then synchronize to any other replicas. In Bayou, a single main site determines actions to execute or interrupt and informs other sites.

RDFGrowth [58] focuses on semantic data sharing where a single peer can modify the shared knowledge, while the others have the right to read. RDFGrowth targets a particular scenario where peers participate in interest groups to develop their internal knowledge on one or more thematic areas.

The concept of OT (Operational Transformation) [59–61] has been developed for collaborative publishers. OT is based on the principle that operations are directly executed at the local site and commands are then forwarded to other sites. Therefore, the same operations sequence is executed by all sites, possibly in different orders. OT’s objective is to maintain operations intent and ensure replicas converge. This is done by using a rewrite rule for each simultaneous operations pair.

Skaf et al. [62] presents the first semantic peer-to-peer wiki, SWOOKI. SWOOKI’s network is composed of a set of interconnected autonomous semantic wiki nodes that can join and leave the network dynamically. It is an unstructured and decentralized P2P system that requires no central coordination or knowledge. It is based on a symmetrical communication model where each peer can act as both server and client. Data management is based on optimal data replication where each peer hosts a copy of the wiki pages and the associated semantic data. Each peer can autonomously offer all the services of a semantic wiki server, access, search and requests are executed locally without any routing of requests on the network (full replication).

Weiss et al. [63] presents Logoot-Undo CRDT (Commutative Replicated Data Type) algorithm that incorporates the *undo anywhere, anytime* functionality. For

reasons of efficiency and fault tolerance, the network content is replicated. This replication can be either total or partial. The Logoot-Undo approach belongs to the CRDT framework whose main idea is to provide real commutability between simultaneous operations. An operation is either an insertion or a deletion. Operations are grouped into patches and sent to all other replicas for integration. Each patch is delivered once and only once for each replica.

In [64], **Spaho et al.** consider peer-to-peer systems with an architecture that includes super-peers. A peer group consists of several peers that may be geographically distant from each other but have a common objective. The work is comprised of tasks to be performed by group peers. Replicating peer group documents is a major task. Peer group has a central manager referred to as the super-pair. It assigns tasks to the group’s peers and keeps track of how the work is being done. It facilitates interaction with other peer communities. Super-peer connects group peers with other network peers and super-peers. If any portion or all of a peer’s document evolves, remaining peers holding the document’s replica will apply changes.

Ibanez et al.[65] presents SU-Set (SPARQL-Update Set), a CRDT (Commutative Replicated Data Type) for RDF graphs updated with SPARQL Update 1.1 operations. A CRDT is a type of data whose operations, when simultaneous, give the same result regardless of the execution order. This is an emerging formalism for optimistic replication. The authors design a CRDT for RDF graphs updated with SPARQL Update 1.1 operations, thus ensuring the possible consistency of a Live Linked Data (LLD) social network. The latter is considered here as a cooperative publishing system with low latency needs and no editing constraints. The CCI (Convergence, Causality, Intention prevention) coherence model of[60] is used. SU-Set extends the insertion and deletion operations of OR-Set[66] (Observed-Removed Set) to union and difference. In OR-Set, each inserted element is labelled with a unique identifier. This ensures that the elements stored in the payload are always unique, and therefore, added and deleted only once. SPARQL operations on the triplets are performed by the user, then rewritten into SU-Set operations with pairs (*triple, id*) in a transparent manner for the user and sent forward to the other nodes, where they are re-performed at the reception.

Crate [32] is a decentralized, real-time collaborative editor that runs directly in web browsers using WebRTC. To provide document availability and responsiveness, Crate follows the optimistic replication

1 scheme. Each publisher reproduces the document locally
2 and performs directly its operations. Then, the
3 publisher distributes its changes to all other participants.
4 The system is correct if editors with the same set
5 of changes have convergent replicas to an equivalent
6 state, i.e. users read the same document. This property
7 is the strong eventual consistency[67].
8

9 4.3. Distributed graph: cloud and fog computing

10
11 This sub-section discusses on the evolving paradigm
12 of Cloud Computing, which aims to provide reliable,
13 customized and QoS (Quality of Service) guaranteed
14 dynamic computing environments for end-users. Although
15 this paradigm is mainly driven by the high availability
16 of Internet access, it presents a relevant approach
17 for us which consists in providing power (storage,
18 calculation, processing, etc.) for end-users via Internet
19 instead of obtaining this power by acquiring hardware
20 and software. We are particularly interested in this
21 approach as it could be envisaged in a local environment
22 with limited Internet access. Mobile contributors
23 could form a local common storage and possibly benefit
24 from power of local super-contributors (i.e. more
25 powerful contributors in terms of storage, calculation,
26 processing, etc.) via a peer-to-peer connection.

27 The size, diversity and increased complexity of RDF
28 reasoning makes it difficult to maintain huge RDF data
29 volumes. Distributed data store architectures are required
30 to overcome volume related challenges. Cloud computing
31 has become a widely adopted paradigm for scalability,
32 fault tolerance and elasticity features offered to many
33 applications, facilitating distributed and parallel
34 architectures deployment. Semantic Web community
35 researchers focus on solving the scalability and performance
36 problems of traditional Semantic Web tools by leveraging
37 cloud computing technologies. The advent of Cloud
38 Computing has paved the way for a distributed ecosystem
39 of RDF triple stores that has the potential to provide
40 very large scale storage and distributed query processing
41 capabilities. The MapReduce paradigm, which is built
42 on Google's file system[68], is the dominant parallel
43 and distributed programming paradigm in the cloud
44 computing community because of its high performance
45 and fault tolerance capability[69]. MapReduce is an
46 programming model for parallel processing of huge
47 data volumes. It is an evolutionary technology
48 welcomed by the scientists. This is used by Google
49 for web indexing, data storage, social networks. Apache
50 also implements MapReduce in the open-source
51 framework

1 Hadoop[70], which is successfully applied to solve
2 data intensive problems in different domains. This is
3 a distributed file system in which files are stored
4 using replication. Hadoop offers a high degree of
5 reliability and fault-tolerance.

6 4.3.1. Cloud for distributed RDF data

7 In recent years, cloud computing provided many
8 opportunities for companies by offering their customers
9 a range of IT services. The current cloud computing
10 *pay-as-you-go* model is becoming an effective
11 alternative to owning and managing private data
12 centers for customers facing web and batch applications
13 processing[71]. Cloud computing frees organizations
14 and their end users from having to plan for many
15 details, such as storage resources, computational
16 limitations and the cost of network communication.
17

18 Cloud computing is becoming the general Internet
19 approach to information storage, retrieval and
20 management. At the same time, mobile devices are
21 emerging as the main service applications. Successful
22 integration of cloud computing and mobile devices
23 is therefore the key task of the next generation
24 network. However, this integration faces several
25 fundamental challenges: service agility, real-time
26 response, long-term connection[72]. To address
27 these challenges between cloud and mobile applications,
28 fog computing has recently emerged as a more
29 practical solution to enable seamless convergence
30 between cloud and mobile for content delivery and
31 real-time data processing[73]. Fog computing can
32 address these issues by providing resources and
33 services that are accessible to end users at the
34 edge of the network, while cloud computing is
35 more about providing distributed resources over
36 the main network.

37 4.3.2. Fog/edge for distributed RDF data

38 Fog computing is a distributed computing paradigm
39 acting between cloud data centers and devices/sensors
40 (users) as an middle tier[74]. The fog computing
41 concept was introduced by Cisco in 2012 to address
42 the challenges of IoT (Internet of Things) applications
43 in the conventional cloud computing[75]. A fog
44 computing system consists of conventional network
45 devices like routers, switches, decoders, proxy
46 servers, base stations, etc. (Figure 4) placed near
47 peripherals/sensors[74]. These components have
48 various computation, storage, networking, and other
49 features, and can support the execution of service
50 applications. As a result, functional components
51 allow fog based services to build widespread geographic cloud-

based service distributions. In addition, fog computing eases positioning support, enhanced mobility, live interaction, interoperability and evolutivity. Thus, it can operate efficiently in terms of service latency, energy consumption, network traffic, capital and operating expenses, content distribution, etc. In this sense, Fog computing better meets the requirements of IoT applications as opposed to the single use of cloud computing[76].

Fog computing is often assimilated to Edge computing particularly due to the fact that Edge takes up the idea of Fog computing, i.e. bringing computing resources closer to end users[77]. However, there is a particular difference that is based on the location of computing resources. Fog computing is based on small data centers spread over different sites located on the periphery of the network[78]. These data centers typically have several servers and provide computing and storage resources to customers located at the edge of the network. Edge computing, on the other hand, allows data processing on the peripheral network, which consists of end devices (mobile phones, smart objects, etc.), peripherals (edge routers, decoders, bridges, base stations, wireless access points), etc.[77].

There are similar concepts such as Mobile Cloud Computing (MCC) and Advanced Mobile Computing (AMC) that self-identify themselves in Fog concept[74]. MCC describes an infrastructure where the storage and processing of data take place outside of mobile equipments[74]. Mobile cloud-based services transfer processing and data storage power from smartphones to the cloud, providing mobile services and applications not only to the users themselves, but to a wider set of mobile subscribers as well[79]. MEC may be considered like a cloud service operating on a dynamic network and accomplishing particular functions not achievable using a conventional network architecture[80]. In the context of Internet of Things, fog computing appears to be a mix of MCC and MEC, while it stands out as an increasingly promising and widespread computing paradigm.

4.3.3. Selected Fog/edge approaches

Cloudlet [82] is considered as an exemplary implementation of resource-rich Fog nodes. Three layers made up its architecture. The lower layer consists of both linux kernel and cloud data cache, the middle layer is virtualization with a set of cloud software such as OpenStack[83], and the upper layer consists of applications isolated by different virtual machine (VM) instances. Cloudlets have been specifically designed to

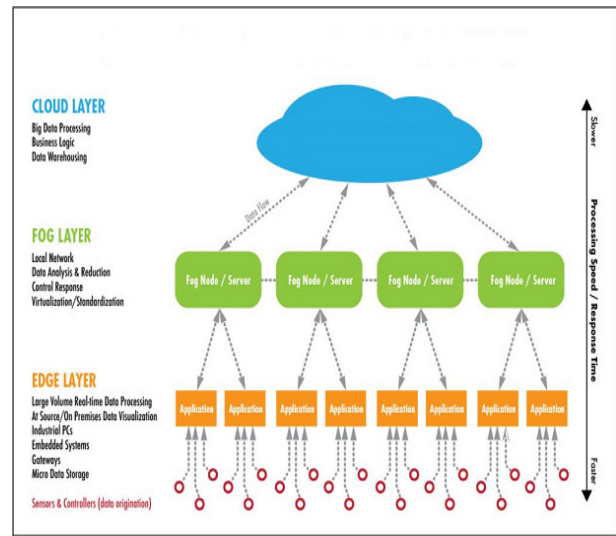


Fig. 4. Example of Fog/Edge architecture [81].

provide services to mobile users with limited local resources that can act as lightweight clients and access cloud resources that are one-step away via a wireless network.

Zhu et al. [84] apply existing methods for web optimization in an innovative way. In the context of Fog computing, these methods can be combined with unique knowledge that is only available on Fog devices. A more dynamic adaptation to the user's conditions can also be achieved with specific knowledge on the network periphery. Consequently, the rendering performance of a user's web page is improved beyond that obtained by simply applying these methods on the web server.

Hong et al. [85] presents a PaaS (Platform as a Service) programming model, called Mobile Fog, that provides simplified programming abstraction and supports dynamically scaled applications at runtime. In this model, an application consists of distributed mobile Fog processes that are aligned with computing instances distributed over the fog and cloud, as well as various equipment at the network periphery. At runtime each process performs application-specific tasks such as detection and aggregation in relation to its location and level in the network hierarchy. Each Mobile Fog process manages the workload of a certain geo-spatial region.

DiploCloud [86] is an efficient and scalable distributed RDF data management system for the cloud. Three major structures constitute the system: clusters of RDF molecules considered as hybrid structures using both

property tables and RDF sub-graphs, model lists (storage of literals in compact lists as in a column-oriented database system) and an efficient key index that indexes URIs and literals based on the clusters to which they belong. The system design follows the architecture of many modern distributed cloud-based systems (for example, Google's BigTable[87]), where a main node is responsible for interacting with customers and orchestrating operations performed by other nodes (Worker).

Faruque et al. [88] introduces Fog computing as an innovative platform for energy management. The proposed platform uses interoperability, scalability, adaptability and connectivity between intelligent platforms on the fog computing platform, which is a low-power, low-cost device for computing, storage and communication. Energy management or control software is implemented as a service based on Devices Profile for Web Services (DPWS) also used for discovery to provide plug-n-play functionality. This service-oriented architecture also summarizes the heterogeneity of communications and hardware. With a huge number of vehicles in urban areas, bringing underused vehicle resources into service offers an excellent opportunity and value. Hou et al.[89] thus conceive the idea of using vehicles as communication and computing infrastructures, called *Vehicle Fog Computing (VFC)*, which is an architecture that uses a multitude of collaborative customers/end users or onboard devices close to the user to perform communications and calculations, based on a better use of each vehicle's individual communication and computing resources.

Rahman et al. [90] presents a fog-based distributed semantic model named Semantic-fog allowing semantic services in the vicinity of IoT devices. The semantic fog structure comprises IoT features in the perception level, fog units in the treatment level, and cloud infrastructure for the treatment and application level. The fog nodes are organized according to their functionalities. Layer 2 fog unit gathers raw sensory data and execute certain functions like filtering and clustering, and pass them on to the higher level fog unit. Layer 1 nodes will obtain this aggregated data of high quality and carry out compilation, modelling and mapping processes, and initiate suitable measures. Then, data are transmitted to remote cloud for storing, viewing or complex treatment.

Mehmood et al. [91] proposes a cloud-centric IoT platform for virtual object registration and initialization. For security reasons, permission and control are required for registration procedure. Only authorized

persons will be approved by the authorization mechanism to record IoT equipment and prevent unneeded IoT platform exploitation. This differs from traditional IoT platforms as they offer material and application services within a single platform and allow users to connect and use them. RDF is used for finding, exchanging and presenting datas on IoT marketplace.

In [92], **Farnbauer-Schmid et al.** introduces the Semantic Edge Computing Runtime (SECR), an edge computing tool developed to provide a background for IoT peripherals. SECR combines two concepts: data integration to support the diversity of IoT applications, and edge technology to minimize data volume to be transmitted for distant processing. By using data integration, edge processing can be carried out at a greater degree of abstraction. All outputs from SECR services are available as RDF graphs allowing edge level interoperability.

4.4. Synthesis on collaborative graph sharing and modification approaches

The four concepts previously presented (Graph Replication, Distributed Graph and DHT, Distributed Graph and Semantic Overlay, Cloud and Fog Computing) constitute a set of approaches that are relevant for decentralized architectures. Their use in the design of mobile solutions for sharing and contributing Data to the Web could solve the problem of high availability of relevant data in contexts where access to remote sources is constrained by limited connectivity to Internet. The approach of intelligent replication of the graph on the architecture is particularly interesting in this context. The challenge then concerns the preservation of data consistency as update operations are produced at the contributing nodes. Optimistic asynchronous replication effectively addresses this challenge with the assumption that there are few conflicting updates, which, if they occur, are processed at the end of the process. This means that the system tolerates a certain level of divergence between replicas. This compromise may be acceptable for collaborative sharing and contribution solutions. Table 3 summarizes different solutions presented. These models are compared according to the following criteria:

- Data type: Exchanged data types.
- DHT: The architecture relies on DHT.
- Partial replica: The system adopts a partial replication mechanism on the graph.
- Semantic Overlay: The system builds a semantic overlay on the nodes.

- 1 – Total replica: The system adopts a total
- 2 replication mechanism on the graph.
- 3 – Caching: The system has a caching service.
- 4 – Fog layer: The architecture has a Fog layer.

5 The literature shows that the approaches identified
6 above (subsections 4.2 and 4.3) have been successfully
7 applied on architectures based on gossip protocols.
8 The decentralized peer-to-peer architecture is built us-
9 ing the underlying gossip protocol that also ensures
10 connectivity despite node arrivals and departures. The
11 protocol also manages, in some cases, the exchange of
12 update operations between nodes. The data structure is
13 then hosted on the architecture according to one of the
14 previous approaches. We can cite a few examples.

15 In Crate[32], a decentralized real-time collaborative
16 editor that runs directly on web browsers using We-
17 bRTC, the gossip Spray protocol builds and maintains
18 a mesh of contributing web browsers. Spray provides
19 each contributor with a local neighborhood table (the
20 view) that allows communication in a subset of editors.
21 Crate adopts the graph replication approach. The graph
22 represents a document shared by all publishers (con-
23 tributors). Each publisher reproduces the document lo-
24 cally and performs its operations directly. To also en-
25 sure the consistency of the graph on each editor, Crate
26 uses the SPRAY protocol to distribute all update oper-
27 ations to all collaborators in an evolutionary way.

28 Swooki[62] is a peer-to-peer semantic wiki that com-
29 bines the wiki approach of ontologies such as Se-
30 mantic MediaWiki[93] and a peer-to-peer wiki based
31 on total replication and CCI (convergence, causality
32 preservation and intention preservation) model such
33 as Wooki[94]. On the one hand, Swooki is based on
34 the graph replication approach. The graph here rep-
35 represents a semantic wiki page (combination of text
36 and RDF data). On the other hand, update opera-
37 tions will be routed to collaborating nodes using the
38 gossip protocol[95] combined with an anti-entropy
39 protocol[96].

40 Voulgaris et al. [97] use the semantic superposition
41 approach to exploit the semantic structure present in
42 document sharing systems to improve search perfor-
43 mances. They propose an architecture with contributor
44 nodes that are semantically close. Each node maintains
45 a list of semantic neighbors to which requests are sub-
46 mitted first, before using a default search mechanism
47 if no semantic neighbors can respond to the request.
48 To build and maintain the semantic neighborhood, the
49 authors assume the existence of a peer-to-peer system
50 supporting semantic searches. This system is then built

1 with the SCAMP gossip protocol that generates an un-
2 structured overlay network.

5. Discussion and Conclusion

3 Our objective in this paper was to survey the ex-
4 isting solutions (models, architectures, etc.) that could
5 contribute to solve the problem of intermittent access
6 to the Web of Data by mobile contributors. First of all,
7 we confirmed that gossip protocols offer well adapted
8 approaches to the design and maintenance of decen-
9 tralized and dynamic peer-to-peer architectures. Con-
10 sequently, our prospection was guided in its first part
11 by the analysis of solutions based on gossip protocols
12 dedicated to the design and management of peer-to-
13 peer overlay networks, and then to the analysis of ap-
14 proaches, dedicated to data sharing systems construc-
15 tion according to the RDF data model.

16 For architectures based on a gossip protocol, we
17 distinguished two architectures types. The first (*gos-
18 sip protocols with a basic adhesion mechanism*) refers
19 to basic systems dedicated to designing and maintain-
20 ing the connectivity of the underlying architecture on
21 which the various exchanges between peer members
22 are based. The second type of architecture (*gossip pro-
23 tocols with two overlay adhesion mechanisms*) is ded-
24 icated to the automatic formation of clusters of inter-
25 est or proximity aimed to group together peer mem-
26 bers of the architecture that have one or more common
27 interests or that are close according to a given metric
28 of similarity. These two overlay systems are built on
29 top of basic protocols. We also note the possibility of
30 taking into account the location of peers when select-
31 ing neighbours [24]. The neighbourhood will then be
32 formed by semantically close peers, having a certain
33 geographical proximity, i.e. a maximum limit in terms
34 of geographical distance is set between the peers con-
35 sidered as neighbours. Based on parameters such as
36 *fanout*, *view size*, and *node degree*, gossip protocols are
37 generally evaluated by comparing the different archi-
38 tecture behaviors at runtime. Protocol properties such
39 as *failure resistance*, *convergence time*, and *load dis-
40 tribution*, *graph properties* (*clustering coefficient*, *av-
41 erage of shortest paths*, *balanced distribution*), are an-
42 alyzed and interpreted following test scenarios on sim-
43 ulation platforms such as PeerSim[98].

44 The works surveyed in this document present many
45 trends relevant for future work on gossip protocols.

Table 3

Summary table of solutions dealing with mobile access to data: The support of a characteristic is indicated by the sign \checkmark

	Semantic-fog[90]	SECR[92]	Swooki [62]	Cloudlet [82]	Logoot-Undo [63]	Crate [32]	DiploCloud[86]
Data Type	RDF	RDF	RDF	file	file	file	RDF
DHT					\checkmark		
Partial Replica	\checkmark	\checkmark			\checkmark		\checkmark
Total Replica			\checkmark		\checkmark	\checkmark	
Caching							
Fog Layer	\checkmark	\checkmark		\checkmark			\checkmark

Among them, we especially identified: the consideration of the geographical parameter, in particular by applying a deterministic selection during sampling and exchanges; the integration of the adaptive *fanout* to take into account the evolution of the architecture size; the implementation of JavaScript solutions to facilitate the deployment of protocols and peers inside Web browsers; and the exploitation of the advantages of explicit friends' social networks.

The structured analysis of approaches dedicated to the construction of data sharing systems is based on the layout of the architecture graph, i.e. whether it is replicated (partially or totally), or distributed, or shared and modified in a collaborative way through the involved peers in the architecture. Existing solutions are generally boosted by local caching, source indexing and synchronization mechanisms. This last element raises the issue of data consistency during system execution, in particular the divergence of states between remote and local sources when all synchronization operations are performed. To overcome this constraint, in some cases, such as [62], the CCI (Convergence, Causality Preservation and Intention preservation) model is used to ensure system coherence. This model allows the system to maintain the following three properties [60]: Convergence: when the same set of operations is executed on all sites, they will all have the same state; Causality: if an operation O is executed before another operation O' , the same execution order is respected on all sites ; Intent: for any operation O , the effects of the execution of O on all sites are the same as the intentions of O , and the effect of the execution of O does not change the effects of the independent operations. Other solutions [97, 99, 100] also rely on mechanisms for caching relevant data according to the meta-data of peer requests. Replacement (or deletion) policies identify which data to move to persistent storage or permanently delete for proper cache management.

Using metrics such as complexity in time and space and the traffic effect on network architecture, the proposed solutions are compared by analyzing their performance in relation to their own properties. These include data quality metrics (exhaustiveness, conciseness, consistency), cycle number, query load, scalability. Here, we also noted some interesting points for future work. They can be summarised mainly in two directions. The first concerns the problem of synchronization between local and remote sources. It targets the design of relevant mechanisms to improve the consistency and reliability of the exchanged data. The second direction aims to ease the constraints associated with the implementation of CRDT (Commutative Replicated Data Type) by eliminating the requirement for the underlying network to ensure causal ownership.

To conclude, we consider that to achieve a connected architecture that provides mobile contributors with local access to the Web of data, several technological approaches should be combined. On the one hand, to build and maintain the connected architecture, gossip protocols with two overlay adhesion mechanisms are more efficient for building connected overlay networks of mobile contributors. On the other hand, to ensure local access to data, we believe that optimistic replication systems are suitable for environments where access to the Web of data is intermittent. Data consistency can be ensured by following the CCI model. One additional relevant approach that we can use in future work is cooperative cache systems. These systems are also relevant to ensure local access, especially in cases where web browsers represent the contributors. We believe this survey shows that there is a very promising domain of research and an establish set of existing work and research directions to propose innovative and original new ways of sharing linked data even in technologically limited environments or with the goal of reducing our technological footprints.

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