Micro-billing framework for IoT: Research & Technological foundations

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***Abstract*—In traditional product companies, creating value meant identifying enduring customer needs and manufacturing well-engineered solutions. Two hundred and fifty years after the start of the Industrial Revolution, this pattern of activity plays out every day in a connected world where products are no longer one-and-done. Making money is not anymore limited to physical product sales; other downstream revenue streams become possible (e.g., service-based information, Apps). Nonetheless, it is still challenging to stimulate the IoT market by enabling IoT stakeholders (from organizations to an individual persons) to make money out of the information that surrounds them. Generally speaking, there is a lack of micro-billing frameworks and platforms that enable IoT stakeholders to publish/discover, and potentially sell/buy relevant and useful IoT information items. This paper discusses important aspects that need to be considered when investigating and developing such a framework/platform. A high-level requirement analysis is then carried out to identify key technological and scientific building blocks for laying the foundation of an innovative micro-billing framework named IoTBnB (IoT puBlication aNd Billing).**

***Index Terms*—Internet of Things; Micro-billing; Cryptocurrency; Standards; Data quality; Security and Privacy**

I. Introduction

OVER the past few years, digital revolution has significantly changed the way we communicate and act on a daily basis. A flourishing number of concepts and architectural shifts appeared such as the Internet of Things (IoT), Big Data and Cloud Computing. These concepts lay the foundations of the 'Web 3.0' also known as the Semantic Web (connecting Knowledge), and the 'Web 4.0' also known as the Meta Web (connecting Intelligence) [1]. Such evolution brings boundless societal and economic opportunities for reducing costs for cities, increasing the service for the citizens in a number of areas (public health, transport, smart living, industry...), and fostering a sustainable economic growth.

"Value creation" that involves performing activities that increase the value of a company's offering and encourage customer willingness to pay, is the heart of any business model. In traditional product companies, creating value meant identifying enduring customer needs and manufacturing well-engineered solutions. Two hundred and fifty years after the start of the Industrial Revolution, this pattern of activity plays out every day. In a smart connected world, products are no longer one-and-done, and making money is not anymore limited to physical product sales. Indeed, other revenue streams become possible after the initial product sale, including value-added services, subscriptions and apps. Generally speaking, information is the "new oil" of the IoT era, and recent surveys conducted on the early IoT adopters are showing positive and encouraging signs [2].

Besides data availability, it nonetheless remains challenging to leverage, extract and perceive the real value of information, as information is not as tangible as physical assets. This, added to that the fact that most of today's IoT services are Cloud-based (e.g., Apple, Google...), which somehow hinders end-users from having full end-to-end control over their data/privacy (to decide for which purpose the data will be used, how, by whom...). Although there is an increasing trend in storing and processing data at the edge, there is still a lack of frameworks to enable the micro-billing of edge data in a peer-to-peer (P2P) and standardized way (e.g., to enable a house owner to publish/sell house-related sensor data). Our research work aims to investigate, develop and offer such a framework – *referred to as "IoTBnB" standing for "IoT puBlication aNd Billing"* – by identifying, integrating and/or developing key scientific and technological building blocks, which may include among other things: IoT messaging standards, semantic interoperability standards, cryptocurrency technologies, data quality frameworks, privacy modules, *etc.*

Section II discusses IoT concepts, initiatives, and requirements that play a central role in the development of innovative and disruptive micro-billing at the edge. Based on a requirement engineering technique (QFD – Quality Function Deployment) introduced in Section III, those requirements are further turned, in Section IV, into technological and scientific building blocks for laying the foundation of IoTBnB framework; discussion and conclusion follow.

II. Towards disruptive micro-billing markets

According to IBM, the number of connected devices (Things) is forecasted to surpass 25 billion by 2020, meaning that it represents at least as many information providers as connected things. From a business perspective, highly fragmented market places could come into existence, and therefore could open up opportunities for new and disruptive IoT commercial services. To achieve this vision, it is of the utmost importance to enable smart objects and/or people (i.e., IoT ecosystem stakeholders) to discover each other, and perform data and payment transactions in an efficient, flexible, and safe manner. Such a vision and associated concepts (IoT ecosystem, Money and Data Transactions, IoTBnB) are depicted in Fig. 2, which are further discussed in sections II-A to II-C.

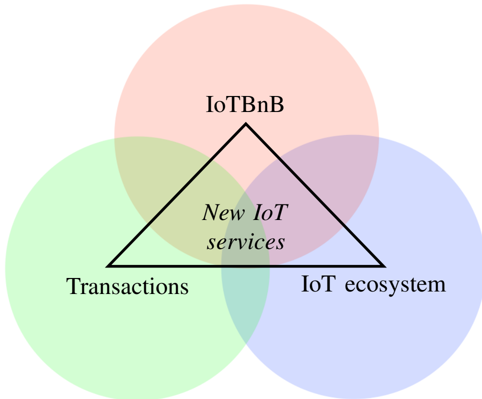

Fig. 1. Concepts playing a key role for achieving micro-billing in the IoT

A. *IoT ecosystems*

Digital and IoT ecosystems comprise a wide range of interacting and cooperating actors such as customers, solution providers, financial institutions, software developers, *etc.*, and open up possibilities for companies to expand or pivot their businesses. Nonetheless, there is still a major obstacle to the creation of striving IoT ecosystems, which is the vertical silos' model that shapes today's IoT. Indeed, vertical silos hamper developers to produce new added value across multiple platforms due to the lack of interoperability and openness [1]. Several organisms and standardization fora understood this problem, and have initiated consortia/initiatives to overcome it. Let us cite, for example (i) the *Web of Things* initiative at W3C that aims to create open IoT ecosystems based upon open standards, including identification, discovery and interoperation of services across platforms; (ii) the *Alliance for Internet of Things Innovation* (AIOTI), launched by the EU, aiming to strengthen links and build new relationships between various IoT players and sectors; (iii) the *Open Platform 3.0™* initiative at The Open Group that promotes open interoperability standards to enable enterprises to more easily use these technologies in business solutions; and (iv) the *OneM2M* global standards initiative that involves 8 standards bodies for Machine to Machine (M2M) communications. Although most of those initiatives promote various types of standards and specific technology enablers, they all share a common vision, namely to rely as much as possible on open and interoperable standards to facilitate the emergence of open ecosystems, and unlock the commercial potential of the IoT.

B. *Transactions*

Based on the Oxford dictionary's definition, a 'transaction' is defined as: *"an instance of buying or selling something"*. If we look at the world around us, everything is transaction based: from the transfer of money (when selling/buying a service) to digital interactions (*e*-mail, tweets…). As passengers make reservations, pay for tickets, board planes and receive frequent flyer miles, every step along the way a transaction is processed, recorded and stored. In the modern era of computing, the scale and volume of transactions have exploded, e.g. the New York Stock Exchange handles 5 million trades a day whereas there are 5 billion social media transactions every day [3]. Now, along comes the IoT, further exploding the scale and volume of transactions to be processed. In contrast to a physical good market, digital services trade intangible assets (i.e., data/information) for a certain amount of money. Transactions in this context is a two-step process: data/information transaction and payment transaction.

1) Data transaction: It consists in accessing heterogenous network elements (data providers) and exchanging data between one or many users/devices. From a high-level perspective, there are three transaction models: device-to-device (sensors, embedded systems…), device-to-server (gateway or shadow object) and server-to-server. To support data transactions in the IoT, several solutions/standards have been proposed such as MQTT (Message Queue Telemetry Transport), CoAP (Constrained Application Protocol), XMPP (Extensible Messaging and Presence Protocol), AMQP (Advanced Message Queuing Protocol), OneM2M, or still O-MI/O-DF (Open-Messaging Interface/Open Data Format), which all run directly on TCP and/or UDP. CoAP is a lightweight publish-subscribe protocol that runs on tiny resource-constrained devices (device-to-device data transactions). MQTT mainly targets device-to-server transactions using the publish-subscribe model. XMPP is initially developed for instant messaging to connect people to other people via text messages, thus representing a specific case of device-to-server transactions (people being connected to servers). AMQP mainly targets server-to-server transactions (e.g., in the banking industry). Finally, the O-MI/O-DF standards provide server-to-server communication support, while enabling text-based representations (XML, JSON…) [4].

2) Payment transaction: A new generation of currency, so-called digital (or virtual) currency, opened up opportunities for faster, more flexible, and more innovative payments [5]. According to the World Bank forecasts, it will represent around 5 trillion of dollars in 2020 just for mobile-phone money exchanges [6]. Today's digital payment systems are built on mobile/online platforms such as mobile phone, Internet, or card. Examples of such payment platforms are PayPal, Apple Pay, Google Wallet and Alipay, which are all based on fiat currencies, thus requiring a central authority like a financial institution. A subclass of digital currency relies on cryptographic protocols that performs a security-related function on the transactions. Since the global financial crisis in 2008, industries and scientists have paid more attention to digital currencies, the best known of which being Bitcoin [7]. The first work on cryptocurrency was introduced in 1983 by Chaum in the form of eCash/DigiCash [8]. On September 2015, 667 Bitcoin-based currencies were already in use, mainly based on a decentralized architecture allowing for P2P transactions and recorded in a public ledger called Blockchain. Noyen et al. [9] present an innovative IoT business model, referred to as *Sensing-as-a-Service*, which uses the Bitcoin technology and enables sensor publishers to communicate all available sensor data to potential data consumers and/or service providers. Along with bitcoin-like currencies and models, it is of the utmost importance to investigate and propose incentives that encourage sensor owners to publish data/information. The design of markets and pricing schemes has been a vital research area in itself, also known as Smart Data Pricing (SDP) [10]. SDP has been introduced as an alternative to address network resource management issues from both a system and business perspective. Niyato et al. [11] applied SDP to the IoT in order to set up prices used to reward the data/information publishers and improve the service quality and revenues. Other SDP-like models, such as crowd sensing, sensing using smartphone, IoT ecosystem, *etc.* [12], [13] try to establish similar pricing/incentive schemes that cope with the IoT peculiarities.

Having introduced the "Transaction" and "IoT ecosystem" aspects, the next section presents the IoTBnB vision that aims to foster publication, discovery and billing of IoT information in and across IoT ecosystems (*cf.* Fig. 2).

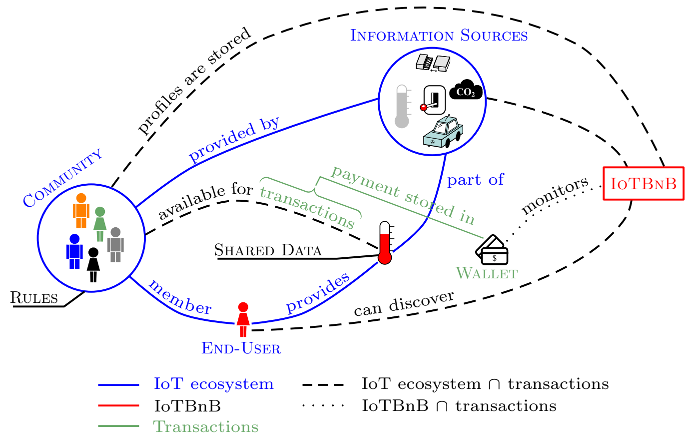

Fig. 2. Key enablers for a successful micro-billing framework (IoTBnB)

C. IoTBnB vision

The basic idea behind a global, open and standardized discovering and billing IoT system is depicted in Fig. 2. IoTBnB primarily aims to support and encourage end-users to publish, share, and potentially sell personal and/or impersonal information (e.g., person-related or organization-relared information) with other members involved in the IoTBnB community[1] (see blue/IoT ecosystem components in Fig. 2). End-user profiles shall be stored in the IoTBnB system, therefore constituting a member community that makes available a wide range and variety of information items. This community should be governed by rules such as *i)* access right definition for enabling one or a group of members to access, subscribe and/or modify information items published by another member, *ii)* account creation (e.g., e-wallet) for ensuring smooth, safe and legal transactions of data/money, *etc.*

IoTBnB makes a point to achieve P2P data and money transactions, meaning that members' data and money are not stored on IoTBnB but stay under members' control (e.g., on members' edge node such as smart home or organization gateway). In addition of the P2P aspect, IoTBnB makes a point of providing IoT members with the possibility to increase the value of the published information (e.g., by increasing the meaningfulness, ground truth, and reputation of the published information), while taking into consideration the publisher's privacy expectations/requirements. On the opposite, customers/buyers must be able to discover, either in a visual or automated manner, the available data based on their own needs and preferences (e.g., location-, category- or reputation-based). This should lead to the creation of new IoT markets since one member who may buy IoTBnB information can potentially create new services on top of it (e.g., by combining/aggregating information sources coming from different information provider members) and re-publish the service outcomes as new information/service items on IoTBnB.

In summary, our research work highlights five key requirements for a successful micro-billing framework for the IoT:

a. *Enable IoT information publication & discovery:* information providers/consumers must be able to publish/discover IoT information based on their own needs and preferences, e.g. taken into consideration publishers' privacy policies as well as customers' discovery preferences (e.g., location-, category- or reputation-based. . .);
b. *Foster open standard-based platform:* it should be possible for any IoTBnB member to easily collect and exchange IoT information (e.g., based on open and standardized APIs);
c. *Provide incentives for information providers/consumers:* motivate information owners to increase the value of their information. On the opposite, customers should be encouraged to develop new services on top of the accessed information, and potentially re-publish the service outcomes;
d. *Foster competition of pricing:* information providers are free to set the price of their information, which inevitably leads to a competition of pricing between IoTBnB members. On the opposite, customers should be able to know whether the prices are in line with the market, but also whether the quality is poor or good, which has a non-negligible impact on the information price;
e. *Enable secure information & money transactions:* it shall be possible to authenticate and authorize information and money transactions between members (i.e., based-intermediary);

The objective of the IoTBnB framework is to satisfy all the above requirements. Given the state-of-the-art platforms, and as summarized in TABLE I and discussed in the next paragraphs, a few address the above requirements such as *Placemeter*[2], *Thingful*[3], *Datacoup*[4] and *Waze*[5].

Placemeter acts as an intermediary between video data stream providers (recording street scenes) and customers (e.g., retailers who want to choose relevant locations to open their shops, government agencies who want to expand public areas), *etc.* The principle underlying Placemeter is that anyone can set up a camera system at home (or in front of his/her

[1] Note that IoTBnB is developed in the framework of the bIoTope H2020 project (http://biotope-h2020.eu) and, as a first step, targets the end-users/stakeholders of the bIoTope project outcomes.

[2] https://www.placemeter.com
[3] https://thingful.net
[4] http://datacoup.com
[5] https://www.waze.com

TABLE I
IoTBnB *vs.* EXISTING INITIATIVES

High-level requirements	IoTBnB	Placemeter	Thingful	Datacoup	Waze
a) IoT information publication & discovery	✓	✗	✓	✗	✗
b) Open standard-based platform	✓	✗	✗	✗	✗
c) Incentives for information providers/consum.	✓	✓	✗	✓	✓
d) Competition of pricing	✓	✓	✗	✓	✗
e) Secure information & money transactions	✓	✓	✗	✓	✗

shop) to record street scenes; the video data stream is then processed by the Placemeter's platform, and results (e.g. statistics about how many cars drive down the street…) are sold as a service. Placemeter provides incentives to each camera owner depending on the quality of their data stream, thus addressing requirements *c.* to *e.* (*cf.* TABLE I). Nonetheless, Placemeter does not rely on open standards (even though APIs are provided), does not offer an online data discovery engine, and does not aim to manage all types of IoT information sources (only dealing with video data streams).

Although *Datacoup* focuses on person-related information such as social network data streams (e.g. Facebook, Twitter…), it nonetheless relies on a similar information and money transaction model as the one underlying *Placemeter*. Indeed, information providers are rewarded (using fiat currency) based on the quality of their information, and services created on top of those information resources are sold at different prices according to the type of aggregated data, generated services, *etc.* However, as Placemeter, it fails in addressing requirements *a.* and *b.* in terms of heterogenous information source management and providing a standardized and open solution for discovering and accessing them.

Waze, which provides a service enabling people to get information about the road traffic conditions and predictions, is based on a slightly different incentive model since it is not money-based but it allows a person for accessing to Waze's information if, and only if, he/she agrees on sending live information (via a mobile) about his/her surrounding traffic condition (e.g. moving speed, closed roads…). As a consequence, Waze fails in addressing requirements *a.* and *b.*

One initiative that fulfils those two requirements is *Thingful*, which provides an IoT search engine enabling people to find any type of IoT-related information throughout the world, including information about how to access it (URL-based…). However, Thingful is completely free, thus not addressing requirements *c.* to *e.* as it does not intend to provide incentives to nudge information providers into joining the initiative, or still supporting them in increasing the "value" of their information assets. Furthermore, Thingful does not rely on any open and standardized solutions (not addressing requirements *b.*), thereby likely leading to interoperability issues (e.g., may have as many platform-specific APIs as information providers).

In order to fill the gap of existing initiative/platforms, a requirement engineering technique – *which is described in section III* – is applied in section IV for turning the five above-mentioned requirements into relevant technological and scientific specifications/building blocks.

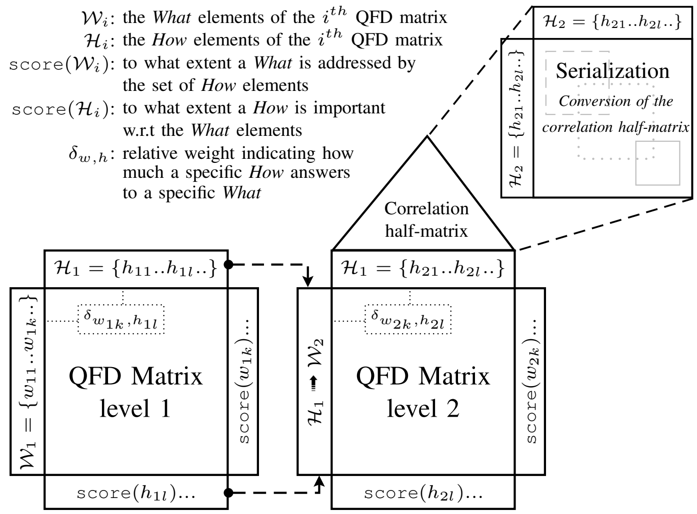

Fig. 3. Research methodology for turning high-level requirements into scientific and technological specifications

III. QFD-BASED FUNCTIONALITY IDENTIFICATION

Accurate requirements provide the foundation for successful product development. Three main steps can be identified in requirements engineering [14]: (i) *requirements inception:* start the process (business need, market opportunity…); (ii) *requirements development:* include requirements elicitation, analysis and negotiation; (iii) *requirements management*: to capture new needs/contexts over time.

In our context, the five requirements identified in the previous section must be transferred into specifications without necessarily developing all possible technical characteristics. To this end, our study adopts and adapts the QFD technique, which is a requirement definition and conceptual design tool that systematically documents customer needs, benchmarks, competitors, and transforms prioritized requirements into design specifications [15]. While the traditional QFD methodology flow involves four phases that occur over the course of the product development process, our approach implements a two-phase approach (*cf.* "*QFD Matrix level 1*" and "*QFD Matrix level 2*" in Fig. 3), combined with a spectral algorithm method (*cf. Serialization* in Fig. 3) for clustering positive and/or negative correlations (e.g., conflicts) among distinct Hows in a QFD matrix [16]. Section III-A and III-B respectively presents the QFD matrix and Serialization processes.

A. Quality Function Deployment

In any QFD matrix, rows/columns are referred to as the "Whats/Hows" of the matrix, respectively denoted by $\mathcal{W}_1/\mathcal{H}_1$ and $\mathcal{W}_2/\mathcal{H}_2$ with respect to"*QFD Matrix level 1*" and "*QFD Matrix level 2*" in Fig. 3. A priority value, representing the voice of the customer, must be specified for each What in the first QFD matrix (i.e., at level 1). This priority is denoted by $p_{w_{1k}} \mid w_{1k} \in \mathcal{W}_1$. An interaction between a What and How is also specified, denoted by $\delta_{w_{ik},h_{il}}$ in Fig. 3 ($w_{ik} \in \mathcal{W}_i$, $h_{il} \in \mathcal{H}_i$), thus indicating to what extent a

How (specification) addresses a What (requirement). Based on those priority and interaction values, two indicator scores, respectively denoted by $\texttt{score}(w_{ik})$ and $\texttt{score}(h_{il})$ in Eq. 1 and 2, can be computed for a given QFD matrix i. The first indicator (Eq. 1) provides the relative influence of all specifications/Hows on a single requirement/What w_{ik}, while the second indicator (Eq. 2) provides the relative influence of a single specification/How h_{il} on all the requirements/What specified in the QFD matrix i.

$$\texttt{score}(w_{ik}) = p_{w_{ik}} \cdot \sum_{h_{il} \in \mathcal{H}_i} \delta_{w_{ik},h_{il}} \tag{1}$$

$$\texttt{score}(h_{il}) = \sum_{w_{ik} \in \mathcal{W}_i} (p_{w_{ik}} \cdot \delta_{w_{ik},h_{il}}) \tag{2}$$

It must be noted that the Hows/specifications from the QFD matrix at level 1 become the Whats of the second QFD matrix, as emphasized in Fig. 3 (see $\mathcal{H}_1 \rightarrow \mathcal{W}_2$). The influence scores of the Hows (see Eq.2) are also propagated to the second QFD matrix, thus ensuring that the initial requirement priorities are spread throughout the iterative QFD matrix method.

At this stage, the correlation half-matrix (also referred to as the Roof of the House of Quality) is specified to highlight the correlations between distinct Hows. Those correlations may be either positive or negative since the development process of a specification may have a positive or negative impact on the development process of other specifications. To put it another way, a set of specification development processes may potentially reinforce or harm/constrain each other. As a result, the roof correlations in our study are based on a five-point scale: $\{++,\ +,\ 0,\ -,\ --\}$.

B. Identification of Hows interdependance

The objective is now to organize the specifications/Hows ($\mathcal{H}_2$) to be fulfilled according to their negative or positive correlations. To this end, we propose to define clusters of conflicts/constraints and cooperations by relying on a serialization algorithm, and particularly on the spectral algorithm proposed in [16], whose principle is:

> Given a set of elements n to order and a correlation function $f_{(i,j)}$ (corresponding to an attraction level between two elements i and j), the algorithm finds the optimized sequence between elements according to their attraction. More formally: Let π be the permutation of elements and $\pi_{(i)} < \pi_{(j)} < \pi_{(k)}$, then $f_{(i,j)} \geq f_{(i,k)}$ and $f_{(j,k)} \geq f_{(i,k)}$.

Given this, it is necessary to transform our correlation half-matrix into an appropriate matrix for being processed by the serialization algortihm. Concretely, our five-point scale $\{++,\ +,\ 0,\ -,\ --\}$ is turned into a five-numerical scale, namely $\{20, 10, 1, 50, 100\}$ respectively (the diagonal elements being set to 0). The arbitrary choice of the five-numerical scale reflects the fact that we want to stress/foster the clustering of negative correlations over the positive ones. The reason is that a negative correlation indicates a potential conflict or constraint to be considered between two distinct Hows/specifications, thus requiring a particular attention when developing associated solutions. Clusters can therefore be identified, where the overall contribution of a cluster with respect to the whole project can be evaluated as in Eq. 3, C being a cluster and $\texttt{rate}(C)$ the overall contribution of that cluster.

$$\texttt{rate}(C) = \frac{\sum_{h_{il} \in C} \texttt{score}(h_{il})}{\sum_{h_{il} \in \mathcal{H}_2} \texttt{score}(h_{il})} \tag{3}$$

IV. IoTBnB framework: Research & Technological building blocks

Our research methodology is now applied to turn the five requirements introduced in section II-C into relevant technological and scientific building blocks. In this regard, sections IV-A and IV-B respectively present the QFD-based methodology and serialization outcomes, along with an overview of the overall IoTBnB framework that will be developed in further research.

A. QFD methodology instantiation and outcome

The five requirements introduced in section II-C are used as the "Whats" of the first QFD matrix, as highlighted in Fig. 4. Such requirements have been first prioritized[6], whose results show that requirement "*a. Enable IoT information publication & discovery*" and "*e. Enable secure information & money transactions*" are the most important requirements from an end-user perspective ($p_{w_{1a}} = 42.7 \cdot 10^{-2}$ and $p_{w_{1e}} = 24.7 \cdot 10^{-2}$), respectively followed by requirements *c.*, *b.* and *d.* All the What/How interactions in this matrix are then specified; for example, *Open messaging APIs/Standards* (see first How's column) will play a key role in achieving IoT information publication & discovery services as well as on relying on open solutions and standards (reason of attributing an interaction value of "9" with regard to requirements *a.* and *b.*). To a certain extent, this How also acts as an incentive for end-users to share/publish their information since open and standardized APIs leverage interoperability and, as a consequence, the number of consumers that could potentially be interested in the published information (reason of attributing an interaction value of "3" with regard to requirement *c.*). In general, it can be noted that the three Hows/functionalities that contribute the most in addressing the initial requirements are (*cf. "Histogram_H1"* in Fig. 4): *Data & Service discovery mechanisms* and *Semantic interoperability standards*, followed by the development of a *User friendly Interface* and appropriate *Member's Profile Quality Support & Assessment* tools.

As emphasized in Fig. 4, the Hows and associated importance (i.e., $\texttt{score}(h_{1l})$) of the first QFD matrix becomes the new Whys and priority weights of the second QFD matrix. In a similar way, all the What/How interactions are specified, whose results show (*cf. "Histogram_H2"* in Fig. 4) that a *web-based interface*, the possibility of downloading and installing on site (e.g., on the home gateway) *software modules*, as well as the three types of *discovery mechanisms* (*Geo-discovery*, *Semantic web discovery,* and *Technology-based discovery*), are the most important building blocks for addressing the overall IoTBnB vision and underlying requirements.

[6]Note that in this study, the prioritization has been carried out using the AHP pairwise comparison method based on a panel of end-users.

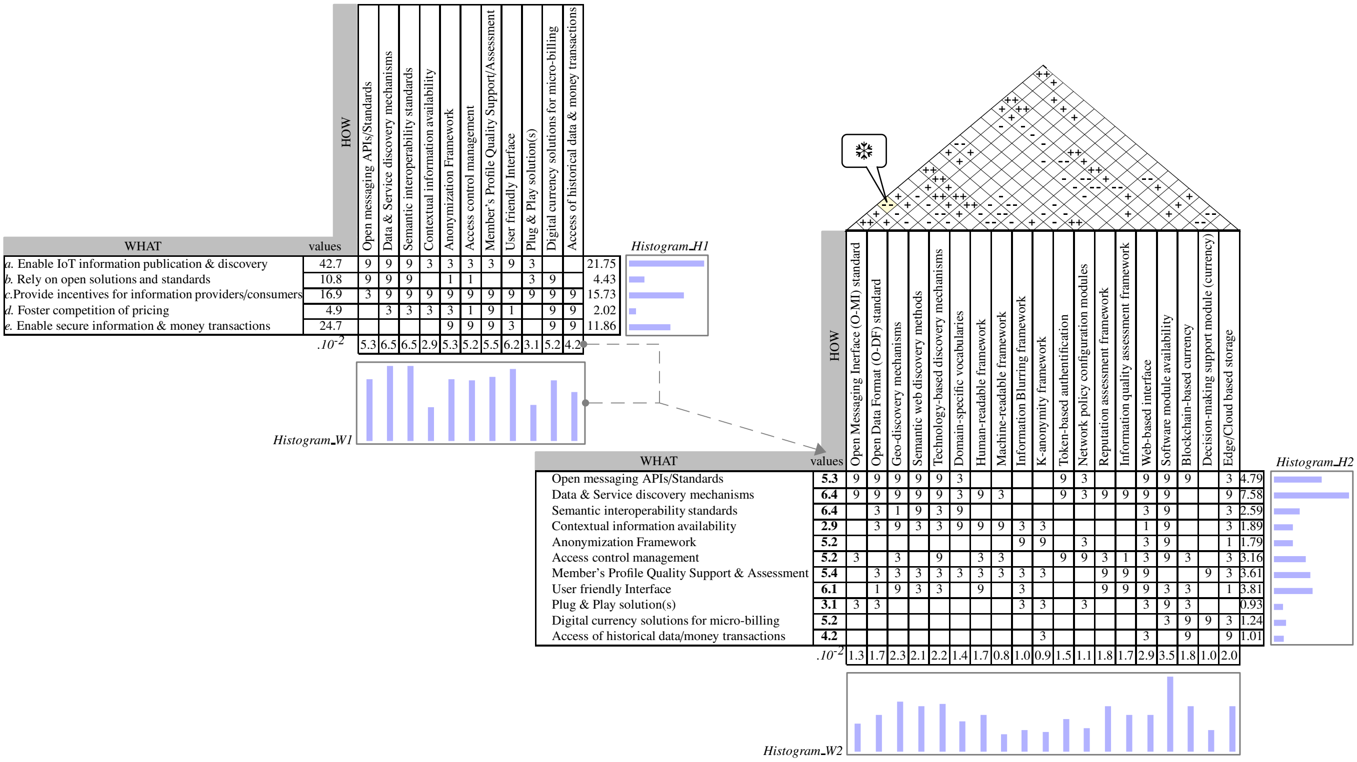

Fig. 4. QFD methodology applied based upon the five key requirements identified in section II-C

Based on our methodology flow, the correlation half-matrix is built based using the five-point scale $\{++, +, 0, -, --\}$, as shown in Fig. 4. Due to space limitations, we hereinafter detail one striking example of two distinct Hows/building blocks that could potentially negatively impact on each other if solutions regarding each building block are developed independently of each other. This example is emphasized in Fig. 4 (see tooltip ❆), where the problem that may occur when developing semantic web discovery solutions (often requiring a specific data structure and query language such as SPARQL) [17] is that it could be in conflict with other IoT messaging protocols that could propose and/or impose another data structure and query language. For example, in our proposed building blocks, we aim to use the O-MI and O-DF messaging protocols for interoperability purposes, where O-MI uses a RESTful URL-based query language. It is therefore of the utmost importance to think about how both technologies/solutions could be integrated when investigating and developing semantic web discovery modules. This is the reason why a strong negative correlation ("$--$") has been specified between both Hows.

The following section presents the serialization outcome, along with a discussion about the identified clusters and an overview of the overall IoTBnB framework based upon the identified clusters and building blocks.

B. Serialization outcome & IoTBnB framework overview

After applying the serialization algorithm on the correlation half-matrix, four distinct clusters emerged, as shown in Fig. 5. If we have a closer look at the different clusters, it is possible to identify families of building blocks that – *positively and/or negatively* – impact on each other, namely building blocks related to:

- *Billing services (Cluster 1):* about components and technologies that make it possible money transactions between information providers and consumers based on cryptographic moneys (not necessarily on specific cryptocurrency). In this respect, one building block that raises research questions – *not addressed to the best of our knowledge* – is how to support and help information providers to choose the best currency for selling/buying information according to their profile, expectations and preferences (*cf.* "Decision-making support module for currency choice" in Cluster 1). Indeed, digital currencies is now expanding rapidly and although BitCoin is today the most known and used cryptocurrency, a growing number of cryptographic moneys are emerging (e.g., Ripple, Bytecoin, NXT...), all offering different features that may be suitable/recommendable for specific uses (e.g, a developer might be interested by the development community and activity, while other persons can be more interested in the cryptocurrency economy as the market capitalization...);
- *Service publication & discovery (cluster 2):* about components and technologies that make it possible information and service discovery. From a publication perspective, this includes privacy enablers such as anonymization and blurring capabilities (*cf.* Cluster 2), as well as network policy configuration modules to deal with the information provider's network infrastructure (e.g., for opening/closing specific network ports...). From a dis-

Cluster 1 : Billing services
rate(C_1) = 0.27

Cluster 2 : Publication & discovery services
rate(C_2) = 0.46

Cluster 3 : Information quality
rate(C_3) = 0.27

Cluster 4 : End-user system deployment
rate(C_4) = 0.41

	Reputation assessment framework	Decision-making support module (currency)	Blockchain-based currency	Edge/Cloud based storage	Network policy configuration modules	Web-based interface	K-anonymity framework	Information Blurring framework	Human-readable framework for smart object…	Geo-discovery mechanisms	Technology-based discovery mechanisms	Semantic web discovery methods	Domain-specific vocabularies	Information quality assessment framework	Machine-readable framework for smart object…	Open Messaging Inerface standard	Token-based authentification	Open Data Format standard	Software module availability
Reputation assessment framework	0	10	1	1	1	10	1	1	1	1	1	1	1	1	1	1	1	1	1
Decision-making support module for currency choice	10	0	100	1	100	10	1	1	1	10	10	10	1	1	1	1	1	1	1
Blockchain-based currency	1	100	0	100	1	10	1	1	1	1	1	1	1	1	1	1	1	1	1
Edge/Cloud based storage	1	1	100	0	1	10	1	1	1	1	1	1	1	1	1	20	1	10	1
Network policy configuration modules	1	100	1	1	0	1	50	50	1	1	1	1	1	1	1	1	20	1	10
Web-based interface	10	10	10	10	1	0	100	100	100	50	50	50	1	1	1	10	1	10	1
K-anonymity framework	1	1	1	1	50	100	0	10	100	1	1	1	50	50	1	10	50	10	10
Information Blurring framework	1	1	1	1	50	100	10	0	100	1	1	1	50	50	50	1	50	1	20
Human-readable framework for smart object…	1	1	1	1	1	100	100	100	0	20	10	10	1	100	100	1	1	10	1
Geo-discovery mechanisms	1	10	1	1	1	50	1	1	20	0	1	50	50	1	10	10	1	10	1
Technology-based discovery mechanisms	1	10	1	1	1	50	1	1	10	1	0	50	50	1	20	10	1	10	1
Semantic web discovery methods	1	10	1	1	1	50	1	1	10	50	50	0	100	1	20	100	1	50	1
Domain-specific vocabularies	1	1	1	1	1	1	50	50	1	50	50	100	0	50	50	1	1	50	1
Information quality assessment framework	1	1	1	1	1	1	50	50	100	1	1	1	50	0	50	1	1	50	1
Machine-readable framework for smart object…	1	1	1	1	1	1	1	50	100	10	20	20	50	50	0	20	1	20	10
Open Messaging Inerface standard	1	1	1	20	1	10	10	1	1	10	10	100	1	1	20	0	100	20	20
Token-based authentification	1	1	1	1	20	1	50	50	1	1	1	1	1	1	1	100	0	10	100
Open Data Format standard	1	1	1	10	1	10	10	1	10	10	10	50	50	50	20	20	10	0	20
Software module availability	1	1	1	1	10	1	10	20	1	1	1	1	1	1	10	20	100	20	0

Fig. 5. Correlation serialization outcome

covery perspective, this includes various types of discovery mechanisms such as *(i) Technology-based discovery* to find information providers according to a specific technology or platform that they would potentially implement on site; *(ii) Semantic web discovery* (e.g., RDF for ICO modelling and representation, SPRQL for querying) to enable smart systems to understand, process and make decisions on the relevance/usefulness of accessing/paying for one or more IoTBnB information items, as well as *(iii) Geo-discovery* to find IoT services and virtual entities based on geographic coordinates;

- *Information quality (cluster 3):* about frameworks that make it possible the assessment of the published information. Information Quality (IQ), also referred to as Data Quality (DQ), has been intensively studied over the last two decades [18], resulting in the definition of a wide range of quality dimensions (e.g., language, semantic, knowledge, completeness, timeliness…) [19]. IoTBnB will develop an appropriate information quality framework based on a throughout state of the art analysis, while adapting it to integrate aspects and building blocks that have been identified through our study;
- *End-user system deployment services (cluster 4):* about components and technologies that enable any IoTBnB end-user to publish information in a standardized manner and, to the extent possible, based on open solutions/standards. As highlighted in Cluster 4, the O-MI and O-DF standards will play a key role to let this happen and to leverage horizontal interoperability across all IoTBnB end-users' system (breaking down the vertical silos).

As formulated in Eq. 3, the overall contribution of each cluster with respect to the whole project and end-user requirements can be computed (see $\texttt{rate}(C_x) \mid x = \{1..4\}$ in Fig. 5). Such cluster contribution values, combined with the resulting clusters, are very interesting indicators from a planning perspective, e.g. to address in priority the most important clusters (e.g., Clusters 2 and 3 in priority) and/or the most critical ones (i.e., the most overlapping ones).

First insights on the overall IoTBnB framework is proposed in Fig. 6, in which we tried to integrate the different building blocks and associated clusters identified through our study. On the one hand, the figure shows the information provider who can publish/sell information using various modules such as privacy modules, semantic and contextual representation modules (to leverage the quality of his/her information), billing modules that helps him/her in evaluating the price of his/her information that depends on DQ (see "\$=f(DQ)"). On the other hand, Fig. 6 gives insight into an information consumer who is looking for IoT information sources relevant for his/her own needs/applications and, if interested in, is able to request for a purchase order. IoTBnB then, as highlighted with the green arrows in Fig. 6, ensures the smooth progress of the money and data transactions – *which are carried out in a P2P manner between the information provider and consumer* – and provides the possibility to the consumer to provide a feedback on whether or not he/she is satisfied with the purchased information which, in turn, shall impact on the information provider reputation.

V. Conclusion

Although the IoT has a lot of promises in a wide range of sectors, it is still difficult to leverage Information-as-an-Asset, as information is not as tangible as physical assets. To put it another way, it is still challenging to make money out of disparate information sources that surrounds us (e.g., sensor data in smart home environments), while leveraging their quality (and thereby price) to their full extent.

So far, and to the best of our knowledge, there is a lack of such IoT intermediary framework/platforms that fulfil key requirements discussed in this paper, namely: (i) enabling IoT information publication & discovery; (ii) relying on open solutions & standards; (iii) providing incentives for information providers and consumers to join the IoT ecosystem; (iiv) fostering competition of prices; and (v) enabling secure information & money transactions. To overcome this lack of frameworks, this paper presents a first and tentative contribution to the identification of scientific and technological building blocks that would fulfil those requirements. Those building blocks will be investigated, integrated and/or developed in further research work, and will contribute to support the overall bIoTope ecosystem.

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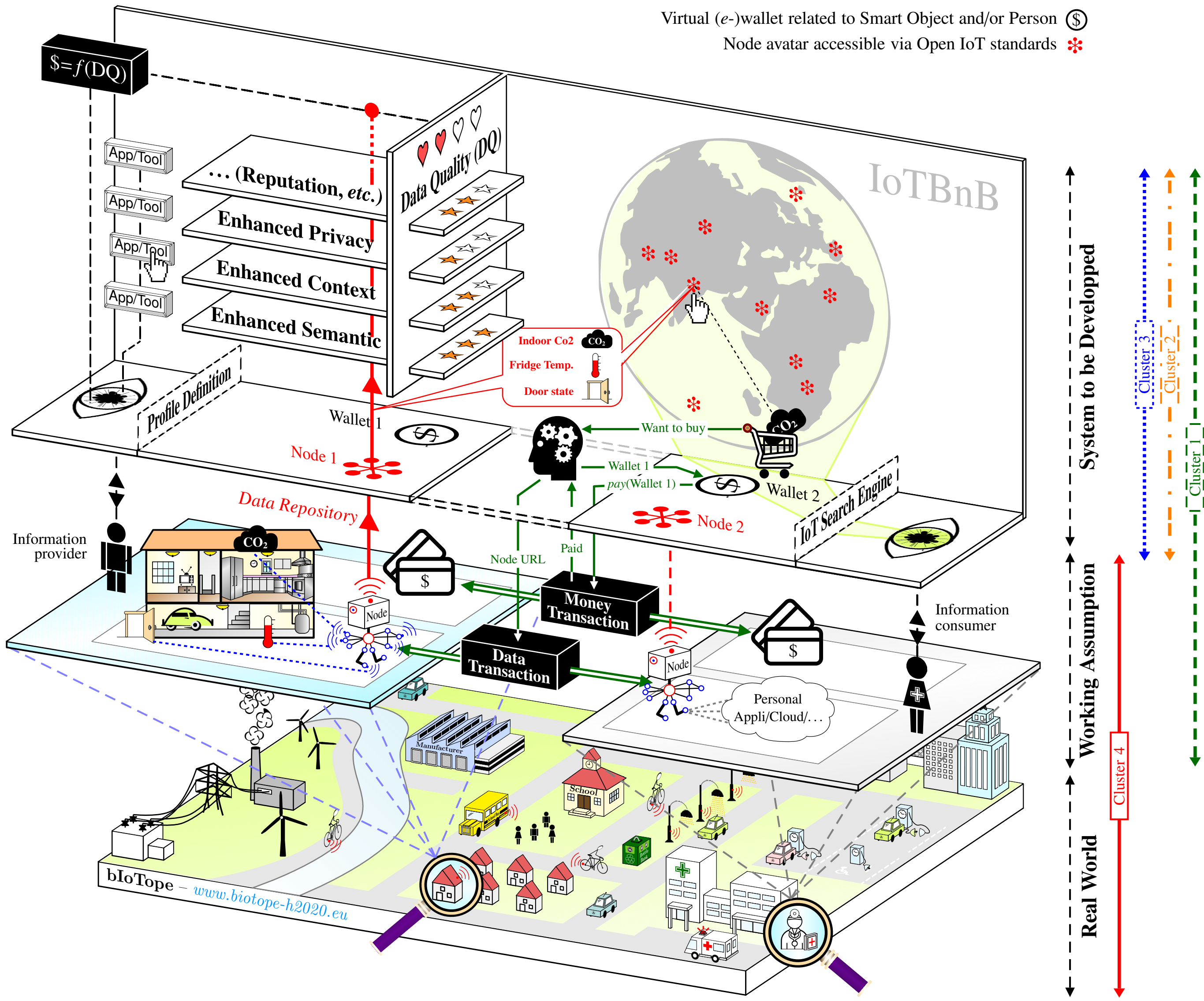

Fig. 6. IoTBnB framework overview considering the set of technological and scientific building blocks identified through our study

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