A SyMPHOnY of Integrated IoT Businesses: Closing the Gap between Availability and Adoption

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***Abstract*—Despite several decades of intense developments, the *consumer* Internet of Things (IoT) market still falls short of delivering its original economic promise. The underlying reasons – largely a fragmentation amongst the key players and their siloed business models – are comprehensively reviewed in this article. We specifically address the stagnant home automation sector, which suffers from a lack of *interoperability* between the existing IoT products. Aiming to unblock its sustainable growth, we systematically report on the development of a next-generation Smart Multi-Purpose Home Gateway (SyMPHOnY) that becomes the key asset of telecom operators willing to understand the true needs of their customers. Supported with a recent user experience study, our SyMPHOnY platform pragmatically integrates a residential gateway module with a multitude of smart home solutions to provide valuable information and services based upon consumer's household automation data. It thus holds a significant promise to bridge the existing divide between the IoT technology availability and its slow market adoption.**

I. Understanding IoT value beyond the hype

The Internet of Things (IoT) – which is presently synonymous with almost any connected electronics other than personal computers and handheld user devices – is perhaps the most confusing and contradictory global technology trend. On the one hand, its ambition is to bridge across the verticals of enterprise and industrial automation, as well as cover automotive, residential, and consumer market segments [1]. Indeed, the rapidly expanding constellation of IoT devices aims to comprise seemingly everything, from home appliances, furniture, food containers, and even paper documents, to connected machinery, drones, and autonomous cars. What appeared a decade ago as a complete science fiction vision, is decisively materializing today by bringing along impressive projections from over 24 billion networked devices by 2019 (Cisco) or even 75 billion such objects by 2020 (Morgan Stanley) to as many as 100 billion Internet-connected things by 2025 that altogether create the economic impact of up to $11 trillion (McKinsey).

On the other hand, despite all the excitement around the IoT market, its challenges from a business and value perspective have also become undisputed. Back in 2013, the IoT appeared to be a radical innovation that promised to transform any physical object into a digital data product, and thus many companies were preparing to embark on a journey of becoming digital businesses. In late 2014, when the IoT has reached the full height of its hype (Gartner), it seemed to have acquired the escape velocity by indicating the potential to offer business value that goes beyond operational cost savings. However, contrary to these "rosy" initial expectations, the IoT is still struggling in 2016 to get past its growing pains, with nearly one in three (31%) companies in the industry yet to even experiment with IoT products or services. At the same time, early IoT providers increasingly revert to incremental solutions that only secure diminishing returns and may fail to offer sufficient value to outweigh the involved risks.

While holding a considerable promise, today's IoT business remains divided and fragmented across the enterprise, industrial, and consumer contexts, still without a clear market leader. This is particularly true for the *consumer* IoT segment (see Fig. 1), which had developed one of the first historically and so far gained the most momentum: it is currently dominated by expensive and often ridiculously complex IoT gadgets that may be labeled as "nice-to-have" rather than "need-to-have" technology. Anecdotal evidence suggests that the "average consumer" could spend hours getting the new IoT device to work – which often feels like running an obstacle course – and then wastes time over the following days or even weeks just to keep it operational. The ongoing struggle is due to several obstacles forming the major roadblocks that must be removed to push the IoT development beyond the present inflection point, where its "future is already here but it is not evenly distributed"[1].

Recently, it has been widely recognized that price, security, and ease of use constitute distinct adoption barriers for consumer IoT devices and services [2]. Strikingly, over 60% of customers believe the modern IoT devices to be overly expensive (Accenture), which is consistent across various age groups and countries as well as holds for both mature and emerging markets. Together with the glaring lack of a compelling value proposition, security and privacy remain the substantial consumer IoT challenges, from the very real risks of private data leakage and device malfunction to the entire "trust factor" behind Internet-connected personal things (opening according to Gartner a $348 million IoT security market only in 2016). Hand in hand with security, resilience, and reliability go hurdles related to the ease of use and customer experience, with almost two-thirds (64%) of consumers experiencing a difficulty when utilizing their new IoT device.

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[1] See http://mattturck.com/2016/03/28/2016-iot-landscape/

Fig. 1: A harmonizing perspective on consumer IoT market.

As consumer IoT market develops, the latter concern imposes tough decision on customers, who may choose to abandon an IoT product or service due to its usage complexity. The underlying reason is in the fact that the contemporary IoT landscape spans a collection of dissimilar markets (see Fig. 1) that may have some common trends, but largely follow very different dynamics. This is aggravated further by the general immaturity of the current IoT ecosystem [3], where (i) interoperability is rudimentary or does not exist, (ii) standards are many but evolve in isolation, (iii) the "zoo" of alternative connectivity solutions creates a profound confusion, and (iv) many other components remain effectively undefined, including regulatory and legislative aspects. As a result, there is no dominant horizontal platform and companies are forced to create a lot of necessary components themselves (radio, networking, software, hardware, data analytics, etc.), whereas many verticals are not built on top of the appropriate horizontals.

Given that it may take years of collective effort across multiple sectors before various IoT equipment can work in concert [4], it remains costly to integrate interoperability features into a product or test it for compliance with a standardized specification. Therefore, many device manufacturers prefer a faster approach offering proprietary solutions [5] that, as they think, can be adopted quicker and easier (as well as out of fear that customers move to a competing product). However, this "cheapest" path to market based on closed protocols and systems is a double-edged sword, as it hinders interoperability and plagues innovation. Interestingly, *interoperability* is deemed to unlock as much as 40% of the total value that can be generated by the IoT (McKinsey), which equals to $4 trillion of potential economic impact per year. In fact, consumers already demand that their IoT devices, from fitness trackers and headsets to home surveillance cameras and cars, be able to interconnect and synchronize seamlessly.

Another effect of the lack of interoperability is in high market entry barriers. In the past, it has typically been taking an IoT startup the staggering 1.5-2 years to begin shipping their first connected product after mediating between all of the stakeholders in the IoT scene, including hardware manufacturers, connectivity providers, software developers, integrators, regulatory bodies, and others. Unless technology innovation is taken to the ecosystem level, integrating products and services by multiple companies, the IoT community may end up missing the forest for the trees. The winners in this "beyond-hype" consumer IoT market will be players who can team up with their value chain partners to supply consumers with technology that they actually need and agree to purchase. In the rest of this paper, we offer a detailed summary of our understanding in this space as well as report on our recent progress towards facilitating fully integrated IoT businesses by taking as a study case the stagnant home automation sector.

II. The Battle for "Smart Home" Supremacy

A. A brief retrospect of technologically augmented homes

Home automation sector has always remained a heated battleground. As a residential extension of building automation, this field had attracted attention of standards and consortia programs as early as in the mid-1980s. The dream of having a clean-slate solution without any backward compatibility constraints haunted many in consumer products industry ever since, often disregarding the fact that the actual smart home market has been evolving tenuously at first [6]. Then, around 15 years ago, affordable broadband connectivity has enabled the home PC to challenge the TV as the heart of residential entertainment universe. In the subsequent years, fueled by the rapid advent of advanced game consoles, set-top boxes, HDTV sets, and DVR products, this battle has gradually become more complex [7]. It is then when it also started to expand "beyond the living room" by embracing the control and automation of heating, lighting, ventilation, air conditioning, home appliances, and security.

Today, home automation business is overcrowded and engages a multitude of stakeholders, such as equipment manufacturers, telecommunication providers, cable companies, insurers, and retailers [8]. These range in scale from smaller and more agile startups to larger technology companies and giant industrial conglomerates, all offering their customers a head-spinning variety of smart-home IoT products: from connected thermostats, locks, lighting and alarm systems to smart refrigerators, self-guided vacuum cleaners, and other home appliances. Often orchestrated by home automation platforms controlled remotely through a mobile application or TV screen, these connected IoT products are being aggressively pushed onto the market by competing companies – sometimes even at the risk of disrupting their own analog products (e.g., GE, Philips, and Comcast). However, the central question of who is going to "drive" the residential automation ecosystem remains essentially open.

With the fast proliferation of connected IoT devices, the entire home is essentially being reinvented as a consumer product, far beyond niche solutions for busy families and people with physical limitations. However, prospective customers

need to be made aware of when their smart-home investments will actually translate into cost savings, energy efficiency, and enhanced convenience. For example, automation of domestic chores alone may save up to 100 hours of labor per year for the typical household (McKinsey). Further, use of intelligent thermostats can lower the air-conditioning and heating costs by 20% (Nest) by only running these systems when occupants need them. In 2025, the savings on the overall electricity use in the home could have an impact of $50 to $110 billion globally out of the projected $200 to $350 billion per year (McKinsey). The latter projection is distributed between chore automation (around $135 billion), energy management (up to $110 billion), and security (over $20 billion).

However, there is yet to be a comprehensive platform solution to "win" the home automation market, which is a consequence of having multiple competing standards (IEEE, IETF, 3GPP, ETSI and OneM2M, etc.) with associated device interoperability concerns. For instance, light bulbs by one vendor may be non-compatible with a lighting system produced by another. This unprecedented fragmentation becomes a major impediment to user choice as well as imposes barriers to innovation and "healthy" competition. As Google and Apple are preparing to boost the market by leveraging the ubiquitous smartphone, there is a growing demand for next-generation IoT platforms that would be open, well-tested, and documented to facilitate their adoption by multiple vendors. Along these lines, *telecom operators* have a unique market position to advance the deployment of new consumer IoT applications and services, and many already view home automation as their strategic business priority.

B. From early adoption to mass market

While early adopters in the smart home market often preferred faster innovation to product maturity, this has changed as of late. Today, even the mainstream customers are willing to understand the expected cost savings before they agree to purchase a new IoT device. If smart-home gadgets, protocols, and systems are unable to talk to one another, the consumer is left with only incremental benefits, which may not be sufficient to overcome the current confusion and remedy the cost concerns. Therefore, a fundamental aspect of future "mass market" home automation vision (see Fig. 2) is for the connected IoT devices to be able to communicate seamlessly between themselves. As a pragmatic example, to ensure that cleaning is only performed when occupants are away, interaction between the automated vacuum cleaner and the presence sensors would be required. Consequently, significant efforts are invested by the IoT community to improve interoperability across existing wireless standards (e.g., ZigBee and Z-Wave).

Beyond enhancing the individual technologies, future households will need a "butler" – a dedicated device that orchestrates a swarm of connected in-home things. Conveniently, there is already an asset that may become such a multipurpose platform, which is the *home gateway* in use for delivering broadband connectivity. Being a decade-long evolution of old DSL routers (for Internet connectivity and telephony) converted in 2000s into residential gateways (for Triple Play

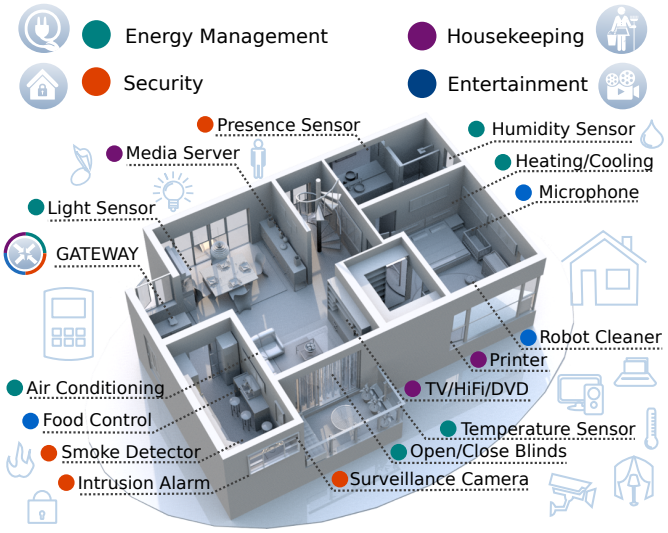

Fig. 2: Integrated consumer-centric smart home ecosystem.

services, remote management, etc.), this piece of equipment has been available 24/7, but its IoT potential remained largely unexplored. With further upgrades, smart home service gateway may become the heart of residential ecosystem by transforming it from connected to "conscious" home that manages energy consumption and automation tasks, is responsible for social media interaction and app stores, facilitates multi-device printing and media streaming, as well as becomes a connected storage.

Maintaining the evolved smart home gateways, telecom operators may in turn assume a central role in creation of integrated IoT applications across multiple businesses as well as provide their customers with better quality of experience over a richer set of services. Indeed, as IoT devices release considerable amounts of information on their state, location, and utilization, these data may be identified, tracked, gathered, personalized, and accessed remotely "in the cloud". In fact, it is the way the data are treated that makes all the difference between a connected home and a smart home [9]. However, most of such IoT data collected and shared today are used either not completely (in some cases, under 1%) or not at all. To ensure a wider product adoption, the consumer IoT market stakeholders must expand their vision from crafting smart home enablers to empowering a smarter consumer behavior through *actionable* data, that is, provide valuable information or services based upon customer's data.

Supplying smart consumers with actionable data, it is essential to help them understand how their multiple IoT devices can control (e.g., security system triggering lighting system) or work with (e.g., smart thermostat interacting with smart meter) one another. With such a customer-centric approach, future smart home solutions will enable valuable, actionable intelligence based on real-time, collective IoT device and sensor data. Coupled further with tools from big data analytics and artificial intelligence, home automation can quickly become predictive, intelligent, collaborative, and in some cases even autonomous (e.g., automatically adjusting a thermostat to save energy and accounting for external weather conditions to optimize heating or cooling operation). This should also

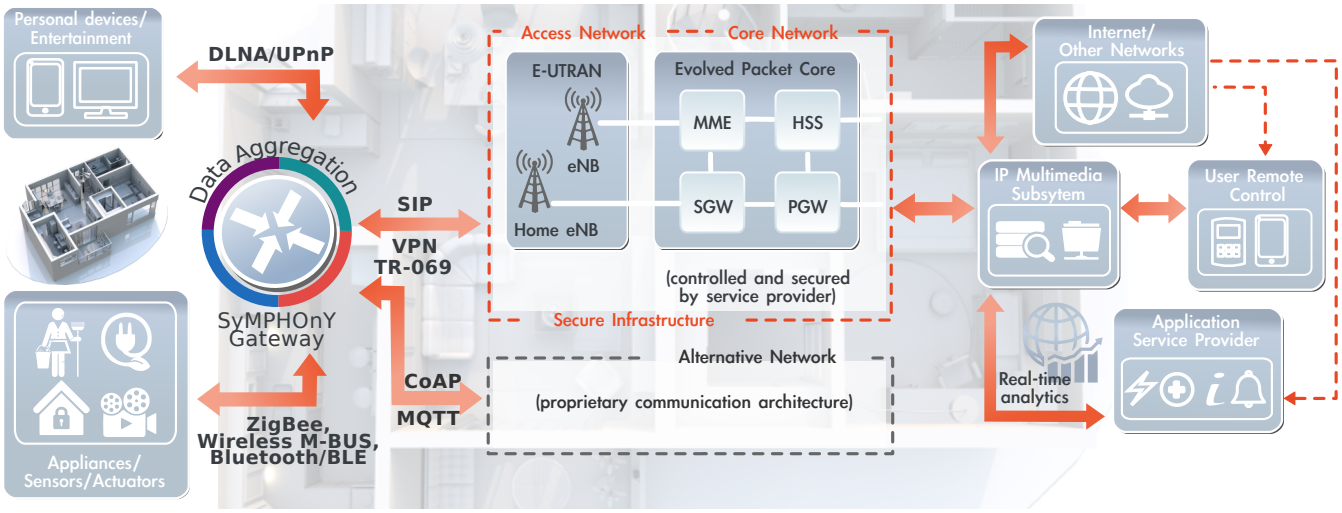

Fig. 3: The core smart home system architecture according to the SyMPHOnY project.

alleviate challenges in presenting to the user in a unified and intuitive, that is, *consumable* manner the massive amounts of information from a wide diversity of IoT sources inside and outside the home.

We continue by providing a systematic perspective on our efforts towards unblocking the mass market IoT, while highlighting the important gaps to be bridged and discussing the alternative implementation strategies.

III. The SyMPHOnY project: executive summary

A. Envisioned development objectives and challenges

In order to facilitate the consumer-centric integration of smart home applications and services across diverse IoT technologies, telecom operators aim to utilize their existing assets to avoid increased costs. To this end, they target to evolve the residential gateways already deployed in many households and make them equipped to provide support for: (i) multiple connected devices; (ii) various user services; (iii) content access via alternative means; (iv) unrestricted end-user mobility; (v) bandwidth-hungry and high-quality applications; as well as (vi) enhanced security and reliability. Hence, smart home gateways become a ”single-stop” solution for a range of future home automation products as well as open door to autonomous actuation based on actionable data. While this strategy generally allows for delivering improved user experience, the multitude of vendors and standards on the market brings along practical challenges that technology developers need to address:

- **Easy configuration and management:** The smart home equipment needs to be configurable and customizable (also remotely) for a range of applications [10], such as housekeeping, energy management, entertainment, security, etc. User-friendly troubleshooting means should also be provided.
- **Adequate security:** Users and operators alike are increasingly concerned about the levels of security and privacy of data handled by the smart home devices. Therefore, it is crucial to offer the appropriate information integrity, authentication, and encryption mechanisms, as well as service separation features [11].
- **Reliable performance:** Many quality-specific parameters should be taken into account [12], including latency, stability/reliability, compatibility with existing ISM, operation channel selection, availability/coverage, and battery life. The connectivity layer needs to support a wide range of standard communication protocols.
- **Coordination with standards:** Tight cooperation with standards developing organizations, including BBF, ETSI M2M, OSGi, AllSeen Alliance, and other relevant partners has to be enforced to resolve compatibility concerns and achieve unification.

Most importantly, all the resultant implementable technology has to be converted into freely available and testable specifications to accelerate its market adoption. To this end, the core architecture, components, features, and middleware of the entire smart home ecosystem should be defined, including the home gateway, home network, connected devices, and other involved sub-systems. With these objectives in mind, we have targeted the development of a next-generation Smart Multi-Purpose Home Gateway (SyMPHOnY) that emerges as a powerful business catalyst in today’s smart home market (see Fig. 3). Our universal platform API bridges across various applications, in-home IoT devices, and associated cloud services [13]. As a result, the SyMPHOnY platform becomes a truly open, multi-purpose smart home solution that has excellent potential to orchestrate a growing variety of capable IoT devices within the residential consumer environment[2].

B. Main development principles of the SyMPHOnY platform

As discussed at length in the previous section, telecom operators are well-positioned in the market to boost the advanced smart home services with high efficiency and productivity. Their longer-term evolution strategy involves migration of the residential connectivity baseline towards employing *cellular* technologies, such as 3GPP LTE based on IP Multimedia Subsystem (IMS) and using SIP protocol as a container for the IoT data. The utilization of the 3GPP architecture is becoming

[2]Full source code of our implementation is freely available at https://github.com/SyMPHOnY-/Smart-Home-Gateway

increasingly attractive to support large-scale IoT deployments, while offering several undisputed benefits, such as (i) wide seamless coverage, (ii) relatively low deployment costs, (iii) high levels of security, (iv) access to dedicated spectrum, and (v) simplicity of management. Accordingly, operators are effectively able to run voice, video, chat, as well as over-the-top rich communication services over an all-IP network. This perspective, however, requires certain capital and operational expenditures to upgrade/replace the platforms and software.

Knowing that contemporary LTE networks already offer consistent coverage, our academic team partnered with Telekom Austria Group (TAG) back in 2013 to investigate the benefits of utilizing cellular connectivity as a primary data communications channel (WAN interface) for the next-generation smart home gateway solutions. In retrospect, the home automation sector has primarily been targeted since telecom operators (including TAG) were deploying residential gateways from "day one" and therefore are long in the business. Driven by the actual needs of TAG customers, who unanimously demand for device- and technology-independent IoT solutions with increasingly higher degrees of user experience, our mission was to deliver a unifying SyMPHOnY platform that serves as an interaction hub for current and future in-home IoT devices and services (see Fig. 4). The above vision helped us carefully identify the key implementation choices, and we systematically explain these in what follows.

1) Our software middleware layer: To reach an ambitious goal of constructing a "sensor-neutral" gateway, we began our work on a software middleware layer capable of accommodating different types of sensors. Aiming to confirm that our proposed upgrade of current residential gateways already deployed by the telecom operators has practical business value, we focused on providing support for existing (and sometimes legacy but widespread) technologies, such as two-wired alarm systems, as well as for more recent products, including smart meters. To this end, an appropriate middleware layer has been created in close partnership with the HGi standardization body. Specifically, we built our software architecture on top of the OSGi framework, which tightly integrates with our SyMPHOnY platform. The two SoC architectures considered were Microprocessor without Interlocked Pipeline Stages (MIPS) and Advanced RISC Machine (ARM), both widespread in modern residential gateway solutions.

To integrate with the OSGi framework, the SoC architecture had to be made capable of running program code written in the widespread Java language. This requirement effectively narrows down the choice of a feasible SoC architecture to ARM since support of the Java stack for MIPS is still limited. Correspondingly, we needed to identify a platform implementing the ARM architecture and having a sufficient number of I/O interfaces. We have therefore learned that it is not trivial to find a piece of hardware that will have on-board technologies for (i) old alarm systems (communicating via the FXS port), (ii) classical Ethernet devices, and (iii) current wireless technologies used for IoT connectivity (e.g., ZigBee, Wireless M-BUS, and Z-Wave). Analyzing the present market situation in terms of the available hardware boards against the requirements of telecom operators, we concluded that it

Fig. 4: Key hardware components of SyMPHOnY platform.

may be infeasible to offer the universal home gateway as a "one-box" solution (mindful of target price for the "complete package").

To this end, we chose to decompose our developed SyMPHOnY platform into two component modules that are closely interconnected (via e.g., Ethernet or WiFi). This elegant move – to have two modules operating as a single virtual platform – proved to be a viable strategy in the course of our project development, and SyMPHOnY is prepared to meet the recent influx of specialized hardware boards with several communication interfaces. Utilizing one of thus coupled modules exclusively for managing data produced by the smart IoT devices (water and electricity meters, temperature and humidity sensors, etc.), we built a solution that is powerful enough to run the OSGi framework with all of our created software packages (named *bundles*), each of which is responsible for a certain task. This allowed the entire solution to become stable and fault tolerant: if one bundle fails but the rest keep running, the SyMPHOnY platform remains operational as a whole.

2) Synergy with standardization efforts: Throughout the development of our SyMPHOnY platform, we remained in close touch with three leading standardization bodies: (i) HGi (Home Gateway Initiative), (ii) OSGi Alliance, and (iii) AllSeen Alliance. These are focused on wireless home area networks (WHANs) and smart home services, respectively. The outcomes of our project have been included as contributions into their recommendations, the most impactful of which are captured by HGI-RD039 (transferred recently to ETSI[3]) and HGI-RD048v2 (published as a key specification[4])

[3]See http://www.etsi.org/news-events/news/1082-2016-04-home-gateway-initiative-transfers-smart-home-related-requirements-to-etsi

[4]See http://www.realwire.com/releases/HGI-Publishes-Key-Specifications-for-Digital-Home

TABLE I: Services and protocols comprising the SyMPHOnY framework

Property/protocol	Market maturity	Benefits for the end-user	Benefits for the service provider
OSGi framework	Well accepted by the community as a middleware for consumer IoT.	OSGi-based smart home gateway is easily extensible with new features and services.	Due to modular design and reliance on the Java programming language, can be deployed fast on top of already shipped residential gateways (xDSL modems).
SIP	All-IP based technology designed to assist mobile operators in delivering next-generation interactive and interoperable services, in a cost-efficient and flexible manner.	Collected data from sensors/actuators are sent via a secure connection provided by the telecom operator.	No need for additional investments into the network infrastructure, since it is deployed as pat of current cellular (LTE) systems.
UPnP	Common technology promoted by the UPnP Forum to enable simple and robust connectivity for stand-alone devices and personal computers by different vendors.	Allows to search for and discover the UPnP compatible devices within the home network as well as push multimedia content to corresponding equipment (e.g., smart TV).	Opens path to rethink the role of smart TVs in today's households and offers a possibility to create new business models.
TR-069	Communications mechanism for remote management of smart home gateways by the telecom operators.	New devices can be added to the home network without the need for end-user intervention.	Includes default implementations of standardized protocols for remote configuration and upgrade of residential gateways.
Wireless M-BUS	Industry communications standard employed widely by the utility sector.	Simple and robust technology to collect data from different sensors (e.g., electricity, water, gas, temperature, humidity).	A low-overhead protocol featuring optimized long-range communication modes over sub-GHz frequency bands.
Legacy security systems	A broadly deployed technology to secure physical premises.	Has possibility to interconnect legacy alarm systems (e.g., two-wire or PSTN-based alarms) with the emerging home automation systems, such as KNX.	Keeps this legacy market segment on the side of telecom operators despite the termination of PSTN and transition to next-generation mobile networks.
Secure data storage and aggregation	Security issues and concerns related to providing sensor data to cloud services.	Offers a possibility to store received data locally and make them available to the 3rd party services (e.g., individual billing plan for electricity consumption/production).	Opens opportunities to create new business models that interconnect consumer and industrial IoT domains based on user data collected by smart home gateways.
Unified user interface for various personal devices, including wearables	The overall usability of a smart home application is strongly affected by the quality of the end-user interface.	A unified graphical interface to interact with all the in-home IoT devices.	Gives a competitive advantage to win new clients or decrease the customer churn rate.

documents. Of particular importance in our cooperation with the HGi community, which has started as early as three years ago, was participation in a heated debate on the choice of parameters for the home gateways. Being an integral part of the standardization process, our team has been able to react in real-time and adjust the SyMPHOnY specifications in accordance with the actual market requirements. Collaboration with standards also allowed us to avoid early pitfalls.

At the beginning of the project, we believed that the current residential gateway hardware is powerful enough to run a complete SyMPHOnY solution. However, after two years of development we realized that such a device is not yet on the market (at least for a reasonable price). Back in 2013, "smart" gateways were for the most part only supporting a single target group of sensors/meters. At that time, it greatly simplified development by restricting the equipment to speaking only one specific programing and communications language. Such somewhat closed mindset of vendors forced customers to install several gateways in the home, each for its own application, which also required a dedicated means of control. This "tragedy of the commons" stemmed from the race between companies to launch their cheaper proprietary solutions faster. It is then when we understood the demand for a truly universal home gateway product, from both the hardware and software perspectives, which was glaringly missing in the market.

C. Useful features and further enhancements

Delivering our constructed software layer as a collection of interconnected bundles, we were able to parallelize the development of the individual SyMPHOnY components into several tracks, which accelerated the entire implementation process. Therefore, within the very limited time frame of this project, we could implement (i) the core bundle that is orchestrating all of the others, (ii) a database bundle, (iii) a Wireless M-BUS bundle, (iv) a SIP bundle that enjoys a completely novel data structure suitable for communicating the IoT traffic via IMS, (v) a Universal Plug and Play (UPnP) bundle, and (vi) a remote management function that utilizes the VPN and TR-069 protocol.

1) UPnP (DLNA): Prior to developing the actual SyMPHOnY bundles, we have accumulated substantial technical experience in providing our managed data to the end customers equipped with mobile devices and laptops. Building on this background in the SyMPHOnY project, we concentrated on the UPnP+, which is a proven and established industry-grade discovery and control framework built specifically for IoT. Hence, UPnP+ has incorporated many important functions, such as access to cloud and web services, sensor integration for any device regardless of its power profile or connectivity, flexible and scalable data model, as well as robust security layer. With these benefits in mind, we created a dedicated UPnP (DLNA) bundle that adds on top of the classical methods for data visualization. It allows a customer to channel the output from the in-home IoT devices to the smart TV, thus creating a singular view of data and making it "consumable".

2) Remote management: The additional complexity associated with delivery and management of broadband services is traditionally driving the costs for the telecom operators higher. Regardless of how much has already been invested into the connectivity infrastructure, the end customer satisfaction levels will primarily depend on the operator's ability to provide seamless deployment and actually deliver what the consumers paid for, as well as on offering simple tools to manage the connected devices and rapidly resolve any problems. Therefore, we took seriously the need for implementing a

standardized remote management solution by utilizing a secure VPN connection. Accordingly, our consumers are able to connect to the SyMPHOnY platform from virtually anywhere and hence flexibly control all the IoT electronics within their home networks.

Further, despite the significant progress that we made along these lines, some telecom operators may still be seeing difficulty in managing all the dissimilar consumer IoT devices both efficiently and securely. Moreover, many smart home products need to perform regular upgrades (or sometimes downgrades), be modified temporarily during ”special offers”, and utilize other capabilities of our proposed technology platform to create revenue-generating business initiatives. To this end, today’s operators increasingly rely on the BBF specification, known as TR-069, for the control mechanism to achieve the above. Recognizing this important trend, we have additionally implemented support for the TR-069 protocol. It allows for smooth remote management on the side of the SyMPHOnY platform as well as offers a possibility to update the software components of the home gateway without the need to assign technical personnel whenever e.g., a new product line of sensors is released.

IV. Solving the Smart Home Market Puzzle

A. *Unblocking future home automation business*

In the remainder of this text, we provide a recollection of our first-hand experience in the smart home market and summarize how our 3-year SyMPHOnY project fits in with it. As reiterated above, home automation is indeed a very complicated domain: it has enormous business potential that however did not unfold the way we expected. This has been in part due to the slow user adoption rates of new consumer IoT products, which became a major disappointment for this sector in the early days, but also due to the fact that the fragmented IoT industry failed to deliver well-articulated smart home solutions thus far. Presently, this gap is rapidly closing with the emergence of viable specialized technologies, such as smart thermostat by Nest, but they may never reach their full potential unless integrated seamlessly and natively with the rest of smart home ecosystem. Ultimately, next-generation houses may come to market with a complete, pre-installed home automation package.

To support this decisive transition to a truly IoT world, where each category is already seeing rapid innovation, we adopted a mission to demonstrate how all the pieces of technology puzzle come together. In fact, up to three-fourths of companies interested in adopting IoT solutions are seeking today for new business opportunities and ways to fortify their existing technologies, from thermostats, locks, and security alarms to home appliances, lights, garden and nursery products. Helping them achieve their goals, our SyMPHOnY platform – which is essentially a residential gateway enhanced with the smart home services – emerges as a genuinely multipurpose connectivity hub. It thus becomes a major departure from the isolated smart-home products that expands the matching IoT devices and services to the ecosystem level. All in all, it aims to solve the central challenge of interoperability in stark contrast to legacy solutions, which address this issue only partially by supporting a slim range of IoT technologies.

An important part of our vision is to reinforce telecom operators – the ”glue” of today’s technology market – in their strategy to win customers as well as explore new market opportunities. To this end, the SyMPHOnY solution is tailored specifically to the network operator environment, with its unique requirements and dynamics, as well as leverages the existing operator assets in a flexible ”plug-and-play” manner. Essentially requiring only a software upgrade on top of the residential gateways already providing network access in the home, our platform becomes the centerpiece of user’s smart home ecosystem, not only maintaining a ”pipe” to the Internet, but also managing in-home IoT links. Our solution also delivers valuable home automation data through various means: from user smartphone or tablet to connected TV screen. This diversity allows to assess and compare the alternative data visualization channels as well as understand what device impacts customer decisions the most (see Fig. 5).

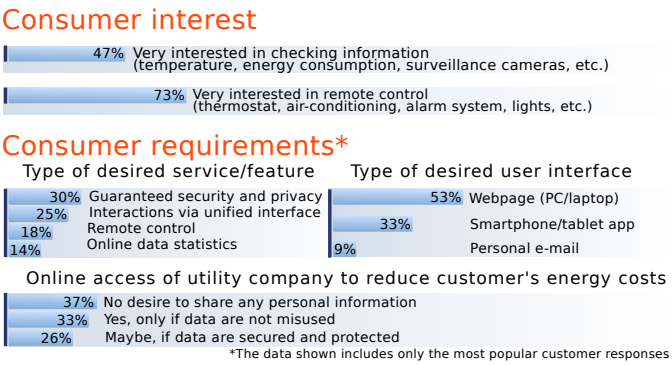

Fig. 5: Results of our user experience evaluation campaign.

Analyzing consumer behavior in the SyMPHOnY-empowered environment, we have recently completed a full-fledged study targeted at identifying the most essential aspects that affect user experience of home automation products. Along these lines, we conducted a customer survey revealing the major concerns that respondents have about smart home gateways (see Fig. 5), the number one of which is the possibility of a data breach. Interestingly, people are more worried about security than they dislike the price. Another crucial learning is in that the customers in fact understand the importance of interoperability and desire a unified interface to interact with their smart home sensors and appliances regardless of the vendor or communications technology. Most importantly, merely supplying users with information on their households may be insufficient to create a meaningful value proposition and the actual consumer demand is indeed in the capability to act based on the collected IoT data.

As a summary, our proposed multi-purpose system should arrive timely to bridge the existing divide between dissimilar consumer IoT players, including chip manufacturers, IP gateway vendors, telecom operators, communications technology providers, and IoT gadgets producers. While in the past these stakeholders were attempting to secure their market share independently – by typically relying on rather narrow-scoped, siloed products – the SyMPHOnY platform is deemed to

effectively unblock their mass market potential. Accordingly, it may offer the much needed flexibility to integrate across the product portfolios of fundamentally different smart home companies and their specific environments: our solution can talk to various elements of the consumer ecosystem, both in-home and in the cloud, to achieve the unprecedentedly high user adoption levels, as well as provide intelligence to seamlessly connect the disjoint pieces of home automation technology belonging to many IoT businesses.

B. An ecosystem perspective on consumer IoT market

Looking back on the IoT market, and in particular on its home automation sector, we realize that after 15-20 years of struggle the disparate consumer technologies continue proliferating but are still not converging: all previous attempts to harmonize over them leave no major success story to tell. This situation appears to be very similar with how we were unable to replace and unify the many remote controls that we have around the house today. History and experience tell us that fragmentation is not a question of technology itself – everybody is working with pretty much the same building blocks and components – but rather a matter of user acceptance, since the demand picks up way too slowly. Analyzing the current discrepancy between the technology availability and its market adoption, the community needs to decide whether we keep pushing with existing strategies waiting for the demand-side problem to resolve, or see if a part of our present value chain is broken and attempt to fix it.

With our proposed SyMPHOnY platform, we carefully addressed this difficulty by offering new smart home services on top of the past successful products. Building upon the landline connectivity asset, which is already there for the network operators, it is easier to evolve into a communications service provider. In fact, the capability to sustain in the IoT era hinges largely on the operator's ability to partially transform into a software company (e.g., towards software-defined smart home business [14]), which brings along the associated technological and organizational modifications. Another important aspect of this transition is to identify the best way to market new services and thus increase user awareness about the extent of benefits that they may actually receive. Indeed, almost half of the respondents in our customer study admitted that they are not really sure as to what a home automation solution would actually mean to them. The alarmingly low user awareness levels regarding the customer IoT products are of serious concern to business.

To accelerate customer engagement, technology operators need to thoroughly study the value structure: users may be unwilling to pay for "just" having the residential automation tool at home, and the key benefit may ultimately be in the amount of control. For instance, the platform may help occupants in case their home is in trouble (e.g., alarm center), while also offering optional useful services, some of which may be available for free (e.g., smart switching or personalized utility profile) primarily to minimize the customer churn. In terms of a viable pricing model [15], a disruption may come from offering an "all-in-one" product "10 times better or 10 times cheaper": a consumer orders hardware installation (minimum fee or at no cost) and then is charged for accessing the service framework. The latter may include basic non-paid services (those hard to monetize), wireless and landline access, digital products in cooperation with the 3rd parties (energy monitoring), critical and safety solutions, etc.

As large companies transition from a product- to a service-centric model, it becomes clear that the IoT ecosystem will enable – and sometimes force – new market strategies. For instance, operators having access to home automation data may open it partly to other businesses subject to appropriate user consent. If consumers are made aware about the benefits of providing their private data to the 3rd parties (or directly paid to open these data), then the entire maturing IoT ecosystem will gain direct knowledge on how the customers actually use the products. This knowledge may then be utilized to market and customize consumer offerings as well as predict when a product fails and will need support. Finally, it opens a possibility to charge customers by real usage, thus reinforcing subscription schemes and long-term relationship with clients. All of this helps ensure that customers always benefit with respect to the ease of product installation and management, price, complexity, and comfort.

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