Halos Networks: A Competitive Way to Internet of-with Things

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Abstract: This paper presents Halos Networks as a competitive architectural paradigm for developing future Internet of-with Things. A Halos Network is like a wireless network spontaneously emerging through the interactions of distributed resources embedding wireless communication capabilities. Halos Networks are capable of delivering services and data virally through multiple devices, machines and objects interconnected with one another. Halos Networks potential impact is discussed and guidelines on future developments are provided.
Key words: Internet of Things, ubiquitous computing, wireless networks.

Technology trends for developing future Internet are progressing at an impressive rate: processing is continuing to follow the Moore's curve and it is doubling in capability roughly every 18 months; storage capacity on a given chip is doubling every 12 months, driving increases in connectivity demand for accessing to the network; optical transmission capacity is doubling every 9 months – by increasing the capacity of a single wave length and by putting multiple wavelengths of light on a single fiber. Also technology adoption is even accelerating: the cell phone took less than 10 years to reach 25% of the US population while the telephone took over 30 years.

As a consequence of these trends, networks are becoming more and more pervasive and dynamic, capable of interconnecting large numbers of nodes, IT resources, machines and consumer electronics devices embedding communication capabilities. In the future, anything will be a network node. Actually, with the deployment of Internet of Things and Machine-to-Machine, current estimates (OECD, 2012) show that in a few years there will be many billions of electronic devices connected with each other and to the Internet.

With the development of the Internet of Things (IoT), any object will be empowered with intelligence and with the capabilities to interconnect with any other object, machine and people anywhere, anytime. Several applications are envisioned today: from health to domotics, from energy management to security to types of digital enterprises.

Whilst the IoT foresees billion of things potentially communicating with one another, the Internet with Things (IwT) foresees a growing number (in the hundreds of millions initially, to become hundreds of billions) of objects that will become accessible to human beings through the Internet. The IwT shares several technologies and architectures with the IoT although the "communications interface" should be adapted to meet human needs and the form factor of the object matters since the object is "visible" and its physical characteristics are a selling point, as important as its functionality. In the IoT the functionalities exposed are the ones designed by the producer of the "T"; in the IwT a significant number of functionalities will be mashed up by third parties. If, in the short term, Halos Networks will pave the way towards IoT, in the medium term, by introducing proper "communications interfaces", they will allow human beings to get access to their resources (e.g. processing, storage, networking, sensoring, actuating) also through the Internet. In this paper we prefer referring both to IoT and IwT avenues (Io-wT).

This evolution will have a deep impact from a socio-economic viewpoint, influencing economy development as a whole, public institutions, social relations, diffusion of information, privacy of citizens, etc. This evolution raises technical challenges and important socio-economic issues for stakeholders to consider: from simplifying such emerging complexity when managing future networks to identifying new business opportunities and models.

In this scenario, it is realistic to imagine the provisioning of services and data through multiple devices, machines and objects interconnected by a dynamic network of networks. Reasonably, this evolution will occur first at the edges of the networks, where we will see the proliferation of Sensor Networks, Personal Area Networks (PAN), Vehicular Area Networks (VAN), and in general, networks of networks and all types of machines and embedded systems.

This paper aims at analyzing an innovative and disruptive Io-wT scenario where ubiquitous local networks of objects, machines and Users' devices spontaneously emerge mainly through device-to-device interactions. These local networks, called Halos Networks (a term coined by the Authors), can obviously interconnect with each other by accessing the Internet, in order to communicate across medium-long distance. Moreover, any object, machine and User device of said Halos Networks can play on augmented capabilities by seamlessly off-loading some tasks to a nearby resource (or *via* the big Net to the cloud), where they are executed in cloned whole-system images reintegrating the results in the smartphone's execution upon completion. This will provide an answer to the dilemma: local or global? Objects physically bound can go beyond the "local area networks of things" through their cloned whole-system images. Obviously this is just a possibility, above all in the context of IwT developments.

A Halos Network is like a wireless network spontaneously emerging through the interactions of distributed resources embedding wireless communication capabilities. For example, a halo could be the set of sensors and actuators plus a controller, a tiny PC and a smartphone creating a User's Wireless Personal Area Network (WPANs). A WPAN is a network centered around an individual person's workspace or context. In general, there will be several co-existing models (depending on the services and applications) for IoT and IwT: Halos Networks is one of the most promising, as it is feasible as of today with limited costs.

The outline of the paper is the following. In the 2nd section an example of Halos Networks scenario is presented. The 3rd section makes a brief summary of the state-of-the-art of autonomic networking and computing which are considered the most relevant avenues of research impacting IoT development. The 4th section focuses on the Halos Network architectural model and prototyping developments. The 5th section provides some preliminary considerations on the potential impact of Halos Networks. Finally, we give conclusions and discuss future work.

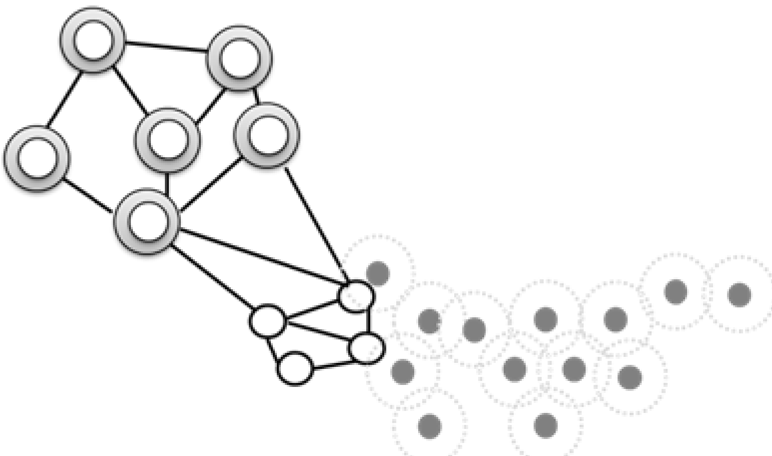
■ Halos Networks scenario

Consider a scenario of "ultra-dense networks" at the edge where a huge number of communicating entities, with storage and processing capabilities, are interacting locally with each other. Imagine, each object, machine or person surrounded by a sort of halo (e.g. a sort of WPAN), within which other devices, sensors, actuators, controllers, tiny PCs, etc. are interconnected with each other and can be autonomically "plugged and played".

Each device within the halo is able to communicate with its peers and has a clone on the cloud. The introduction of autonomic and learning capabilities is dramatically simplifying required configurations by the users. When people's halos come into close proximity (within a few meters), the resources of the halos can flock together and spontaneously create a network of network, which is what we call Halos Networks.

Imagine that communication, storage and processing resources are clustered in "halos" not only centered around people but also vehicles, street lamps, kiosks, and so on.

Figure 1 - Multiple Halos networks paving the way towards Io-wT



Actually some recent advances in ICT have literally been transforming cars into small data centers and mobile nodes of future networks (Siemens, 2012). Then Halos Networks will achieve wide and dynamic distributions by all halos flocking.

It should be noted that Halos Networks go beyond the concept of Wireless ad-hoc networks (e.g. mobile ad-hoc NETworkS, Wireless Meshed Networks, Wireless Sensor Networks) (GOLDSMITH *et al.*, 2011): actually they allow accessing (and providing) service by using and sharing local processing and storage resources. Halos Networks will look like a distributed complex communication fabric composed of large numbers of autonomic halos. This fabric is adaptive as, through the "chaos" of halos interactions and their local adaptations, collective self-organization properties emerge.

Halos Networks are fleeting but also persistent, since many objects are fixed, and others are dynamically moving. Short-to-middle range connectivity emerges through local device-to-device communications, but long-range interactions are enabled only by entering the big Net.

Moreover, different Halos Networks are learning each other's resources, functionalities and services and how to optimally make use of them. It is possible to indicate which networks can make use of the services offered. This includes support for relaying services, thereby offering services from other networks to their own neighbors.

Eventually, the progressive disappearance of Halos Networks' boundaries will pave the way towards resource symbiosis (GEDGE, 2003) over a large scale Io-wT.

■ State of the art

Autonomic networking and computing are considered the most relevant avenues of research impacting IoT developments. There is an impressive number of publications and initiatives investigating the related issues, most of which relate to communication architectures, network and component models, offering the basic building blocks with which to create autonomic self-behaviors. This section presents a brief overview of these works.

IBM, as part of its autonomic computing initiative (KEPHART & CHESS, 2003), has outlined the need for future ICT services of adaptability, self-configuration, self-optimization, and self-healing. Driven by such a vision, a variety of architectural frameworks based on "self-regulating" autonomic components have been proposed (WHITE *et al*., 2004; LIU *et al*., 2004; XU *et al*., 2007).

In Autonomia framework (DONG *et al*., 2003), the autonomic behavior of a system and its individual applications is handled by so-called mobile agents. Each mobile agent is responsible for monitoring a particular behavior of the system and for reacting to the changes accordingly.

Similar to Autonomia, autonomic behavior in the AutoMate framework (AGARWAL *et al*., 2003) is handled by the agents and is implemented in the form of first order logic rules. Agents continuously process these rules and policies among themselves and perform the desired actions.

JENNINGS *et al*. (2007) describe the FOCALE architecture based on mapping business level system constraints down to low-level process constraints in an approach called policy continuum (van der MEER, 2006). This policy-based approach for specifying autonomic system behavior allows network administrators to specify business level policies for network management (using natural language), for example, defining different internet connection bandwidth rates for different users, SLA, QoS policies, etc.

MANZALINI *et al*. (2009) present the Autonomic Communication Element (ACE) model. ACEs can autonomously enter, execute in, and leave the ACE execution environment. In general, the behavior of autonomic elements is typically provided in relation to the high-level policies that define the element's original behavior (PARASHAR & HARIRI, 2005). Within the ACE model, such policies (called plans) are specified through a number of states, along with the transitions that lead the ACE execution process from one state to another. Plans distinguish between the ACE's "regular" behavior, which is its behavior when no events undermining the ordinary execution occur, and the "special cases" that can occur during the plan execution process and which could affect the regular ACE execution process. If such occurrences are foreseen, the ACE behavior can be enhanced with rule modification specifying the circumstances under which the original behavior can be relinquished, along with the new behavioral directions to follow.

A very similar endeavor also characterizes several research efforts in the area of multi-agent systems (VALCKENAERS *et al*., 2007). Multi-agents represent (*de facto*) the types of autonomic components which are capable of self-regulating their activities in accordance with some specific individual goal(s) and, by cooperating and coordinating with each other, according to some global application goal. However, it is worth emphasizing that multi-agent systems does not imply an autonomic behavior per-se. At the level of internal structure, Belief Desire Intention (BDI) agent systems, as implemented in agent programming systems like Jadex, Jack or Jason, or in the context of the Cortex project (BIEGEL & CAHILL, 2004), propose the use of intelligent agents to deal with autonomic and context-aware components. At the core of this model there is a rule-based engine acting on the basis of an internal component state that is explicitly represented by means of facts and rules (KLEIN *et al.*, 2008; LI *et al.*, 2009). At the level of multi-agent systems and their interactions, agents are generally expected to discover each other via specific agent-discovery services, and are supposed to be able to interact.

Common to most of the proposed approaches (both those based on autonomic components and multi-agent systems) is the existence of a traditional middleware substrate to implement discovery and interactions between components or agents. On the other hand, none of the above approaches seems to address the problem of globally re-thinking ubiquitous networks as a complex environment with emerging properties.

Overall, this paper is providing novel contributions on this state of the art by proposing a vision where Halos Networks can flock together and create a large communication network collecting many individuals that form large organized communities, where IoT services can be spread virally. In this sense Halos Networks are leveraging also the Spines (SPINES, 2010) approach, which is a generic overlay network that provides transparent multi-hop unicast, multicast, and any-cast communication with a variety of link and end-to-end protocols.

■ Architectural model

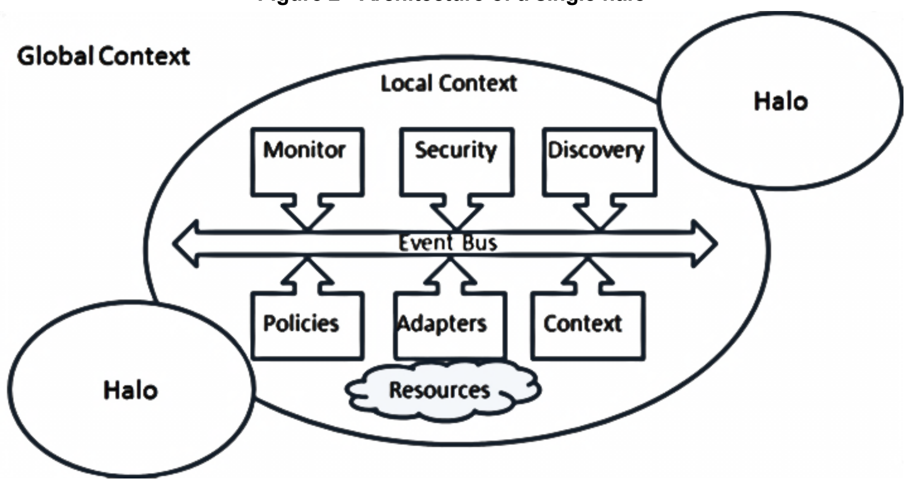
The vision proposed by this paper concerns the development of IoT thorough the flocking of Halos Networks. In order to achieve this, each halo should be capable of managing a set of heterogeneous autonomic resources; moreover it has to be both sensitive to the context variations and capable of reacting "autonomically" in order to self-adapt dynamically.

A halo can be seen as a DES (Distributed Event System): i.e. a dynamic system whose states are time-evolving as events occur. From a theoretical viewpoint, many approaches have been proposed to model DESs, most notably finite state machines, Petri nets and generalized semi-Markov processes. Among these models, Finite State Machines (FSM) represents a computation model that is the most straightforward means to control the stability behavior. FSM provides for a good understanding of the predictable problems such as controllability, observability, co-observability, normality, decentralization, and non-determinism and is the model we adopt for Halos Networks.

Therefore a halo can be modeled as a network of interacting FSMs, since such a network of FSMs would still be an FSM composed of k components' FSMs interacting with each other. Interestingly, non-determinism in FSMs is represented by a choice of states where the optimal action is yet to be decided and where it can be learned, with reinforcement learning.

Figure 2 shows the architecture of a halo consisting of a set of services. This architecture is leveraging the concept of self-managed cell architecture, reported in SLOMAN & LUPU (2005). For example, the discovery service discovers resources and components being part of the halo and the other halos entering in the communication range (each single halo is clearly designed for interactions). The policy service is in charge of managing the policies specifying the halo behavior. A publish/subscribe event bus is used for interaction between halos' components and for distributing events triggering policies.

Figure 2 - Architecture of a single halo

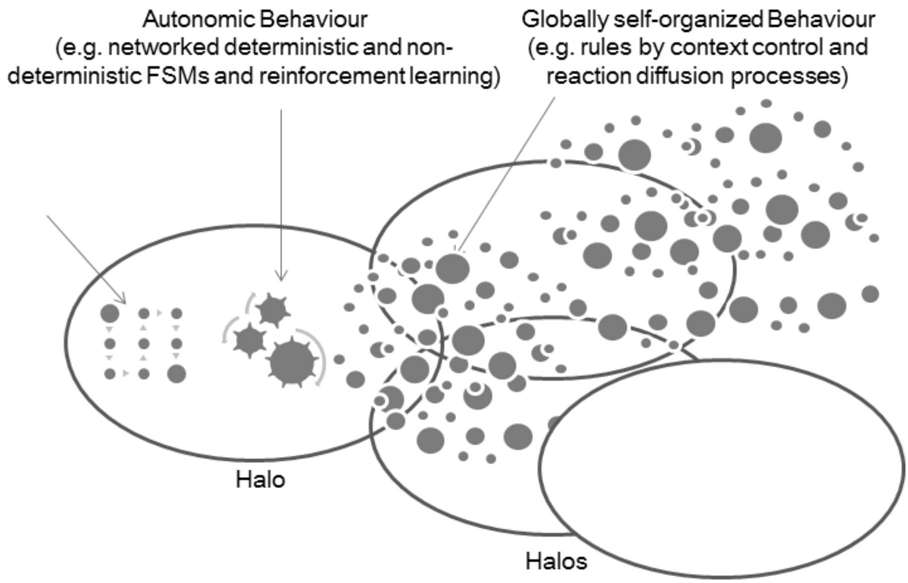


Regarding the overall architecture, a Halos Network is structured into three layers, in charge of actuating three different kinds of behavior:

- *Automatic behavior:* this layer is in charge of fast pre-defined reactions for self-adaptation to predefined contexts and can be designed by means of automatic control-loops modeled with deterministic FSMs.
- *Autonomic behavior:* this layer is responsible for local adaptation achieved by exploiting halos' learning capabilities. The layer can be designed with ensembles of deterministic and non-deterministic FSMs and reinforcement learning methods.

- *Globally self-organized behavior:* this layer is in charge of diffusing local context information to orchestrate local reactions (activation-deactivation of rules) for reaching global goals (self-organization). This layer exploits a sort of "controlled" reaction-diffusion process of context information.

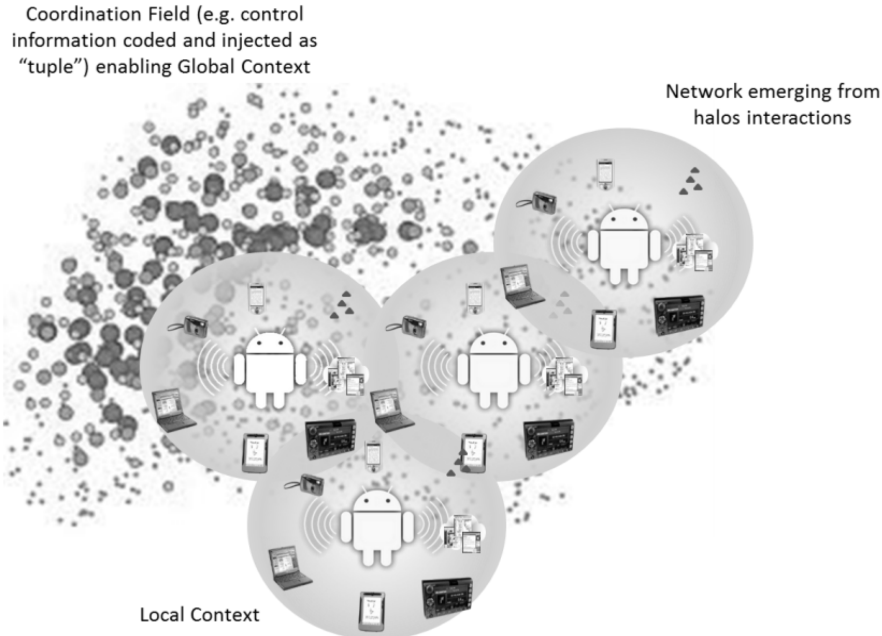
Figure 3 - Overall architecture: three levels of behavior



In a real proof-of-concept (under development) a halo can be easily implemented with a smart phone (acting as a Wi-Fi hot spot), one (or more) cheap, tiny PCs (e.g. a Raspberry Pi costing $25) and one (or more) microcontrollers (e.g. based on Arduino).

The prototype is based on the architecture reported in figures 2 and 3. Specifically, each halo is empowered with the perception of its local context, i.e. the environment inside and around. Each halo diffuses its context information (e.g. tuples) hop-by-hop according to a set of propagation rules (determining how context information should be distributed and propagated in the Halos Network). Any context information can be accessed locally, simultaneously accounting for the influences of the information propagated from other halos (including the fixed ones).

Figure 4 - Halos Networks: local reactions and global self-organization



The idea is developing a sort of global coordination field (i.e. a global context) (figure 4), injected by halos (and potentially control points) in the network and autonomously propagating. In other words, halos are interacting with each other and with the environment by simply generating, receiving and propagating distributed data structures (e.g. tuples), representing context information. This field is providing halos with a global representation of the situation of the overall Halo Network (to which they belong). This coordination field is immediately usable: a halo is moving in this field like an object is moving in a "gravitational" field. Environmental dynamics and halos' local decisions will determine changes in the field, closing a feedback cycle. This process enables a distributed overall self-organization.

As mentioned, a coordination field can be made of tuples of data which can be injected and diffused by each node. Local reading of these tuples of data (e.g. through pattern matching) can trigger local self-adaptation behaviors. A simple event-based engine, monitoring configurations and the arrival of new tuples, reacts either by triggering propagation of other tuples or by generating events. In fact, a number of open source applications are available on the web to implement node primitives and local autonomic behaviors. Moreover, as previously mentioned, any object, machine and

Users' device of a Halo Network can play on augmented capabilities by seamlessly off-loading some tasks (e.g. data intensive applications) to nearby resources (or *via* the big Net to the cloud), where they are executed in cloned whole-system images, reintegrating the results in the smartphone's execution after completion.

■ Impact analysis

Internet is one of the most important inventions in the field of information and communication technology (ICT): it has enabled a highly connected world, which is greatly changing human interaction and therefore society.

Needless to say that we are moving into a highly connected age, where also objects and things will be soon interconnected and accessible by humans through networks of networks. Technology progress and down spiralling costs are fueling a whole range of applications running on top of all sort of devices has come into place enabling convenience and flexibility. This doesn't read well – can you rephrase it? Users have become themselves producers of applications, the so-called "prosumers".

Halos Networks will allow users to create their "own networks" with little cost and effort for using and sharing connectivity, storage and processing resources. Obviously, although this can become a reality in a short time, the scenario does not represent an alternative to traditional communications access services, but rather a novel and complementary approach.

Users' terminals could be based on short-range connectivity and optionally long term connectivity (and hence being associated to a mobile Operator). Terminals are not locked or controlled by a manufacturer (as for instance Apple), they are capable of installing open source software. Additionally they could be capable of adopting open source firmware (much as modems or access gateways can install "openwrt", or mobile terminals can adopt an "openmoko" approach). In this configuration there is no limitation in connectivity capabilities supported by a node. The user can decide to use its nodes for supporting his halo communication needs and can also offer communication, processing and storage capabilities to nearby nodes. Such a model is extremely interesting because these open nodes could be using communication capabilities in a specific area like Wi-Fi connection, bluetooth or other short range ones. In addition if the terminal is enabled for long reach communication, it could become a hub for other nodes. Furthermore, these kind of terminals could be able to use technologies derived from cognitive radio and software defined radio and create very capable and powerful networks with considerable communication capabilities (e.g. whitespaces). This model breaks the current status quo and could also be a disruptive factor for established value networks and business models, especially what is concerned with network operators. On the other hand, the practical applicability of this approach has great obstacles like current regulation, established business models and processes and the reluctance of many Users to engage in unstable and disruptive technologies.

Connectivity will be cheaper and cheaper. Terminals will become more and more intelligent and capable, and their range of connectivity possibility will increase, mixing up long and short or very short-range connection capabilities. In the evolution towards the highly connected age, there is a clear move of the value from networks to terminals (embedding communications): Halos Networks are inserted in this evolutionary move of value in ICT, enabling the development of open IoT and IwT.

As mentioned previously IoT is connecting things, provided these things can connect to the Internet. The IwT is an internet that "contains" things, in the same way as it contains information and services. A thing participating in the IoT does not have a mirror image in the Internet. On the other hand, each thing in the IwT is associated with a mirror image in the web that is kept in synch with it and which can be acted upon and result in a corresponding action, direct or mediated, on the real thing. IwT creates a value through its mirror image whilst in the IoT the value is related to the thing itself. Clearly, providing embedded connectivity enables a thing to be at the same time part of the IoT and of the IwT.

Actually the low cost of creating services in the Internet space is a push towards shifting the service space from objects to their counterpart on the web making those services available on the object through some sort of direct or indirect connection. In this sense Halos Networks extends this value space making it possible to create several of them, one for every relationship between us and them, and makes it possible for third parties to participate in the creation of this value.

The obvious question is about how the network operators will react. In principle, network operators could become resource providers of Halos Networks. The sensors, the poles, the buoys needed for communicating between the user nodes and the environment could be in a large part deployed by operators in conjunction with the public administrations. Actually, deploying networks that do support self-organization of nodes makes life easier from a network management perspective and, as mentioned in this paper, managing a plethora of small communication nodes is not possible with traditional means and approaches. These nodes could also be organized in such a way as to be able to support local services that the Operator wishes to provide to local communities or a dynamic group of users. The infrastructural costs could be reduced because the used platform is the one comprised of the thousands of nodes available locally.

Eventually Halos Networks are creating new ecosystems, defined (as in nature) as environments where multiple players can be at the same time active and passive and relates one another through ever changing relationships, each one creating a context and being influenced by a context. Technology-economics interactions are bidirectional: economic forces shape the evolution of technology, while disruptive architectures and technologies can contribute to rewriting the balance of economic equations of Internet.

■ Conclusions and future work

This paper has presented Halos Networks as an architectural paradigm for Io-wT. A Halos Network is like a wireless network spontaneously emerging through the interactions of distributed resources embedding wireless communication capabilities. Halos Networks are capable of delivering services and data virally through multiple devices, machines and objects interconnected with each other.

In preliminary proof-of-concept activities it has been shown that a halo node can be easily implemented with a smart phone (acting as a Wi-Fi hot spot), one (or more) cheap, tiny PCs (e.g. a Raspberry Pi) and one (or more) microcontrollers (e.g. based on Arduino). We are looking at techniques and self-organizing principles for defining high level policies into implementable lower level policies which entails decomposing and assigning actions to specific entities both within a single Halo and in a Halos Network.

There are, of course, several other aspects related to Halos Networks that we have not discussed in this paper, such as multimedia social networks, resource sharing, economics, or bio-inspired use cases, etc. Nevertheless, we hope that this paper provides a new viewpoint for Internet of Things research.

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