Agent-Based Computing in the Internet of Things: a Survey

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Outline

1) Introduction
2) Background and Motivations
3) Agents' Contribution in Developing Internet of Things Systems
4) Analysis and Conclusion

1_Introduction [MF2010]

- **Internet of Things (IoT)**

Everything is able to be networked, discovered and exploited.

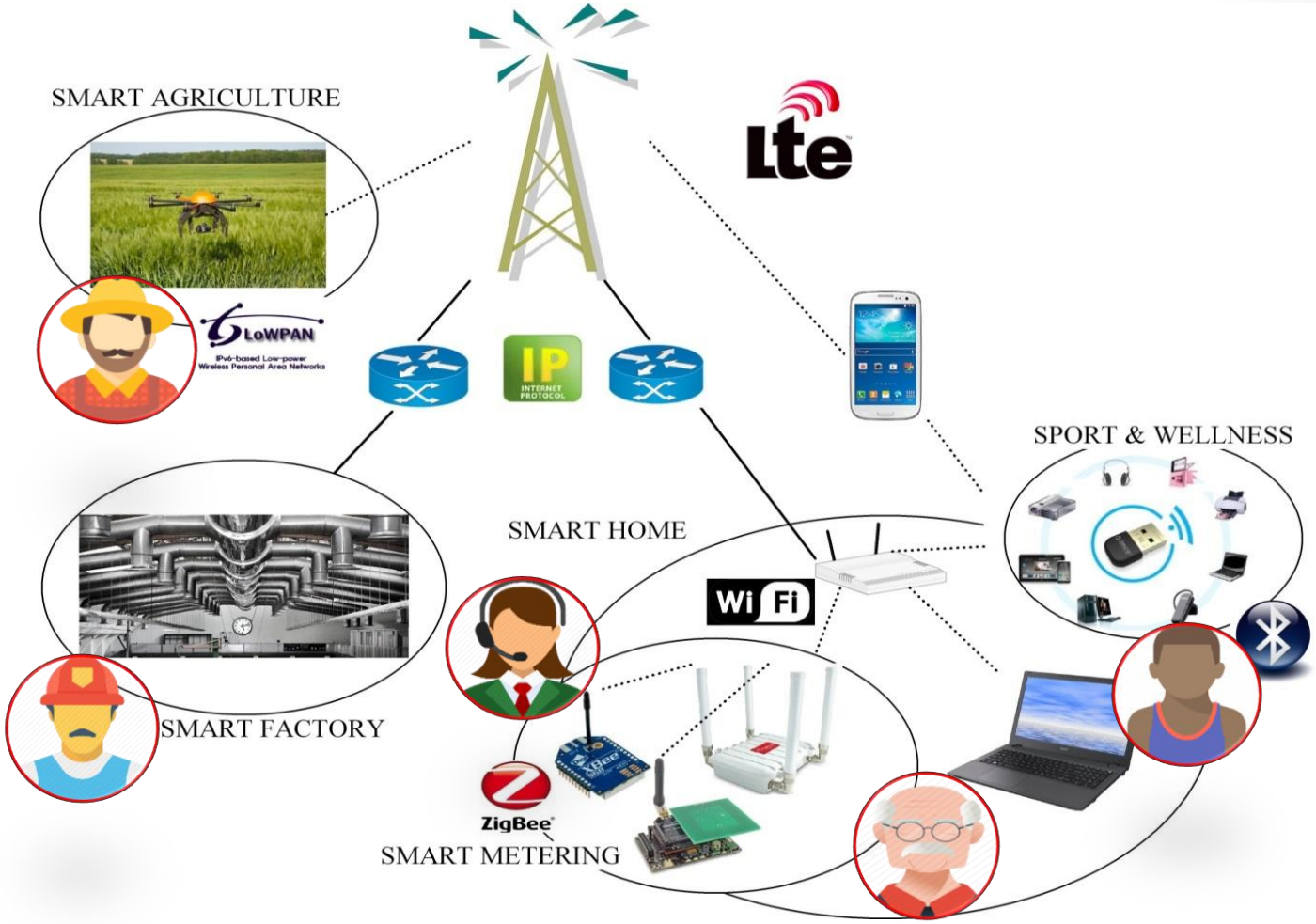
- **Smart Objects (SOs)**

Real world objects with embedded smartness, autonomously interacting each others and proactively providing cyber-physical services

- **Issue**

Proper modeling, programming, and simulation paradigms are required for developing IoT systems.

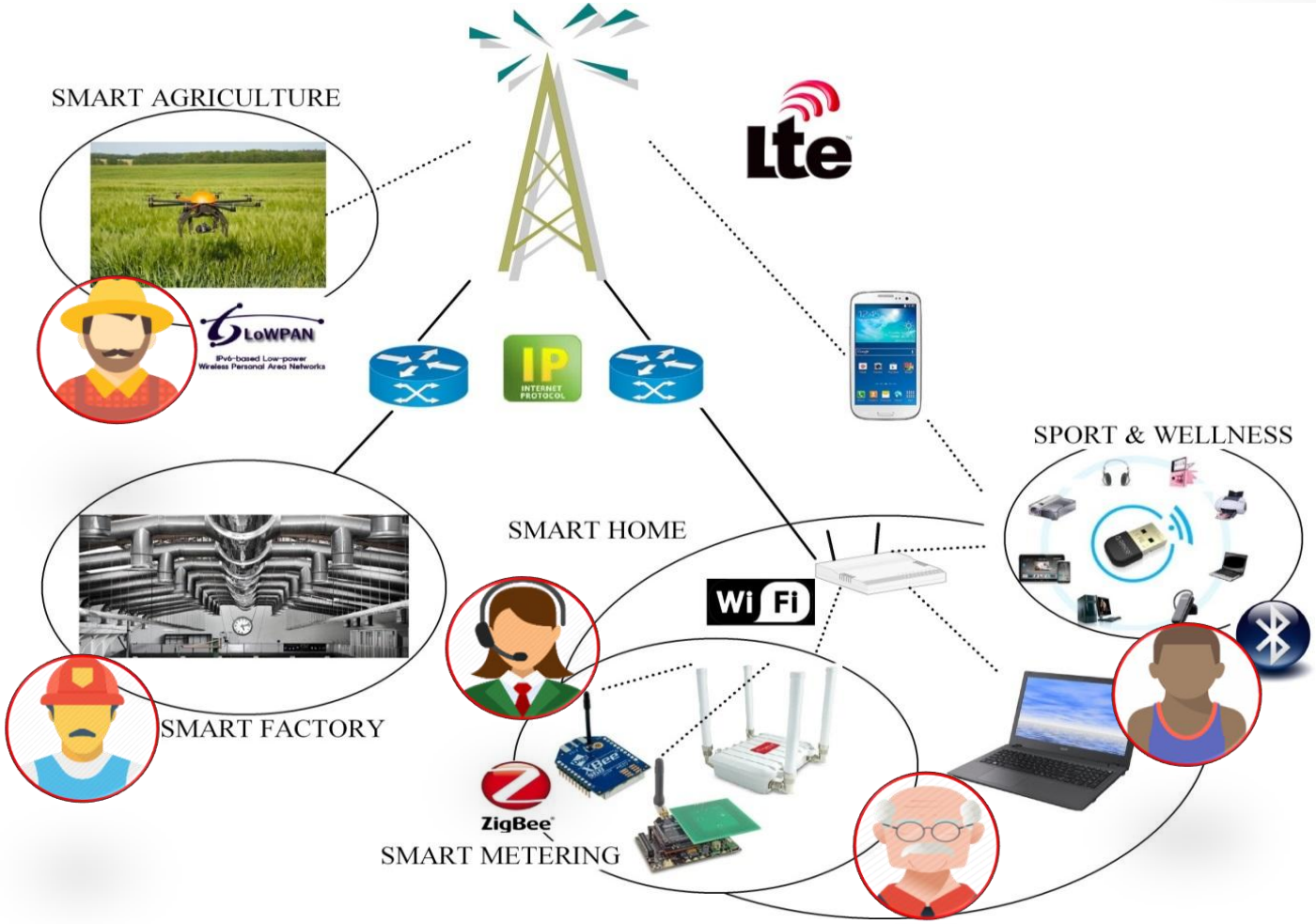
2_Background and Motivations [AIM2010]



<u>IoT Features:</u>
Heterogeneous components
Heterogeneous network types
Heterogeneous stakeholders

<u>IoT Desiderata:</u>
Smartness
Interoperability
Autonomy

2_Background and Motivations [AIM2010]



<u>IoT Features:</u>
Heterogeneous components;
Heterogeneous network types;
Heterogeneous stakeholders.

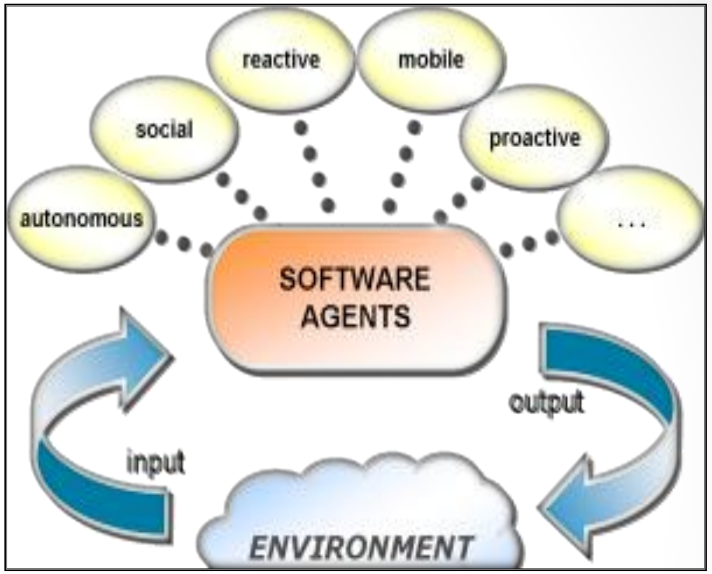
Support required for all the development phases

<u>IoT Desiderata:</u>
Smartness;
Context-awareness;
Autonomy.

2_Background and Motivations [L2004]

A software Agent:

- is an autonomous, goal-directed entity;
- is situated in, is aware of, and reacts to its environment;
- cooperates to accomplish its tasks.



Agents are able to:

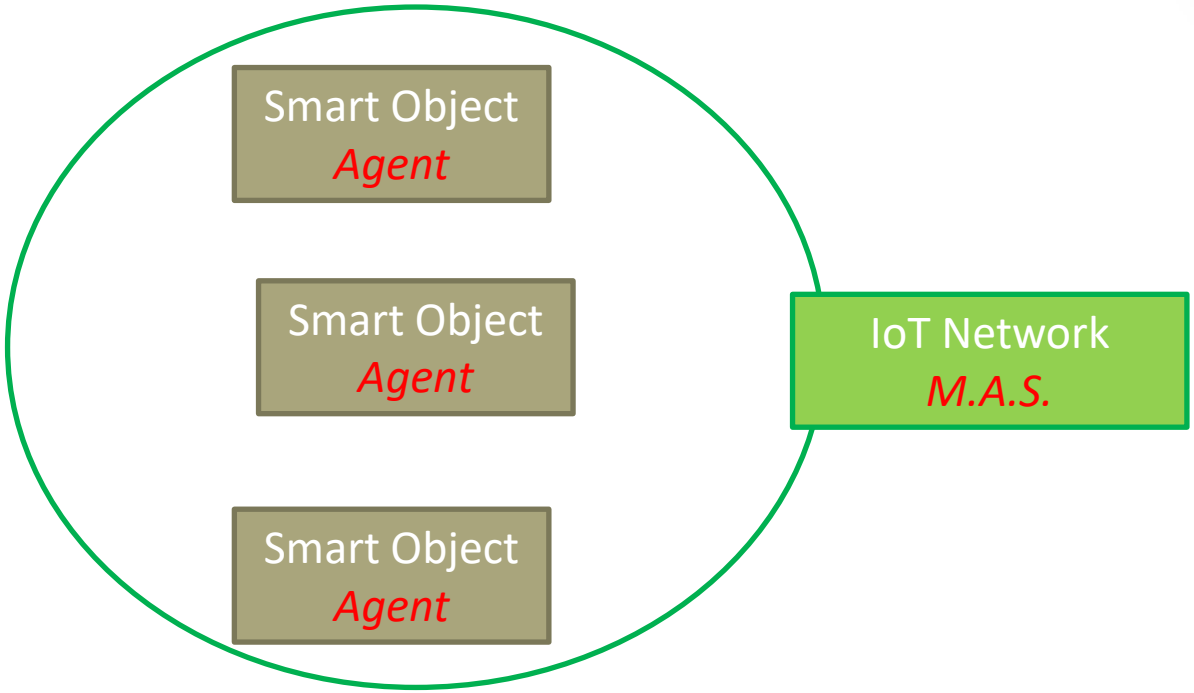
- encapsulate complex functionalities and abstract heterogeneous resources;
- act as interoperability facilitators;
- fully support the development of complex, cooperative and adaptive distributed systems.

2_Background and Motivations [L2004]

Agent-based Computing (ABC) as a well-established

- Modeling paradigm
  - abstractions and metaphors for modeling complex systems, their components, interactions and organizational relationships;
- Programming paradigm
  - for concretely implementing self-steering, smart, context-aware and interoperable agents systems;
- Simulation paradigm
  - for studying macro phenomena and patterns, as well as individual behaviors and environment evolution, before the system deployment;
- Development methodology
  - providing a systematic approach to the usage of agent-oriented metaphors, techniques and tools.

3_Agents' Contribution in Developing IoT Systems



Strong conceptual relation exists between agents and SOs, as well as between MASs (Multi Agent Systems) and IoT systems [FGRS2015].

ABC has been profitably exploited for modeling, programming and simulating IoT applications and systems.

3_Agents' Contribution in Developing IoT Systems

ABC as IoT Modeling Paradigm

Goal: capturing key characteristics of SOs and IoT systems, at different degrees of granularity and in a technology-agnostic way.

SO concept	Agent concept	Example from surveyed work
SO/SOs system	Agent/MAS	Agentified SOs characterized through • Role [SM2015, K2008] • Template [V2013] • Automaton driven by incoming stimuli (messages) [MZ2006 et. Al] • Tasks performed according to events [FGLLR2013]
Functionality	Goal	
Working plan	Behavior	
Device (sensor, actuator, etc.)	Resource	
Autonomy, proactiveness and situatedness	Implicitly embedded within agent abstraction	

3_Agents' Contribution in Developing IoT Systems

ABC as IoT Programming Paradigm

Goal: Implementing SOs and IoT systems according to their features and requirements

SO/IoT system functionality	Agent-oriented mechanism	Example from surveyed work
Augmentation	Resource Interface	Software adapters [K2008, FGLLR2013], device-based interfaces [ZAPKB2016]
Communication	Communication Interface	FIPA ACL [FGLLR2013], KQML, XML and JSON [LRLHO2014]
Knowledge Management	Ontology, Reasoner	Shared ontology and knowledge bases [K2008]
Service provision	Service interface	Cloud-based services [FGRS2014], SOA/REST services [MIBV2014]
Context and Self Management	Environment and self-data analysis	Exploitation of autonomic and cognitive paradigms [SFZ2016]

Technical, syntactical and semantical interoperability

3_Agents' Contribution in Developing IoT Systems

ABC as IoT Simulation Paradigm

Goal: understanding overall dynamics, estimating performance, and validating models, protocols and algorithms featuring under-development SOs and IoT systems.

Approach	Pro	Con
Agent-based simulation [KD2009 et. Al.]	Collective dynamics and behavioral patterns inspection	Quasi aseptic simulation environments
Network-based simulation [WG2017 et. Al.]	Low-level aspects (communication settings, propagation models, etc.) finely handled	Few abstractions for implementing the application logic
Hybrid simulation [FRS2016 et. Al.]	Effective simulation of both low- and high-level aspects	Exploratory approach

3_Agents' Contribution in Developing IoT Systems

Agent-based IoT development methodology

Goal: disciplining the exploitation of agent-based suite of models, programming techniques and simulation tools but, also, specifically considering:

- the cyber-physical nature of the involved entities and environments [MFM2014 et.Al.];
- by design, solutions for interoperability, security and scalability [Z2016];
- the identification of IoT users and stakeholders [SM2015 et Al.];
- proper management, coordination and virtualization mechanisms [FGRS2015 et. Al.];
- infrastructural features and limitations according to the specific IoT system requirements [Z2016];
- guidelines and best-practices decoupled from a specific technology, protocol or application context [FGRS2015 et. Al.].

3_Agents' Contribution in Developing IoT Systems

Table 1. Surveyed works and provided agent-based features - *T=technological, Sy=syntactical, Se=semantic interoperability; A=autonomicity; C=cognitivity; V=virtualization; S=security.*

Surveyed work <name, ref. >	Agent-based IoT model		Agent-based IoT implementation							Agent-based IoT simulation		Agent-based IoT Methodology
	Fine grained	*Coarse grained*	*T*	*Sy*	*Se*	*C*	*A*	*V*	*S*	*Pure*	*Hybrid*	
Cascadas, [17]	X		X	X			X					
iCore, [21]	X		X	X	X	X			X			
ACOSO [6], [9], [22], [42], [43]	X		X	X	X	X	X	X			X	X
UBIWARE, [19]; UBIROAD, [26]	X		X	X	X	X		X	X			
[29]		X	X	X				X				
[44]	X		X	X	X		X	X				X
AoT, [27]		X	X	X		X	X	X				
Smart Grids, [40]		X		X						X		
[41]		X	X	X				X			X	
TAEC, [39]		X	X	X	X		X	X	X			
CIoT, [32]	X		X	X	X	X		X	X			
iSapiens, [23]	X		X	X				X	X			
[31]		X	X	X				X				
Radigost, [38]		X	X	X				X				
ASSIST, [45]	X		X	X	X	X		X		X		
BEMOSS, [25]		X	X	X				X	X			
INTER-IoT, [50]	X		X	X	X	X	X	X	X		X	X
VICINITY, [33]	X		X	X	X	X		X	X			
SOL, [28]	X		X	X	X		X					
[20]	X		X	X	X							
[24]		X	X	X			X					
[30]		X	X	X		X	X					
Smart Santander, [35]		X	X	X	X			X	X			
[34]		X	X	X	X			X	X			
Prometheus, [46]	X		X	X	X			X	X			X
ASEME, [18]	X		X	X	X			X	X			X
SAMSON, [51]	X						X			X		

3_Agents' Contribution in Developing IoT Systems

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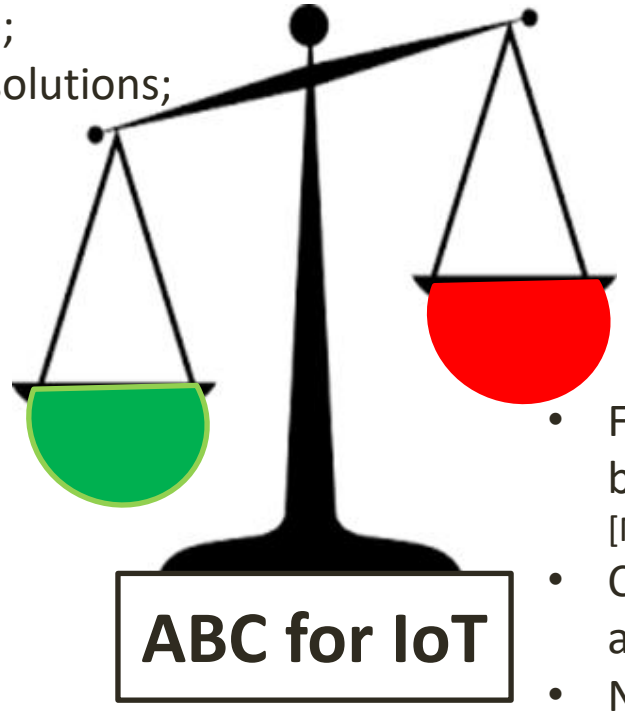
Cascadas, [17]	X		X	X			X					
iCore, [21]	X		X	X	X	X			X			
ACOSO [6], [9], [22], [42], [43]	X		X	X	X	X	X	X			X	X
UBIWARE, [19]; UBIROAD, [26]	X		X	X	X	X		X	X			
[29]		X	X	X				X				
[44]	X		X	X	X		X	X				X
AoT, [27]		X	X	X		X	X	X				
Smart Grids, [40]		X		X						X		
[41]		X	X	X				X			X	
TAEC, [39]		X	X	X	X		X	X	X			
CIoT, [32]	X		X	X	X	X		X	X			
iSapiens, [23]	X		X	X				X	X			
[31]		X	X	X				X				
Radigost, [38]		X	X	X				X				
ASSIST, [45]	X		X	X	X	X		X		X		
BEMOSS, [25]		X	X	X				X	X			
INTER-IoT, [50]	X		X	X	X	X	X	X	X		X	X
VICINITY, [33]	X		X	X	X	X		X	X			
SOL, [28]	X		X	X	X		X					
[20]	X		X	X	X							
[24]		X	X	X			X					
[30]		X	X	X		X	X					
Smart Santander, [35]		X	X	X	X			X	X			
[34]		X	X	X	X			X	X			
Prometheus, [46]	X		X	X	X			X	X			X
ASEME, [18]	X		X	X	X			X	X			X
SAMSON, [51]	X						X			X		

Agent-based simulators and methodology are underestimated

4_Analysis and Conclusion

Strenghts

- Modeling at different degrees of details
- Programming interoperable; autonomous, and distributed solutions;
- Validating multiple design choices, before their actual deployment;
- Systematically supporting all the development phases.



Weaknesses

- Few and outdated agent-based commercial platforms [MM2005];
- Costs for implementing agent-based IoT solutions;
- NOT everything can be profitably agentified and agents are NOT a universal solution [WJ1999].

The adoption of ABC paradigm needs to be carefully assessed but it represents, to date, the most suitable choice for effectively developing the majority of advanced (current and future) IoT systems.

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Thank you for your attention!

Questions?