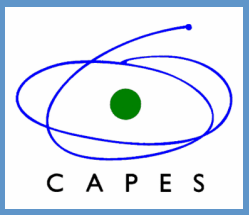


On the Development of Systems-of-Systems based on the Internet of Things: A Systematic Mapping

Pedro Maia, Everton Cavalcante, Porfírio Gomes
Thais Batista, Flávia Delicato, Paulo Pires

Vienna, Austria – August 26th, 2014

Agenda

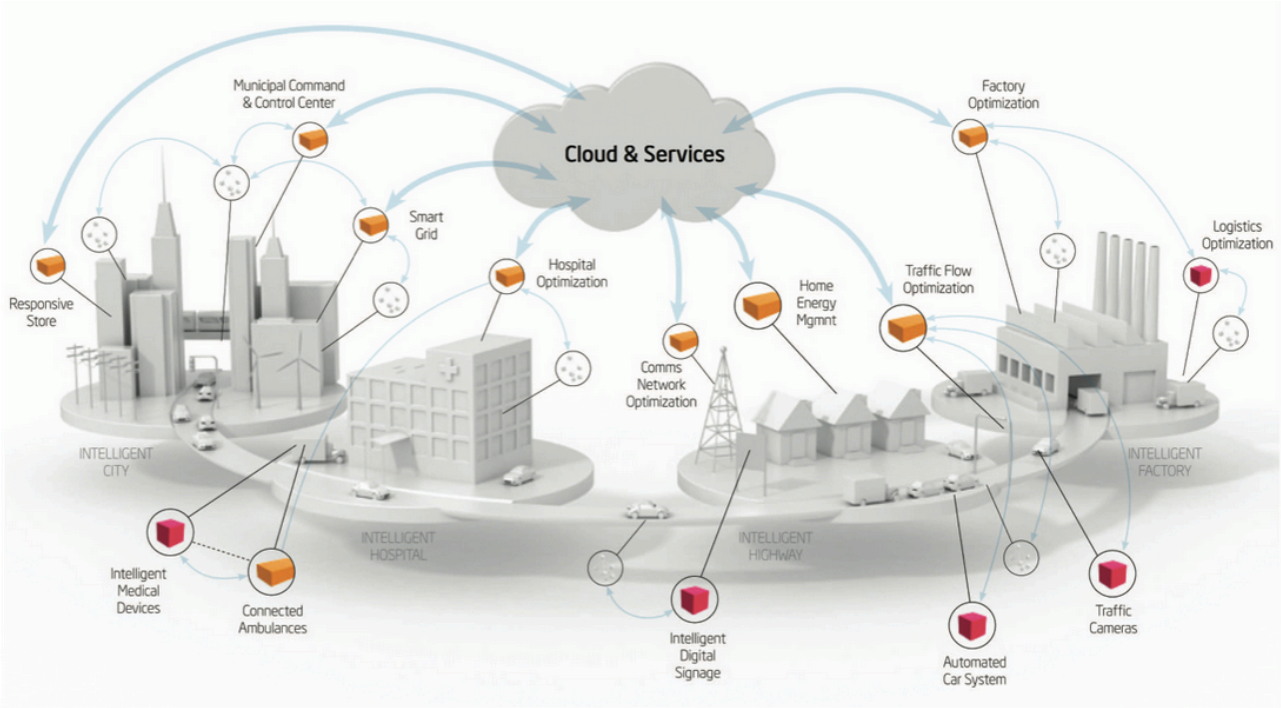
- Introduction
- Systematic Mapping
  - Planning
  - Conduction
  - Reporting
- Discussion
- Threats to validity
- Final remarks

Introduction

- The Internet of Things (IoT) paradigm
  - In the near future, it will be possible that every single object on the Earth can be identifiable, addressable, controlled, and monitored through Internet.
  - "Smart things" integrated in the Internet will actively collaborate among them and with other physical and virtual resources available in the Web, opening a new world of infinite possibilities.

Introduction

- Things engaged in complex relationships including the composition and collaboration with other independent and heterogeneous systems, thus leading to the so-called *systems-of-systems* (SoS).



Motivation

- The promising integration of IoT-based systems in order to compose complex SoS requires a study addressing a comprehensive analysis about this topic.
  - to present an overview about the current scenarios and approaches in the development of IoT-based SoS

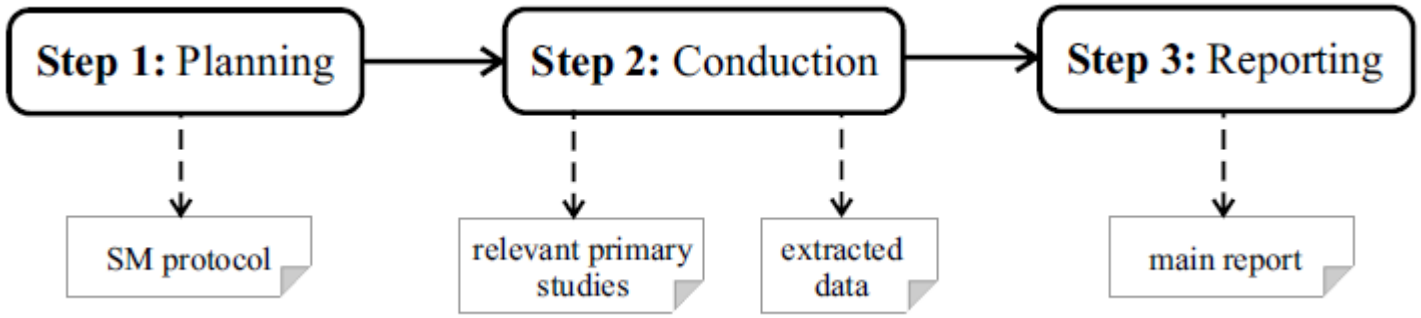
  - to identify and discuss some challenges and research opportunities.

Goal of this paper

- To present a Systematic Mapping (SM) as a means of evaluating and interpreting this research topic (IoT + SoS) by using a rigorous methodology.
  - the rigorous methodology is the main point that differentiates a systematic procedure from a traditional literature review.
  - seeks to avoid the maximum of bias, thus providing scientific value for the obtained findings.

Systematic Mapping

- Provides an overview of the investigated topic
- Follows a systematic process typically divided in three basic steps:
  - **Planning:** defines a protocol
    - research questions, search strategy, selection criteria, data extraction and synthesis methods
  - **Conduction**: identifies, selects, and evaluates the studies
  - **Reporting (or Analysis)**: aggregates information and outlines conclusions from them



Planning
Research Questions

- Aiming at finding primary studies to understand IoT-based SoS and the existing solutions, scenarios, and research challenges, the following research questions (RQ) were proposed:
  - RQ1: Which are the main research topics that have been investigated on the development of IoT-based SoS?
  - RQ2: Which are the application domains that have been targeted by IoT-based SoS?
  - RQ3: Which are the existing IoT-based SoS architectures and implementations?

Planning
Search Strategy

- In order to establish the search strategy based on the defined research questions, two main terms were initially identified, namely **Internet of Things** and **systems-of-systems**.
- Possible variations such as synonyms and singular/ plural forms were considered, thus resulting in the following search string:
  - (internet of things OR iot OR web of things OR wot) AND (system-of-systems OR systems-of-systems OR system of systems OR systems of systems)

Planning
Search Strategy

- Six electronic databases were used for the search process:

Database	URL
IEEEXplore	http://ieeexplore.ieee.org
ACM Digital Library	http://dl.acm.org
ScienceDirect.com	http://www.sciencedirect.com
Scopus	http://www.scopus.com
ISI Web of Science	http://www.webofknowledge.com
SpringerLink	http://link.springer.com

Planning

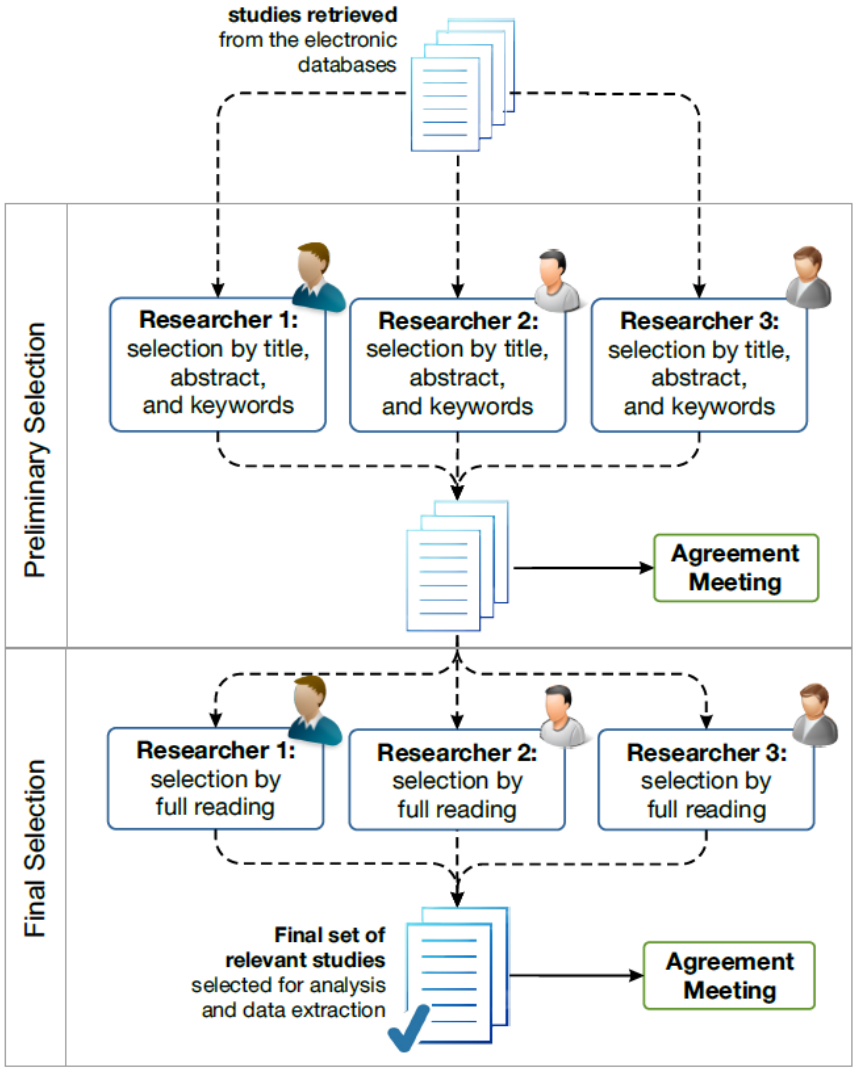
Inclusion and Exclusion Criteria

INCLUSION CRITERIA (IC)	EXCLUSION CRITERIA (EC)
IC1: The study presents a SoS composed of IoT-based systems;	EC1: The study does not address IoT or SoS;
IC2: The study presents a relevant work in the development of IoT-based SoS;	EC2: The study is a previous version of a more complete paper about the same research;
IC3: The study presents scenarios and research challenges and opportunities in the development of IoT-based SoS.	EC3: The study does not have an abstract or the full text is not available.
	EC4: The study is a table of contents, foreword, tutorial, editorial or summary of conference.
	EC5: The study is not written in English.

Planning
Data Extraction and Synthesis Methods

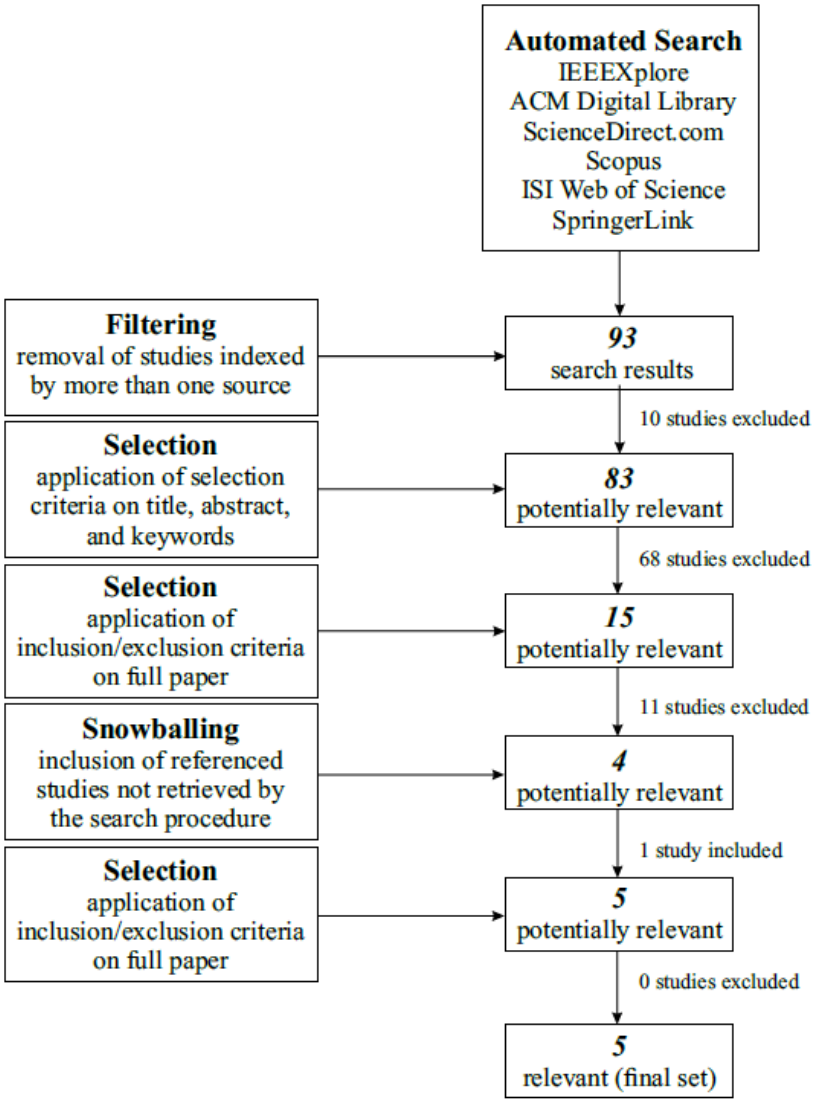
- Data extraction spreadsheets related to each research question were built to synthesize the results and support drawing of conclusions.
- Data of each primary study were independently extracted by the researchers when considering each research question.
- Conflicts found during the process were solved by discussions between the researchers.

Conduction



Each study was fully read by two researchers. In case of divergence, the third one solved the conflict.

Conduction


Automated Search
IEEEXplore
ACM Digital Library
ScienceDirect.com
Scopus
ISI Web of Science
SpringerLink
93
search results
10 studies excluded
83
potentially relevant
68 studies excluded
15
potentially relevant
11 studies excluded
4
potentially relevant
1 study included
5
potentially relevant
0 studies excluded
5
relevant (final set)
Filtering
removal of studies indexed by more than one source
Selection
application of selection criteria on title, abstract, and keywords
Selection
application of inclusion/exclusion criteria on full paper
Snowballing
inclusion of referenced studies not retrieved by the search procedure
Selection
application of inclusion/exclusion criteria on full paper

Conduction

Source	Number of studies			Index rate	Precision rate
	Retrieved	Filtered	Selected		
IEEEXplore	7	5	1	20.00%	14.29%
ACM Digital Library	2	2	1	20.00%	50.00%
ScienceDirect.com	1	1	0	0.00%	0.00%
Scopus	13	8	1	20.00%	7.69%
ISI Web of Science	2	2	0	0.00%	0.00%
SpringerLink	68	7	2	40.00%	2.94%

ID	Title	Publication year
S1	Combining cloud and sensors in a smart city environment	2012
S2	SCCIR: Smart cities critical infrastructure response framework	2011
S3	Smart cities at the forefront of the Future Internet	2011
S4	Web-of-Things framework for cyber-physical systems	2011
S5	Towards an IoT ecosystem	2013

Reporting

- In this phase, the results of the SM are presented according to the research questions and the extracted and synthesized data.

Reporting

RQ1: Which are the main research topics that have been investigated on the development of IoT-based SoS?

- all selected papers were published in the last three years:
  - research topic is relatively new and most works are in an initial stage of development;
- most efforts are concentrated on:
  - (i) understanding the requirements for these systems and the application domains in which they can be deployed;
  - (ii) designing and implementing high level architectures and frameworks that could support and provide applications in SoS, based on sensor and actuator networks (SANs) and IoT.

Reporting

RQ1: Which are the main research topics that have been investigated on the development of IoT-based SoS?

- functional and non-functional requirements on the integration of the IoT paradigm and SoS engineering:
  - The main functional requirements are presented in study S5:
    - (i) *communication abstraction*, as means of addressing interoperability and heterogeneity concerns;
    - (ii) *unified information models*, which are used as means of sharing information among different applications, services, and systems;
    - (iii) *open services development*, which is aimed to ensure interoperability at both application and service levels.

Reporting

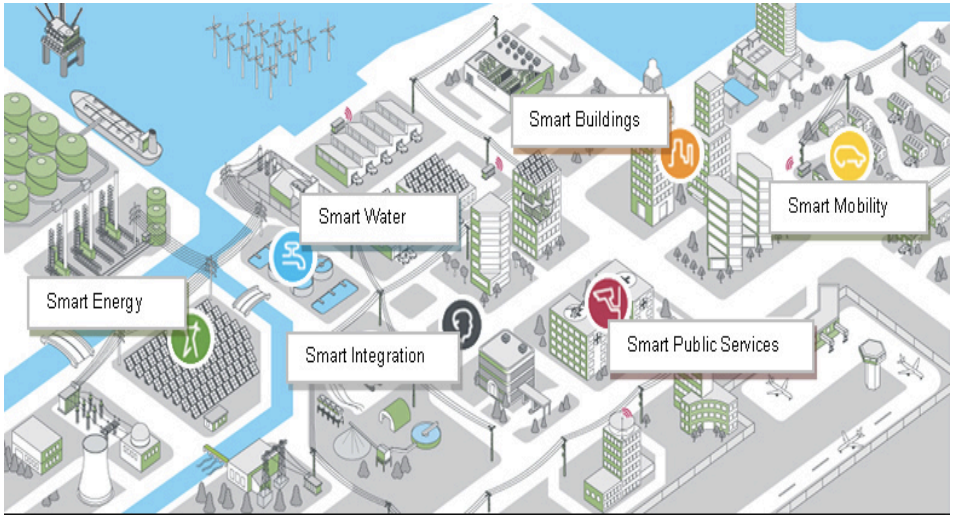
RQ1: Which are the main research topics that have been investigated on the development of IoT-based SoS?

- The most relevant non-functional features are highlighted in study S3:
  - *scalability:* the need of coordinating a myriad of devices to perform tasks;
  - *heterogeneity* of devices and systems: requires interoperability solutions
  - *resource constraints* in terms of time, memory, energy consumption, processing power, etc.;
  - *uncertainties*, related to the dynamic discovery of devices and systems, as well as adaptation and context-awareness capabilities;
  - *conflict resolution*, to solve possible conflicts in terms of the devices and systems;
  - *management* issues related to massive data, privacy, and security concerns;

Reporting

RQ2: Which are the application domains that have been targeted by IoT-based SoS?

- We have noticed that three of the five selected studies (S1, S2, and S3) target smart cities as the main reference scenario for their proposals.
  - Smart cities rely on information and communication technologies for collecting data from several urban sensors, which can range from simple sensors to complex SANs.
  - With the information provided by IoT, such systems would be able to elaborate complex decision-making processes and communicate to each other



Reporting

RQ2: Which are the application domains that have been targeted by IoT-based SoS?

- Another interesting application domain refers to intelligent vehicle systems, presented by study S4.
  - Intelligent vehicles are equipped with IoT-enabled devices, such as body control, light, navigation, fueling, and other critical electrical control modules.
  - Data collected by the external sensor systems (road sensors, traffic lights,…) can be used by the internal systems of a vehicle to set up vehicle parameters or to plan routes

Reporting

RQ2: Which are the application domains that have been targeted by IoT-based SoS?

- Study S5 also describes other motivational scenarios in different application domains for IoT-based SoS.
  - As IoT systems are able to transmit real-time information about natural processes such as temperature, wind, vibration of structures, rain, water level of rivers, etc., this information can be used in an integrated way with decision-making systems for different purposes, e.g., environmental protection, natural resources management, biodiversity conservation, and prevention of environmental disasters.

Reporting

RQ3: Which are the existing IoT-based SoS architectures and implementations?

- Each selected study uses a different approach to tackle the requirements of SoS scenarios by means of middleware platforms and frameworks that are mainly employed to abstract away the heterogeneity of IoT devices.
- The proposed solutions are typically structured upon three broad layers:
  - (i) a layer associated to devices in which heterogeneous *devices* are responsible for data provisioning and actuating tasks;
  - (ii) an *aggregation* layer, responsible for abstracting the communication with sensors and actuators and for aggregating data provided by them in a meaningful way;
  - (iii) an application/services layer, responsible for providing services and applications to end-users, decision-making systems, and control systems based on the information provided by the aggregation layer.

Discussion

Challenges and research opportunities identified from the analyzed studies

- Strategies to address the heterogeneity of both IoT devices and constituent systems of SoS
  - recent work pointed out to middleware platforms to provide interoperability capabilities and abstractions over physical devices and services to applications and/or end-users.
- Provision of qualitative information about each constituent system of the SoS by using aggregation mechanisms
  - end-users, applications, and other constituent systems are often more interested in aggregated and qualitative (coarse-grained) information about each constituent system than in fine-grained measurements of every single device deployed on the system.

Discussion

Challenges and research opportunities identified from the analyzed studies

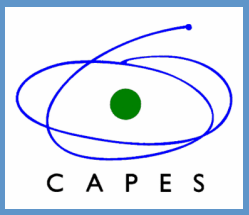
- Storage of raw and historical data
  - useful when the aggregated information has some anomaly or atypical behavior that cannot be well understood. The need of storing and manipulating large volumes of data is a typical feature of an IoT environment, thus might requiring Big Data solutions.
- Understand the challenges of Cyber-physical systems
  - the understanding of the challenges arisen from this type of SoS and the proposition of effective multidisciplinary solutions in this scenario are quite important due to its relevance and potential influence in the well-being of people and the optimal management of resources, services, energy, cost, and environment in several application domains.

Threats to validity

- Completeness: studies may have been missed due to technical limitations of the search engines.
- Reviewers' reliability: conclusions might have been influenced by the researchers opinions;
- Data extraction:
  - Not all information was obvious to answer the research questions;
  - Data interpretation was needed;
  - Discussions were conducted whenever a disagreement between researchers occured.
- Quality assessment:
  - Assessment criteria was considered in the planning phase, but it was not conducted because it would narrow the number of primary studies even further;
  - Can be considered in a future revision.

Final remarks

- Existing works are in an initial stage of development
- Most works focus on the understanding of the requirements for IoT-based SoS and propose high level architectures for supporting this class of systems.
- The development of a middleware platforms is pointed out a trend as they are able to abstract away heterogeneity and interoperability issues regarding physical devices and heterogeneous constituent systems.
- Smart cities might become a typical reference scenario of SoS leveraged by the IoT paradigm mainly due to their relevance to several aspects of economy, society, and wellbeing of people in a near future.

On the Development of Systems-of-Systems based on the Internet of Things: A Systematic Mapping

Pedro Maia, Everton Cavalcante, Porfírio Gomes
Thais Batista, Flávia Delicato, Paulo Pires

Vienna, Austria – August 26th, 2014