On Internet of Things Education

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***Abstract*—In this paper, we discuss educational courses for Internet of Things and related areas such as Machine to Machine communications and Smart Cities. The Internet of Things models introduce many new business prospects and, of course, they should be presented in the university curriculum. The purpose of the discussed educational program is to examine issues related to information and communication technologies used in Internet of Things projects and related areas based on them, such as Smart Cities. The educational course proposed in this paper aims to introduce students to modern information technology, standing for such areas as Machine to Machine communications, Internet of Things, and Smart Cities.**

I. Introduction

In this paper, we provide an extended and redeveloped version of Internet of Things (IoT) education related article [1]. We present the new educational products that appeared during the time that has elapsed since the writing of that work, as well as discuss our new experience gained during this time.

Currently, issues related to the Internet of Things and Machine to Machine communications (M2M) are attracting a lot of attention. In the same time, many presentations of IoT applications and systems contain only futuristic descriptions and their impact on an everyday life. The technical things are completely missed. However, all these acronyms (IoT, M2M) have nowadays a full line of standards, frameworks, development tools etc. So, it is very important to discuss the technical aspects of IoT (M2M). By 2020, the global demand for IoT developers is estimated at 4.5 million people [2]. This demand naturally raises the questions of learning for IoT technologies.

Currently, we cannot mention a single course on the Internet of Things covered all the aspects. Actually, there are no even unified approaches to its content and structure.

Naturally, both of these technologies – IoT and M2M (or more accurately - both of these directions) did not arise in a vacuum, they are not administered (at least in large numbers) of their own areas in the disciplines related to information and computer technology (Computer Science).

However, of course, we can talk about the development of specific programming architectures and models for IoT (M2M), etc. For example, some of the top-level models for IoT and M2M programming models have been published in our papers [3], [4]. It seems that, at least, the navigation tool for the audience (students) in the current situation in IoT (M2M) could be very useful.

In the current state of our project, we are talking about a semi-annual course which aims to introduce students to modern information technology, standing for such areas as the M2M and IoT. In this case, it refers to students studying in areas related to Computer Science. In our practice in Russia, for example, such a course could be a part of master's program in Faculty of Computational Mathematics and Cybernetic Lomonosov Moscow State University and master program in Prince Sattam bin Abdulaziz University.

The big question here is debatable - it is necessary or not to include here the materials for the Smart City. Very often, it is considered in conjunction with IoT, for example. In our vision, at least for now, we should not include Smart City related questions into IoT courses. Firstly, in many aspects, it seems still more related to the processes of the organization, rather than information technologies. And our idea was to stay in computer science and computer engineering domains, which include precisely IoT and M2M. In general, Smart Cities themes should be closer to the general sections of the digital economy. On the other hand, the borders are often blurred. For example, we can mention here such a popular direction as cyber-physical systems [5]. As per definition, they are engineering systems based on the interaction of software algorithms and physical objects. Cyber-physical systems (CPS) are integrations of computation and physical processes.

The rest of the paper is organized as follows. In Section II, we discuss the general content for IoT courses. In Section III, we provide an overview of existing courses. In Section IV, we describe our IoT course content and proposals.

II. On general content for IoT courses

In this section, we would like to discuss the common content for IoT educational programs. According to [6], [7], IoT directions could be grouped into five classes (sections):

Sensors – here are devices for data measurements and collections.

Network - how to transfer the data collected by sensors.

Standards - describe how to process the data and to provide interaction between different subsystems.

Intelligent analysis tools - the storage and analysis of the collected data.

Intelligent interaction tools - interaction with the system. This should include end-users tools and machine to machine APIs.

This list is illustrated in Fig. 1.

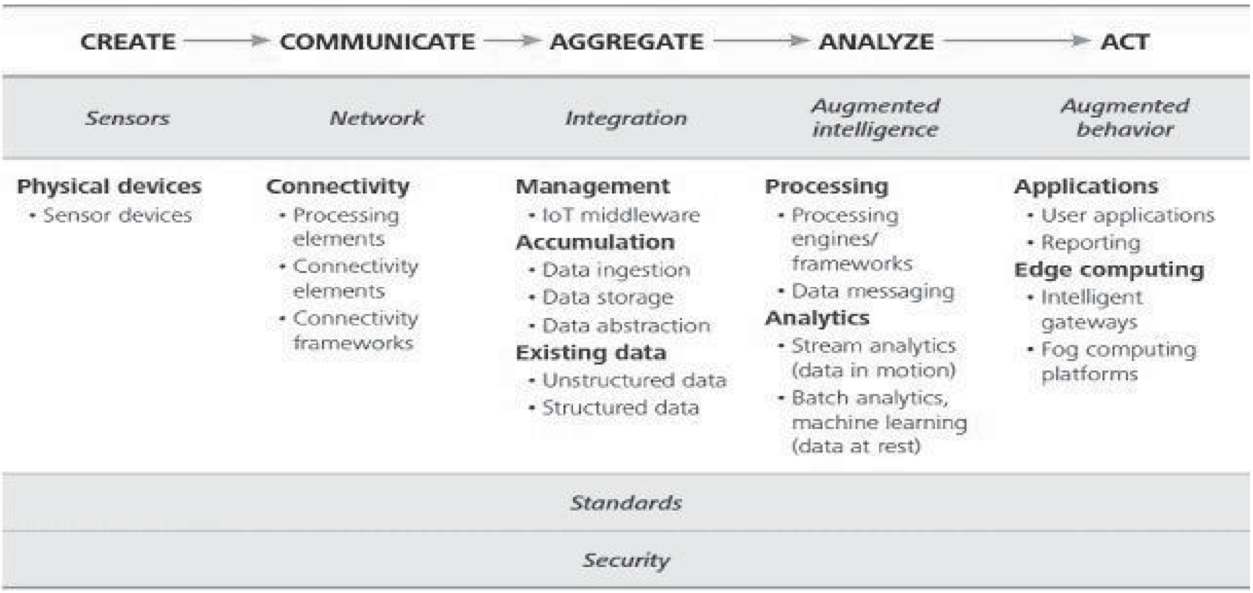

Fig. 1. IoT Functional Analysis [6]

The issues for discussions regarding the sensors and IoT are:

- the power consumption of sensors [8],
- the safety of measurements [9],
- the interaction with sensors [10].

The last point is directly related to communication protocols: CoAP, MQTT, HTTP (HTTP/2), etc. [11].

The section related to networks should include, of course, the IP protocol (IPv6), wired and wireless networks, Bluetooth and Bluetooth Low Energy, ZigBee, Wi-Fi, WiMAX, LTE [12], [13].

The section related to standards should target, on the first hand, IoT platforms. IoT middleware should be explained from the platform's point of view. Consideration of standardization should include both technological standards (networking, data collection, and analysis), and regulatory aspects (e.g., security).

Among technology standards which are important for IoT, we should mention the relatively isolated moments associated with the aggregation of data (ETL - extract, transform, load [14]).

Sections related to analytical processing include descriptive analytics (with visualization), predictive analytics and recommendation systems. For IoT especially, we would like to highlight the importance of the real-time processing and event processing (CEP - complex event processing [15]).

Means of cooperation include both machine to machine (M2M) and machine to human interaction (M2H). The last section (M2H) is the main section for cyber-physical systems [16].

III. ON EXISTING COURSES

This section presents some of the training programs for Internet of Things and Smart Cities. We include Smart Cities too because IoT is the data layer for Smart Cities. IoT is the foundation for data-driven cities.

At the first hand, we could mention Master's Program for Smart Cities and Urban analytics [17]. It covers the following issues:

- networks and communications,
- planning of traffic flows,
- real-time systems,
- geo-information systems,
- simulation system.

The focuses are urban planning and management. This is what it refers to the Smart Cities.

As the next issue, we could mention Master City Science program [18]. Its network-related part covers the following topics:

- New Generation Networks (NGN).
- Broadband communications.
- Quality of Service (QoS).
- Optical and wireless networks.
- Telecommunication network architecture.
- 4G networks.
- Mesh-networks.

The main emphasis, as can be seen from the content is Networking

In general, Masters City Science [18] covers a wide list of areas:

- Transport and Mobility.
- Information and Communication Technologies.
- Urban and Landscape Design.
- Society and Governance.

- Environment and Sustainability.
- Economy and Business.
- Ecological Urbanism.
- Energy.

EIT Digital Master School presents a program for Embedded Systems [19]. The seven specializations are:

- Embedded Platforms.
- Embedded Multicore Processing.
- Embedded Networking.
- Mobile Cyber-Physical Systems.
- Internet of Things and Energy-Efficient Computing.
- Real-Time Systems and Design of Cyber-Physical Systems.
- Critical Embedded Systems.

Actually, it is one of the most technically deep and elaborated programs.

SAP provides an online course on the Internet of Things [20]. In general, it is just an introduction. It covers two IoT perspectives: Societal Perspective and Business Perspective.

Among other online courses can be noted Open University program to IoT [21]. It uses elements of IoT for general learning computer science. In particular, it is used for teaching programming based on the Arduino.

Oxford University offers a course of Data Science for the Internet of Things [22]. It includes:

- Statistics.
- Time Series analysis.
- Deep Learning.
- Real Time processing.
- IoT Data Visualization.

Sure, time series processing is very important for IoT analytics, but this course is really about data science only and uses IoT just as a name.

Coursera [23] offers a specialization (a set of courses, thesis project, and a certificate) for Internet of Things. The specialization consists of the following courses:

- Introduction to the Internet of Things and Embedded Systems - an introduction to the topic, general information.
- The Arduino Platform and C Programming - course content corresponds to the name. Working with Arduino.
- Interfacing with the Arduino - work with external devices to Arduino.
- The Raspberry Pi Platform and Python Programming for the Raspberry Pi - programming for Raspberry Pi.
- Interfacing with the Raspberry Pi - working with external devices in the Raspberry Pi.

The professional training program at MIT also offers the detailed and well-elaborated training program for IoT [24]. This program includes the following sections [25]: the architecture of the IoT, processing sensor data, SLAM, stand-alone devices (cars, robots), IoT standards, wearable devices (wearables), security, Web of Things, wireless protocols, storage and analysis of data, man-machine interfaces. Course module to develop applications includes Smart Homes, Smart City, Smart materials, medical applications, and cyber-physical systems.

As per our review, it is the most advanced offering for IoT education. As per MIT model, Smart City is just an application (use case) for IoT. So, their program includes Smart Cities too (as an application and example for IoT).

Kings College London offers a free survey course on IoT [26]. The University of Washington offers a practical course on the IoT (Raspberry Pi and other devices) [27]. It includes also cloud computing part: how to store, process, present and visualize data from the internet of things, how to setup micro-services in the cloud, including data schema, database, API development and server elements, as well as simple and complex visualization tools experience (such as Tableau Public) [28].

HP also has its own training course on IoT [29]. This a two-day course, although, formally, it presents many topics. For example, we could mention network technologies such as RFID, WSN, and Smart-applications (Smart Cities, Smart Home, Smart Metering, and Smart Health). In general, it looks more as an introduction for managers.

Waterford Institute of Technology (Ireland) offers an undergraduate program for Internet of Things [30]. It contains six big areas.

1) Programming: includes the fundamental algorithms & data structures relevant to the field. Especially, the nature and performance of distributed, networked applications.
2) Data Science: the ability to select the appropriate technological components, including warehousing and analysis. The knowledge to integrate the components into a single data-analytics solution and extract meaningful insight from the IoT data.
3) Mathematics: examines the formal reasoning, modeling, and analytical skills.
4) Devices & Systems: explores analogue and digital interface components; insight and understanding of the components, and the integration processes.
5) Networks & Cloud: provide a practical understanding of Operating Systems and the tools they require to deploy, manage and troubleshoot the underlying infrastructure required to support IoT.
6) Project: deliver concrete experience IoT domain.

Intel offers an open course, called the Internet of Things [31], [32], but, in fact, promotes their own programming for Edison platform.

IV. On the possible structure for IoT course

The main result of our review in the previous section is the conclusion that there is no single course we could use as a prototype. In our opinion, the most elaborated program has been proposed by MIT [24]. But this course is short and targets postgraduate managers. And our idea is to propose a two-year master program.

The idea is to combine in a single course of four basic components: application architecture, network interoperability standards, data storage systems, and principles of their analysis and processing. Accordingly, the course may include four main sections.

The first one deals with modern standards in the field of M2M and IoT. Here we should talk about IoT-GSI, OpenIoT, FI-WARE, OMA, etc. Actually, the amount of the proposed solutions, in varying degrees of readiness, is sufficiently large. At the same time, they can promote different approaches to building systems, data collection, and processing. It is, in fact, consideration of possible architectural solutions for building IoT systems. Course participants will need to get an idea of the existing architectural solutions, their comparative characteristics, and applicability depending on external conditions.

The second section will focus on network solutions for the IoT. Here, in particular, we consider network solutions such as 802.15.4, 6LoWPAN, etc. and data protocols such as COAP, MQTT, etc. It is closely related to the previous section, since the choice of network protocols can determine the application architecture. Table I [33] illustrates this area.

TABLE I. IoT APPLICATION PROTOCOLS

Protocol	Transport	Messaging	2G/3G/4G	Low Power	Compute Resources	Security	Success Stories	Arch
COAP	UDP	Req/Resp	Excellent	Excellent	10K/RAM Flash	Medium-Optional	Utility field	Tree
Cont. HDP	UDP	Req/Resp Pub/Sub	Fair	Fair	10K/RAM Flash	None	Medical	Star
DDS	UDP	Req/Resp Pub/Sub	Fair	Poor	100K/RAM Flash+++	High-Optional	Military	Bus
DPWS	TCP	Req/Resp Pub/Sub	Good	Fair	10K/RAM Flash++	High-Optional	Web Servers	Clent-Server
HTTP/REST	TCP	Req/Resp	Excellent	Fair	10K/RAM Flash	Low-Optional	Smart Energy	Clent-Server
MQTT	TCP	Req/Resp Pub/Sub	Excellent	Good	10K/RAM Flash	Medium-Optional	IoT messaging	Tree
SNMP	UDP	Req/Resp	Excellent	Fair	10K/RAM Flash	High-Optional	Network monitoring	Clent-Server
UPnP	arbitrary	Req/Resp Pub/Sub	Excellent	Good	10K/RAM Flash	None	Consumer	P2P Clent-Server
XMPP	TCP	Req/Resp Pub/Sub	Excellent	Fair	10K/RAM Flash	High-Mandatory	Remote management	Clent-Server
ZeroMQ	UDP	Req/Resp Pub/Sub	Fair	Fair	10K/RAM Flash	High-Optional	CERN	P2P

Interaction with a wide range of external devices (sensors) is naturally associated with the collection and storage of some of the information (measurements). Accordingly, the problems associated with the storage and processing of large data sets are among the top priority areas for the IoT applications. The third section of the course and discussed issues related to the storage of large data sets. For IoT and M2M application, we propose to teach students to data stream processing systems (e.g. Apache Storm [34] and Apache Spark [35]) and appropriate architecture models (Lambda architecture [36], Kappa architecture [37]).

The Lambda Architecture (Fig. 2) targets applications built around complex asynchronous transformations that need to run with low latency [38]. It is a typical use case for IoT systems. The Lambda Architecture offers a dedicated real-time layer. It solves the problem with old data processing by taking its own copy of the data, processing it quickly and stores it in a fast store. This store is more complex since it has to be constantly updated.

The next step in this direction (real-time processing) is so-called Kappa architecture [40], where everything is a stream. By our opinion, it is the most suitable approach for sensing data persistence (Fig. 3).

And sensing, obviously, is a huge part of IoT applications.

Currently, much attention is paid to data analysis (data mining), while data engineering attracts less attention in universities. However, before we can start the process the data, we need to learn how to save them in one form or another, provide the right architecture of systems. In this regard, e can point to the Big Data standards NIST [41]. They are currently freely available as drafts. Their distinguishing features are the focusing on the application layer and discussions about specific use cases. Based on the fact that standards are the best practices, the NIST describes and discusses the best practices exactly.

Such documents as Big Data Use Cases and Requirements, Big Data Security and Privacy, Big Data Architecture White Paper Survey, Big Data Reference Architecture are well-organized materials which could be used as tutorials. Fig. 4, for example, presents Big Data Reference Architecture.

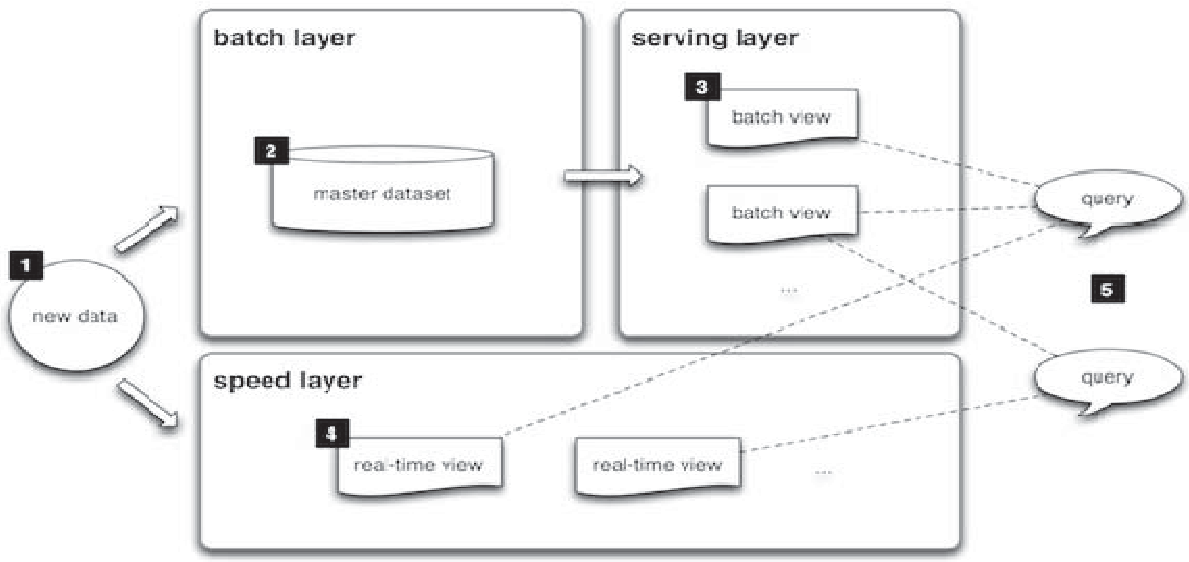

Fig. 2. Lambda architecture [39]

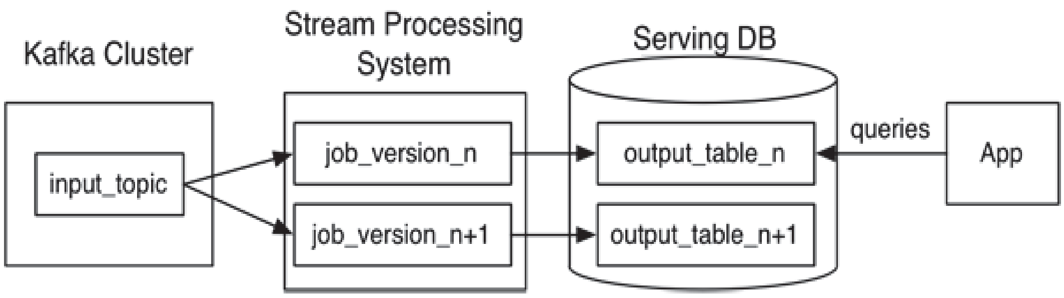

Fig.3. Kappa architecture

And Big Data Use Cases and Requirements [43] contains 50+ detailed use cases (data architectures) including IoT examples for cargo shipping, health care, unmanned air vehicle, life science, etc.

The last section is completely devoted to the consideration of data processing in real time. The main applied area is the classification and identification of anomalies. In this particular domain, IoT requires consideration in the first place, namely streaming algorithms.

The streaming, dynamic, and distributed algorithms are key elements for analyzing big data in IoT applications. We discuss sampling and sketching as two basic techniques for designing streaming algorithms and hash functions most data streaming algorithms rely on.

In general, streaming algorithms [44] are seriously underestimated in the existing educational courses. At the same time there is a whole world of approaches such as data-based and task-based techniques, sampling, load shedding, sketching, creating a synopsis of data (e.g., wavelet analysis, histograms, frequency moments, etc.), aggregation, and approximation.

Finally, the proposed course should create the following formation of competencies:

- understanding of the architecture of IoT and M2M applications;
- understanding of the model of networking in IoT;
- knowledge of the basic models used in the design of IoT and M2M systems;
- understanding of the network standards used in IoT;
- understanding of data models used in IoT applications;
- ability to select the data model according to the requirements;
- orientation in real-time data processing;
- understanding of the basic streaming algorithms.

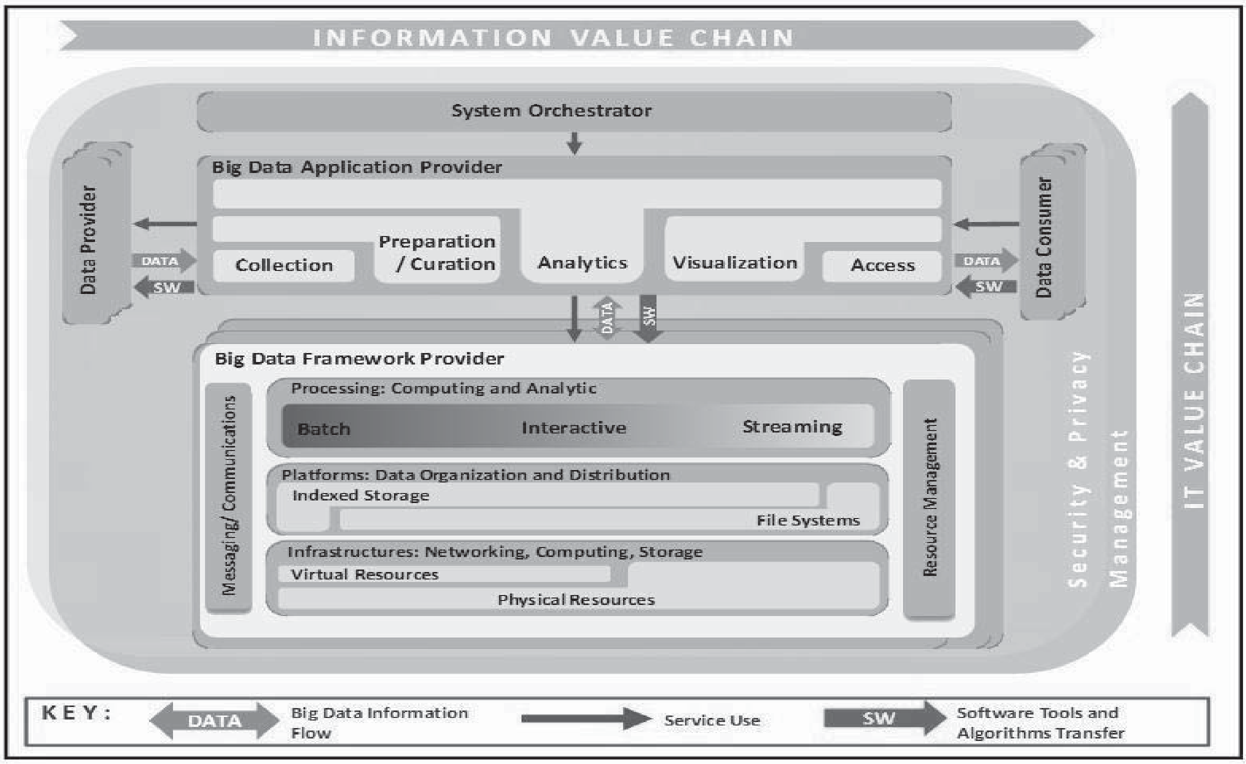

Fig. 4. Big Data Reference Architecture – NIST [42]

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