Survey on Internet of Things Architecture

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Outline

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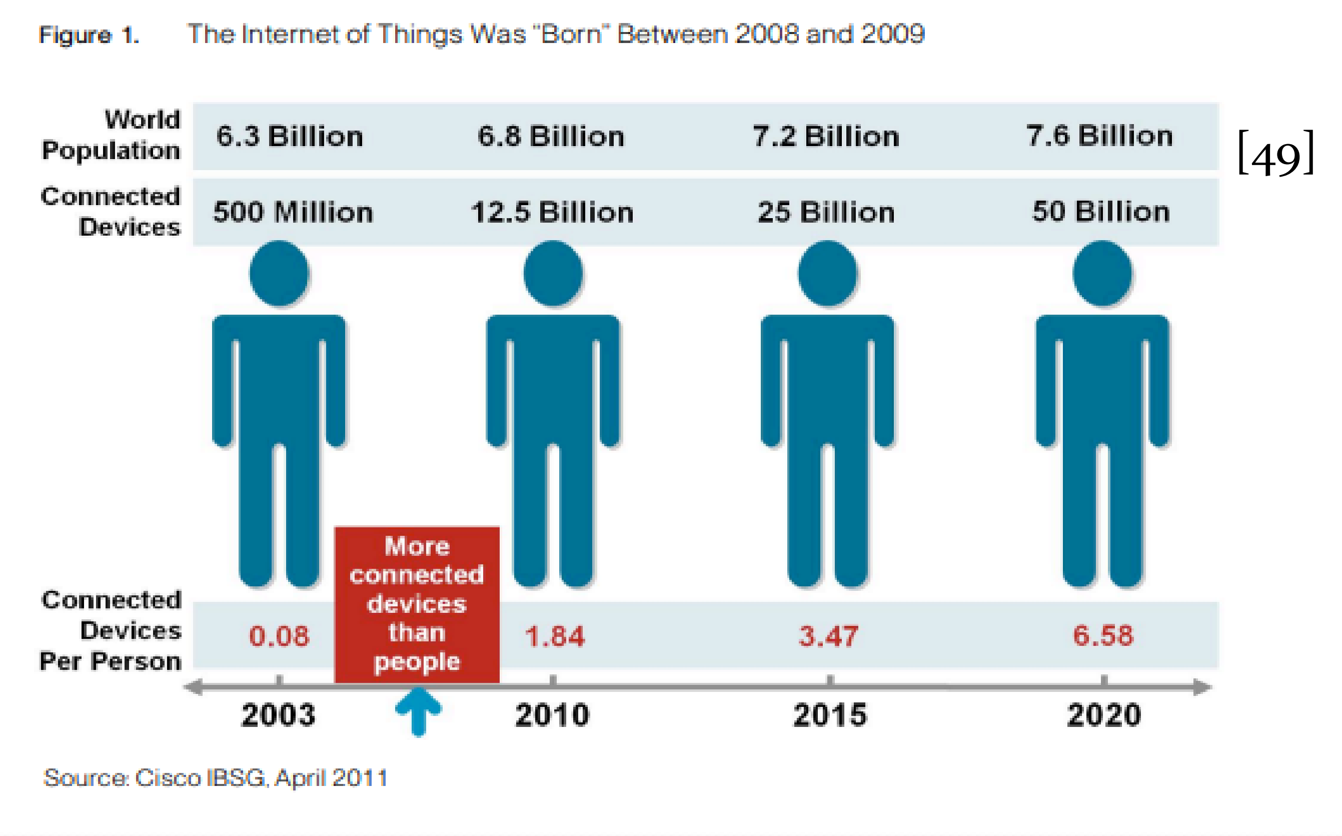
Introduction

- Internet of Things (IoT): Global infrastructure of interconnected physical and virtual elements sharing interoperable information and communication technologies [5]
- 'IoT' term, first devised in 1999 by Mr. Kevin Ashton, one of the co-founders and an executive director of the Auto-ID Center at Massachusetts Institute of Technology (MIT) [3]

Research Motivation

- 50 billion IoT devices within the year 2020



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Research Motivation

- Turing lecture at ISCA 2018 by 2017 A.C.M. Turing award winners, Prof. John L. Hennessy and Prof. David A. Patterson [29]
- Lecture on the need of fundamental changes in the Instruction Set Architecture (ISA) to service heterogeneous IoT devices [29]
- Upcoming Golden Age of Computer Architecture with focus on cost, performance, energy and security [29]

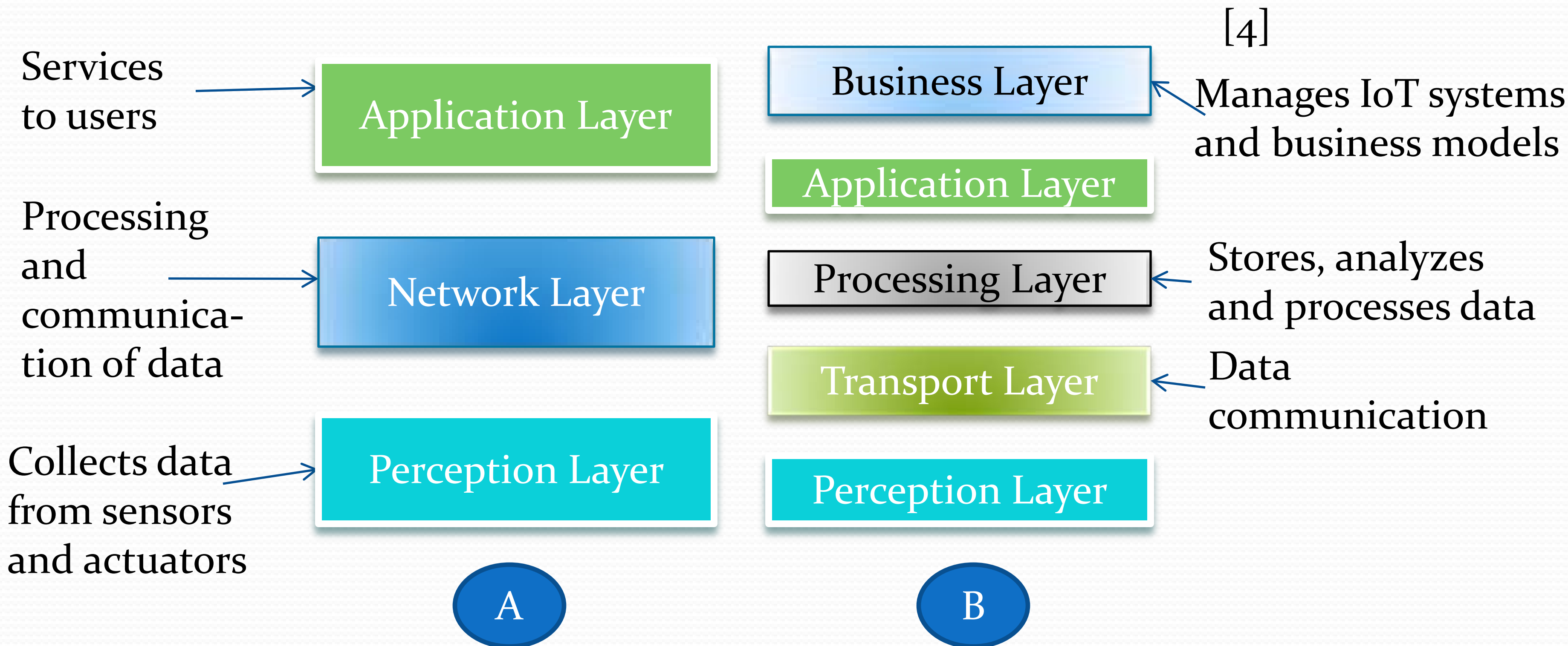
Paradigms of IoT

- Internet-oriented: Focus on the middleware [2]
- Things-oriented: Focus on integrating generic objects like RFID (radio frequency identification), sensors and actuators on a common framework [2]
- Semantics-oriented:
  - Focus on the unique addressing of generic objects and about the storage and information of exchanged data [2]
  - Support to different devices, clouds or gateways by being compatible to their standardization initiatives [2],[12]

IoT Architecture Components

- Hardware: Sensors and actuators for embedded communication [1]
- Middleware: It stores on demand and carries out data analysis [1]
- Presentation: It ensures easy presentation and visualization of the architecture [1]

IoT Architecture Layers



A: Basic IoT Architecture

B: Domain-specific IoT Architecture e.g. RFID [5], Cloud or Fog-based Architecture [4],[5]

IoT Architecture Layers (Another Representation)

- Device Access Layer: Device identification and communication [6]
- Device Management Layer: Control of devices using status information [6]
- Data Warehouse: Heterogeneous data [6]
- Behavior Management Layer: Satisfies commercial requirements [6]
- IoT Layer: Communication among objects [6]
- Service Integration Layer: Connecting users to their service [6]

Industrial IoT (IIoT) Architecture

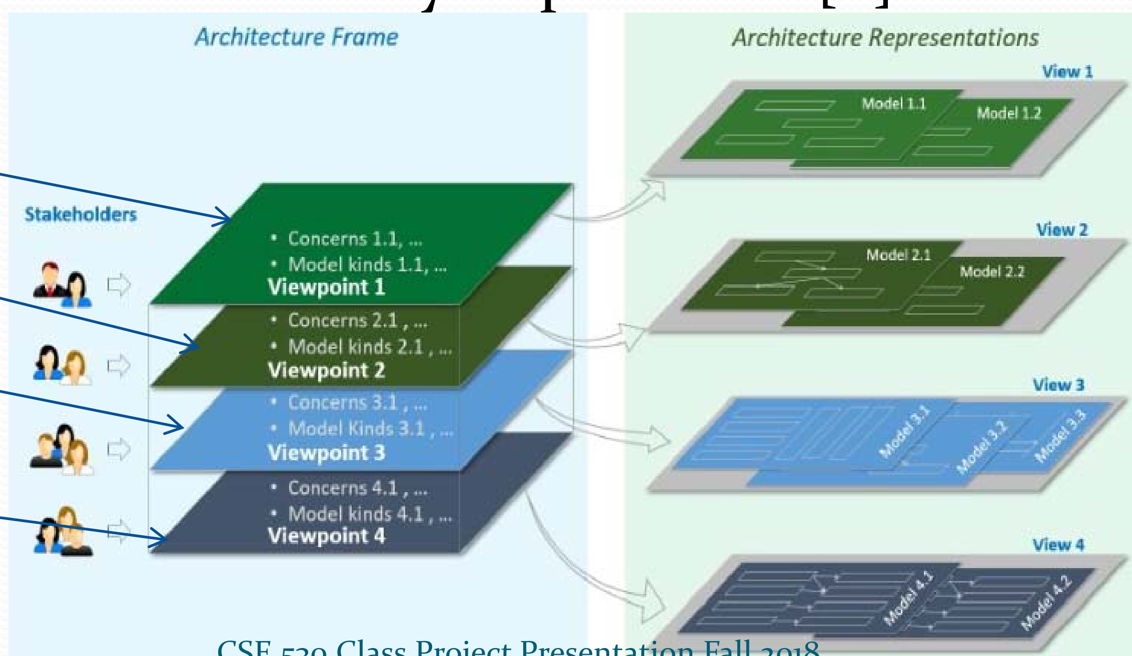
- Industrial Internet Reference Architecture (IIRA) [8]
- Viewpoint of stakeholders in the architectural framework [8]
  - Bound to the life-cycle processes [8]

Business

Usage

Functional

Implement-ation



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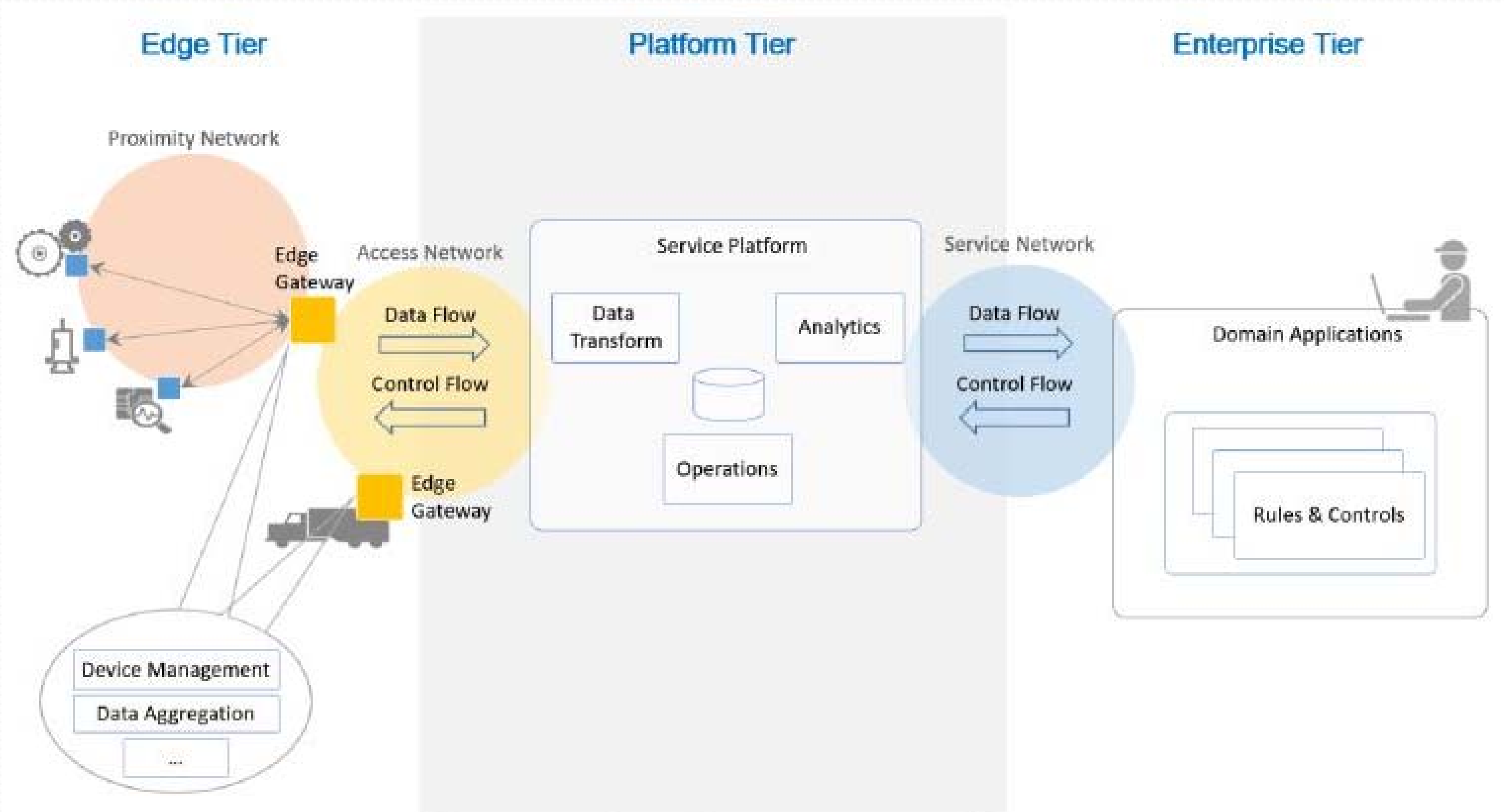
Tiered IIoT Architecture



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Security Concerns of IoT Architecture

- Centralized architecture [11]
- Single addressing format [11]
- Single addressing model [11]
- Appropriate Scalability [17]
- Distributed [37] and constrained [17] resources
- Heterogeneity [17]
- Interoperability [17]
- Latency constraints [17]
- Open network interfaces [12]
- Suitable recovery mechanisms in the architecture [9]

Goal of Secure IoT Architecture

- Absolute perception [35]
- Reliable transmission [35]
- Intelligent processing [35]

Secure Perception Layer of IoT Architecture

- Challenges
  - Differential Power Analysis [35]
  - Exposed endpoints [35]
  - Node capture, fake nodes and Denial of Service (DoS) [35]
  - Side Channel Attack (uses unnecessary time and power) [35]
- Solutions
  - Access control: Protects data in RFID tags and chips [35]
  - Protection from SCA: Hiding removes data dependencies of energy consumption. Masking randomizes the intermediate values in the encryption devices [35],[36]
  - Secure design and data encryption [36],[37]
  - Monitoring of IoT nodes for intruder detection [35]

Secure Network Layer of IoT Architecture

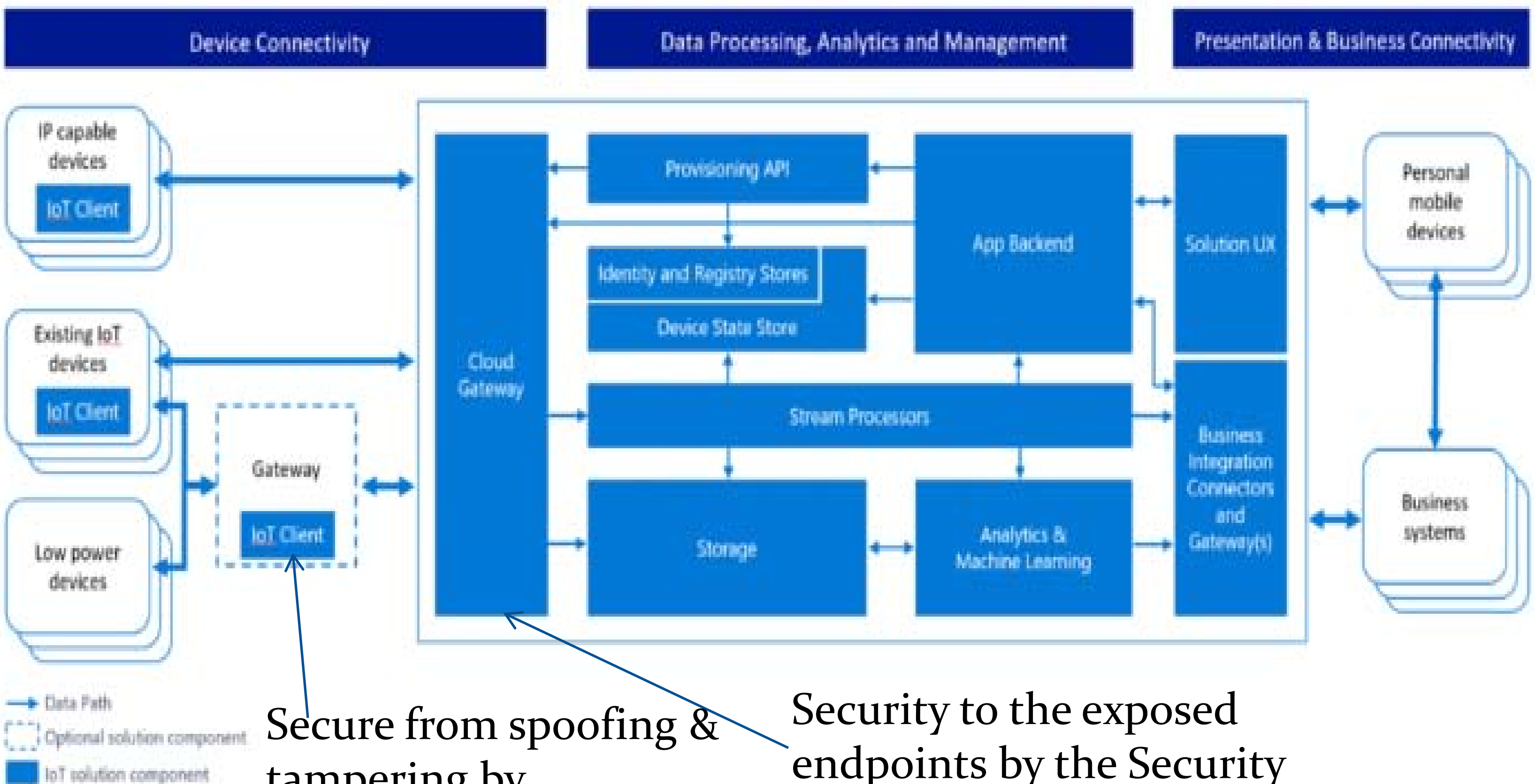
- Challenges
  - Compatibility among heterogeneous IoT devices [36]
  - Network congestion due to authentication in clusters [36],[37]
  - Sinkhole attack: Connection to a compromised IoT device [38]
  - Wormhole attack: Connection to 2 malicious colluding nodes [38]
- Solutions
  - Proper authentication [36]
  - Public-key infrastructure [36]
  - Security routing (e.g. onion routing) [36]
  - Network virtualization [36]

Secure Application Layer of IoT Architecture

- Challenges
  - Spurious data attacking user access and identification [35]
  - Improper mass node management [35]
  - Software vulnerabilities due to non-structured programming [35]
- Solutions
  - Heterogeneous network authentication [35]
  - Digital watermarking [35]
  - Information security management [35]

Microsoft Azure IoT Security Architecture

[34]



Secure from spoofing & tampering by encryption

Security to the exposed endpoints by the Security Development Lifecycle

Challenges of Power in IoT Architecture

- High power consumption during communication [12]
- Discontinuous power supply to all devices [9]
- Energy dimensioning among IoT devices based on user requirements [22]
- Increase in scale leading to more energy consumption [40]
- Uncertain reliability of IoT applications due to energy harvesting [19]

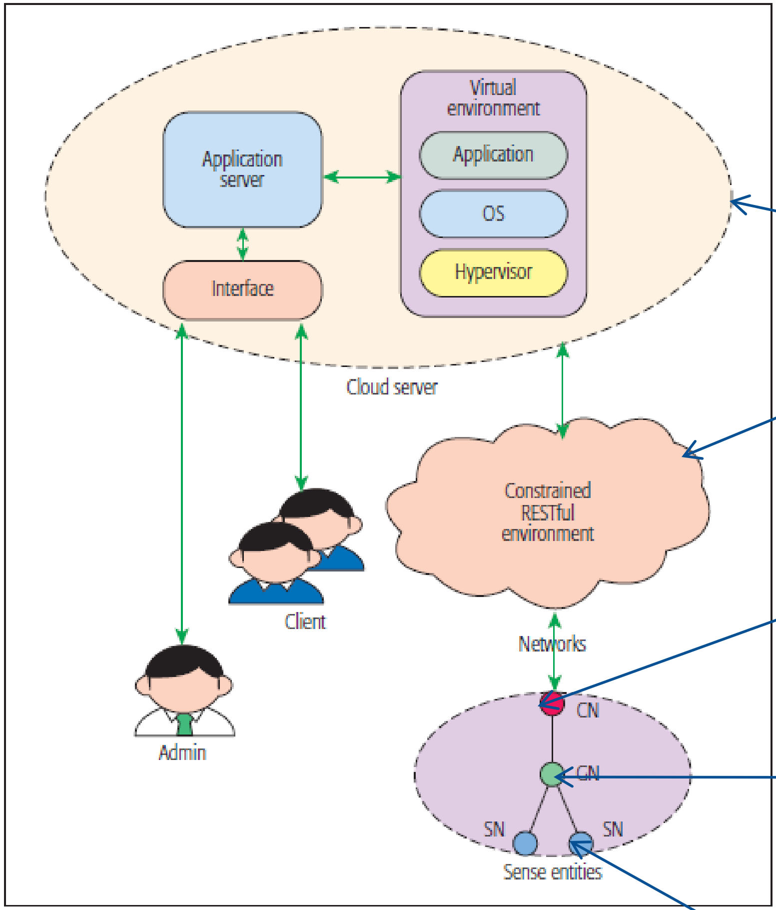
Other Challenges to Power Efficient IoT Architecture

- High quality of processed information if more data is harvested at shorter sleep intervals but at the cost of spending more energy [42]
- Overlap of coverage area of sensors controlling their power consumption[42]

Re-usable IoT Architecture

- Energy profiling of reusable components in IoT software architecture [20]
- Selection of the energy-efficient components [20]
- Smart IoT framework [21]
  - Location-based automated and networked energy control [21]
  - Scale of energy used proportional to the area of application [21]

Energy-efficient IIoT Architecture



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Improves processing

Switches the nodes to sleeping and waking up mode based on the requirement

Control nodes

Gateway nodes: Forward the data to the cloud servers -> alters state of SNs for efficient energy consumption

Sense nodes: Transfers data to Gateway nodes

Optimized Design of the IoT Architecture

- Modular design of nodes to save power [41]
- Computing capacity and elasticity of the cloud to satisfy the energy requirement also on the service-side [41]
- Power management unit per IoT node removes the standby energy of the system when individual nodes are not being used [41].
- Customization of the gateway architecture by combining the functionality of a general purpose microprocessor with an extremely low power controller [41]
- Connectionless protocols in the gateways of the IoT architecture will decrease the consumption of power due to data transmission [41]
- Only the radio module has to be kept switched on always as the microcontroller can wake up once a packet arrives to the radio module and the microprocessor can stay switched off unless data collection is being done [41]
- Shortcoming:- The gateway may not always be available for reconfiguration from the Internet side [41]

Wireless Energy Harvesting of IoT Devices

- Prolonged battery longevity of these devices [43]
- Energy source not dependent on the environment [43]
- WEH unit in PMU harvests radio frequency energy [43]
  - High efficiency wireless energy harvesting rectifiers with low power wake-up radio transceivers in the WEH unit [43]
- Wake-up radio scheme for radio transceivers: Receiver switches between the listening and sleeping states by duty-cycling based on requirements [43]
- Architecture of PMU able to detect and pre-empt node failure [43]

Ubiquitous IoT Architecture

- Similar to social organizational framework [44]
- Co-operative services based on low-power wireless personal area networks (WPANs) of sensors and actuators and RFID systems reduce the energy consumption of wireless devices [43],[44]

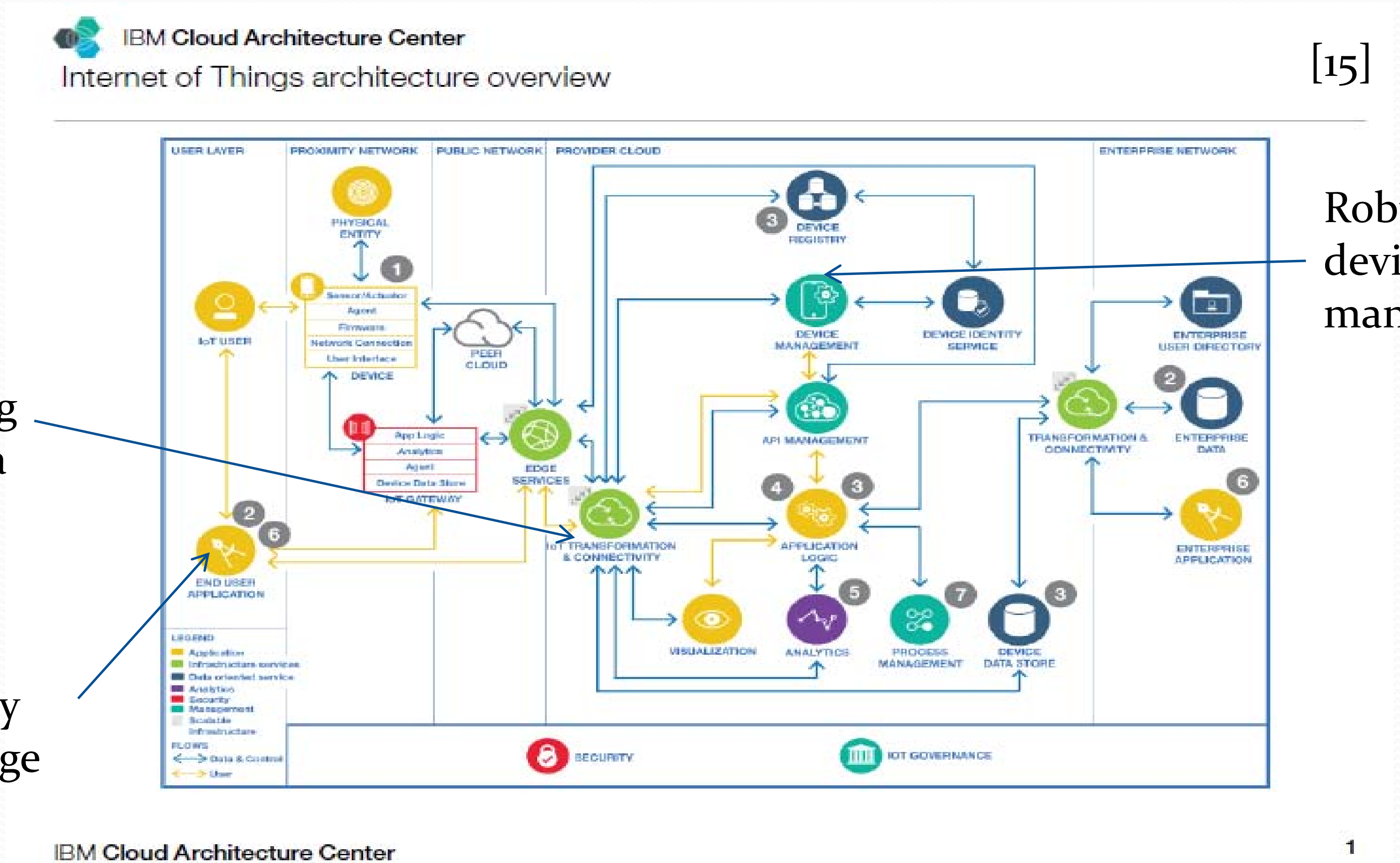
Integration and Interconnection of Devices and Services

- Components of IoT architecture and cloud computing to be integrated for improved scalability & processing
  - Batch processing [13]
  - Distributed databases: Interconnection of multiple data centers [13]
  - Real time processing [13]
  - Distributed queries [13]
  - Cluster deployment and management [13]

Efficient Architecture for Integration

- Unifying Sensing Platform (USP): Seamless integration of many dissimilar objects efficiently in a reusable and context aware way [5]
- USP architecture: Stratified into the sensor framework, resource framework, observation framework and context framework [5]
- Efficient sensor-oriented usage is ensured by the control methods using contextual observations towards the upper level of applications [5]

IBM IoT Architecture



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Robust device management

Easy sharing of data

Easy usage

Micro-services Architecture

- Deployment of services independently [14]
- Atomicity of services [14]
- Resilience to single point failure [14]
- Synchronization of IoT services [14]
- Security transaction management [14]

Other Challenges of IoT Architecture

- Scalable architecture [9], [12]
- Support of multi-tenancy [9]
- Support to complex dependencies [9]
- Resilience [9]: Can be supported by redundancy in the IoT architecture [12]
- Flexibility to user requirements [12]
- Mobility of IoT services [12]: Solved by caching and tunneling [12]
- Mapping of virtual resources to shared physical infrastructure [9]

Predictive Analytics to IoT Architecture

- Significant role in IIoT architecture [24]
- Collection of by conditions monitoring [24]
- Estimation is done by machine learning techniques
  - Polynomial regression to find the upper limit of the confidence band to fit the non-linear data [24]
  - Lower limit is estimated by linear regression [24]
- Challenging implementation of the neural architecture across different IoT devices and systems

Scalable IoT Architecture in Blockchain

- Distributed access control system for IoT built using the blockchain technology [26]
- Bitcoin: One of the first applications of peer to peer trustless electronic cash [26]
- Block chain: A secure distributed database which is the ledger of bitcoins [26].
- Management hub obtains control data from the blockchain for the IoT devices [26]

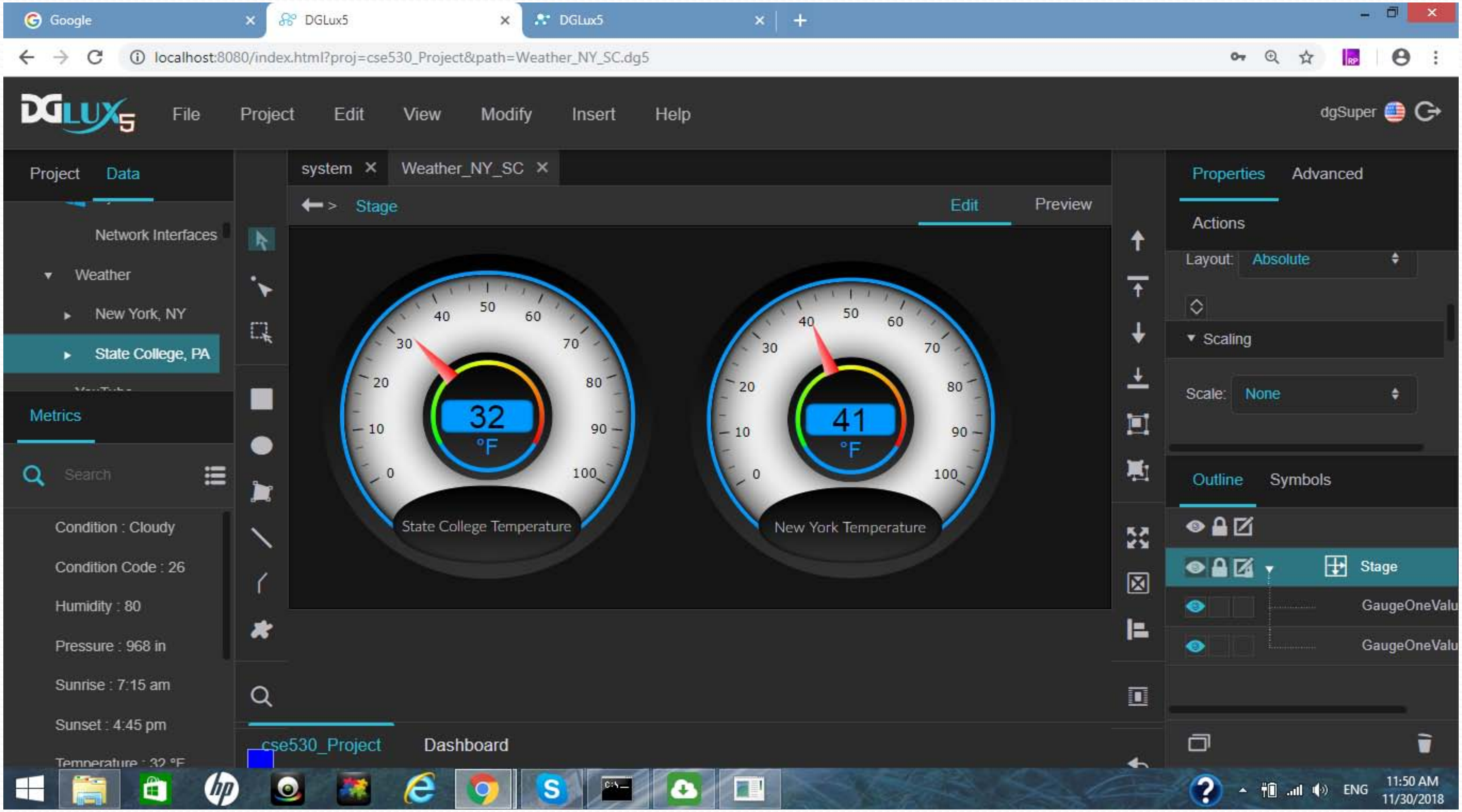
Pros and Cons of Scalable IoT Architecture in Blockchain

- Overcomes the limitations of centralized access management models which have technical problems in global management [26]
- Fully decentralized architecture and scalable in specific IoT scenarios [26]
- Facilitates easy integration of the IoT systems [26]
- Limitations of crypto-currency fees and processing tines [26]

Distributed Services Architecture

- Three components [48] which are:
  - DSA-Broker routing the incoming and outgoing data streams [48]
  - DSLinks connecting the DSA-Broker and originate the data-streams on the same machine or on distributed machines [48]
  - nodeAPI which ensures communication among DSA nodes and maintains node compatibility along with bidirectional control and monitoring among connected components [48]
- Distributes functionality among different computational utilities for architecting IoT based products [48].

Illustration of DSA



Future Work

- Development of a new Instruction Set Architecture is needed to service heterogeneous applications
- Challenges to security, energy, scalability, integration and interconnection of the components of the IoT architecture needs to be addressed.
- More detailed review of the publications and study of new papers in new workshops and symposiums of IoT under the noted ISCA and Microarch conferences [22], [27], [29], [31]
- More experimentation on the tools should be done to understand the scalability effects on the architecture with a large number of IoT devices.

Conclusion

- Idea of the salient issues in IoT architecture with increasing application of IoT like analytics of social media data across IoT devices and studying real time weather in remote places to name a few
- Increasing number of smart devices point out the unavoidable requirement of improving the efficiency of the IoT architecture
- More optimizations are required in the access management, security, power consumption and new ISA to improve the efficiency of IoT architecture

References

1. J. Gubbi, R. Buyya, S. Marusic and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions" by, Future Generation Computer Systems, Volume 29, Issue 7, September 2013, pages 1645-1660,
DOI: https://doi.org/10.1016/j.future.2013.01.010

2. L. Atzori, A. Iera and G. Morabito, "The Internet of Things: A survey", Computer Networks: The International Journal of Computer and Telecommunications Networking, Volume 54, Issue 15, October 2010, pages. 2787-2805,
DOI: 10.1016/j.comnet.2010.05.010

3. That 'Internet of Things' Thing by Kevin Ashton, https://www.rfidjournal.com/articles/view?4986

4. P. Sethi and S. Sarangi, "Internet of Things: Architectures, Protocols, and Applications", Journal of Electrical and Computer Engineering, Volume 2017, Article ID 9324035, 2017, 25 pages DOI:https://doi.org/10.1155/2017/9324035

5. P.P. Ray, "A survey on Internet of Things architectures", Journal of King Saud University - Computer and Information Sciences, Volume 30, Issue 3, July 2018, pages 291-319,
DOI: https://doi.org/10.1016/j.jksuci.2016.10.003

6. https://www.alibabacloud.com/blog/the-building-blocks-of-an-iot-architecture_593731

References

7. Intel IoT Platform Reference Architecture https://www.intel.in/content/www/in/en/internet-of-things/white-papers/iot-platform-reference-architecture-paper.html

8. IIC: Industrial IoT Reference Architecture
https://iiot-world.com/connected-industry/iic-industrial-iot-reference-architecture/

9. R. Alur, E. Berger, A. W. Drobnis, L. Fix, K. Fu, G. Hager, D. Lopresti, K. Nahrstedt, E. Mynatt, S. Patel, J. Rexford, J. Stankovic and B. Zorn, "Systems Computing Challenges in the Internet of Things", White paper at Computing Community Consortium (CCC), April 2016, arXiv:1604.02980

10. I. Lee and K. Lee, "The Internet of Things (IoT): Applications, investments, and challenges for enterprises", Business Horizons Journal, Volume 58, Issue 4, July-August 2015, pages 431-440,
DOI: https://doi.org/10.1016/j.bushor.2015.03.008

11. IoT architecture Factsheet
https://www.scribd.com/document/356485436/2InternetofThingsFactsheetArchitecture-pdf

12. A. Gill, V. Behbood, R. Ramadan-Jradi and G. Beydoun, "IoT Architectural Concerns: A Systematic Review", Proceedings of the Second International Conference on Internet of things, Data and Cloud Computing (ICC '17), Article No. 117, Cambridge, United Kingdom, March 2017,
DOI: 10.1145/3018896.3025166

References

13. M. Díaz, C. Martín and B. Rubio, "State-of-the-art, challenges, and open issues in the integration of Internet of things and cloud computing", Journal of Network and Computer Applications, Volume 67, Issue C, May 2016, pages 99-117,
DOI:10.1016/j.jnca.2016.01.010

14. O. Uviase and D. Kotonya, "IoT Architectural Framework: Connection and Integration Framework for IoT Systems", D. Pianini and G. Salvaneschi (Eds.): First workshop on Architectures, Languages and Paradigms for IoT EPTCS 264, 2018, pages 1–17, DOI:10.4204/EPTCS.264.1

15. Internet of Things for insights from Connected Devices
https://www.ibm.com/cloud/garage/architectures/iotArchitecture/0_1

16. H. Lin and N. Bergmann, "IoT Privacy and Security Challenges for Smart Home Environments", Information Journal, Special Issue on Preserving Privacy and Security in IoT, Volume 7, Issue 3, Article No. 44,
DOI: https://doi.org/10.3390/info7030044

17. C. Bekara, "Security Issues and Challenges for the IoT-based Smart Grid", Procedia Computer Science, Volume 34, 2014, pages 532-537, DOI: 10.1016/j.procs.2014.07.064

18. IoT Security Reference Architecture
https://www.symantec.com/content/dam/symantec/docs/white-papers/iot-security-reference-architecture-en.pdf

References

19. B. Martinez, M. Montón, I. Vilajosana, and J. Daniel Prades, "The Power of Models: Modeling Power Consumption for IoT Devices", IEEE Sensors Journal, 15(10), pages 5777-5789, October 2015, DOI: 10.1109/JSEN.2015.2445094

20. D. Kim, J. Choi and J. Hong, "Evaluating energy efficiency of Internet of Things software architecture based on reusable software components", International Journal of Distributed Sensor Networks, 2017, https://doi.org/10.1177/1550147716682738

21. J. Pan, R. Jain, S. Paul, T. Vu, A. Saifullah and M. Sha, "An Internet of Things Framework for Smart Energy in Buildings: Designs, Prototype, and Experiments", IEEE Internet of Things Journal, 2015, DOI: 10.1109/JIOT.2015.2413397

22. The 54th Issue (Volume 15, Number 2) Special Issue on Advances in IoT Architecture and Systems (AioTAS'17) (5/2018) in ACM SIGBED Review (ISSN: 1551-3688) (Special Interest Group on Embedded System)
http://sigbed.seas.upenn.edu/vol15_num2.html

23. Cloud Customer Architecture for IoT https://www.omg.org/cloud/deliverables/cloud-customer-architecture-for-iot.htm

24. https://www.datascience.com/blog/predictive-analytics-in-industrial-iot

References

25. Architecture for IoT applications https://medium.com/@maheshwar.ligade/architecture-for-iot-applications-d50ece031d38

26. O. Novo, "Blockchain Meets IoT: An Architecture for Scalable Access Management in IoT", IEEE Internet of Things Journal, Volume 5, Issue 2, May 2018, pages 1184-1995,
DOI: 10.1109/JIOT.2018.2812239

27. http://comparch-conf.gatech.edu/iot15/

28. https://techbeacon.com/67-open-source-tools-resources-iot

29. http://iscaconf.org/isca2018/turing_lecture.html

30. https://en.wikipedia.org/wiki/Internet_of_things

References

31. https://sites.google.com/view/aiotas2018/

32. M. Weiser, R. Gold, and J. S. Brown, "The origins of ubiquitous computing research at PARC in the late 1980s", *IBM Systems Journal, Volume* 38, Issue 4, December 1999, pages 693-696. DOI: http://dx.doi.org/10.1147/sj.384.0693

33. C. Zavazava, "ITU work on Internet of things", Presentation at Workshop on Scientific Applications for the Internet of Things, at International Centre for Theoretical Physics (ICTP), March 2015.
http://wireless.ictp.it/school_2015/presentations/secondweek/ITU-WORK-ON-IOT.pdf

34. https://docs.microsoft.com/en-us/azure/iot-fundamentals/iot-security-architecture

35. K. Zhao and L. Ge, ", A Survey on the Internet of Things Security", 2013 Ninth International Conference on Computational Intelligence and Security, December 2013, pages 663-667
DOI: 10.1109/CIS.2013.145

36. R. Weber, " Internet of things: Privacy issues revisited", Computer Law and Security Review, Journal, Volume 31, Issue 5, October 2015, pages 618-627,
DOI: https://doi.org/10.1016/j.clsr.2015.07.002

References

37. M. Conti, A. Dehghantanha, K. Franke and S. Watson, " Internet of Things security and forensics: Challenges and Opportunities", Future Generation Computer Systems Journal, Volume 78, Part 2, January 2018, pages 544-546, DOI: https://doi.org/10.1016/j.future.2017.07.060

38. Jie Lin, Wei Yu, Nan Zhang, Xinyu Yang, Hanlin Zhang, and Wei Zhao , "A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications", IEEE Internet of Things Journal, Volume 4, Issue 5, October 2017, pages 1125-1142, DOI: 10.1109/JIOT.2017.2683200

39. https://www.microsoft.com/en-us/sdl

40. K. Wang, Y. Wang, Y. Sun, S. Guo and J. Wu, "Green Industrial Internet of Things Architecture: An Energy-Efficient Perspective", IEEE Communications Magazine, Volume 54, Issue 12, December 2016, pages 48-54,
DOI: 10.1109/MCOM.2016.1600399CM

41. A. Perles, E. Pérez-Marín, R. Mercado, J. Damian Segrelles, I. Blanquer, M. Zarzo and F. Garcia-Diego, " An energy-efficient internet of things (IoT) architecture for preventive conservation of cultural heritage", Future Generation Computer Systems Journal, Volume 81, April 2018, pages 544-546,
DOI: https://doi.org/10.1016/j.future.2017.06.030

42. N. Kaur and S. Sood, " An Energy-Efficient Architecture for the Internet of Things (IoT)", IEEE Systems Journal, Volume 11, Issue 2, October 2015, pages 796-805,
DOI: 10.1109/JSYST.2015.2469676

References

43. P. Kamalinejad, C. Mahapatra, Z. Sheng, S. Mirabbasi, V. Leung and Y. Guan, "Wireless energy harvesting for the Internet of Thing", IEEE Communications Magazine, Volume 53, Issue 6, June 2015, pages 102-108, DOI: 10.1109/MCOM.2015.7120024

44. L. Atzori, A. Iera, G. Morabito and M. Nitti, "The Social Internet of Things (SIoT) – When social networks meet the Internet of Things: Concept, architecture and network characterization", Volume 56, Issue 16, November 2012, pages 3594-3608, DOI: https://doi.org/10.1016/j.comnet.2012.07.010

45. http://iot-dsa.org/get-started/download-dsa

46. https://stackoverflow.com/questions/39632667/how-to-kill-the-process-currently-using-a-port-on-localhost-in-windows

47. https://www.youtube.com/watch?v=x3JMquRp6BA

48. http://iot-dsa.org/get-started/how-dsa-works

49. https://www.cisco.com/c/dam/en_us/about/ac79/docs/innov/IoT_IBSG_0411FINAL.pdf

Thank You