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The Wild World of Wireless in the 2020s – What do we Need to be Teaching?

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The Wild World of Wireless in the 2020s –

What do we need to be teaching?

Abstract

Today, a Google search of the Internet of Things (IoT) routinely yields upwards of 5 billion hits. Even if the average person doesn't know what the IoT entails, they have probably heard this newly coined term at some point during recent times. Likewise, a Google search of wireless technology commonly yields over a billion hits. The relationship between the two: most of the IoT applications recently implemented and those conceived/planned for future deployment depend upon wireless connectivity. Predictions by IoT Analytics are that less than 10% of future IoT apps will be of the wired variety! The average technology savvy individual would probably believe that the other 90% would be provided wirelessly by either cellular or Wi-Fi technology. They would most likely be mistaken!

IoT applications are planned for almost all sectors of the economy mainly in the operational technology (OT) space. However, these various application sectors bring with them their own particular wireless connectivity challenges. Advanced manufacturing touts Industry 4.0 or the industrial IoT (IIoT) but the typical factory floor presents an extremely harsh environment for present day wireless data systems. e-healthcare is the future of medicine in both clinical and home settings but interference from other IT oriented data services is extremely undesirable. The automobile industry is rapidly introducing new vehicle safety features that are based on cyber-physical systems with the ultimate goal of vehicle-to-everything (V2X) wireless communications to achieve the most reliable accident-avoidance safety systems. However, the congested highway environment with bumper-to-bumper traffic and a need for extremely low-latency for this type of application brings complexities that present-day wireless systems cannot deal with. Other IoT applications with geographically dispersed extremely low power, battery operated remote sensors present further wireless system problems.

This paper will attempt to answer the following: At the two-year college level, how should these wireless technologies be taught, to what level, and by whom? To get to the answer to these questions, I will look at the application areas, examine the available technologies and make a prediction of which technologies might be employed by which application area. That said, I will attempt to estimate the need for various wireless technology skill sets and the need for field technicians to deal with the various application spaces. There are some common skills that technicians for all application areas should have but with today's throwaway technology an intimate knowledge of the wireless hardware and its operation are not high on the list. Today, as with most technicians involved with applications implemented with electronics hardware, their job is not to repair the particular hardware unit but to ascertain whether or not the unit is operating correctly and take actions to replace faulty hardware or reprogram a faulty unit caused by a software fault. Presently, the curricula need appears to be more on a course or module level as opposed to a certificate of entire program in wireless.

Introduction

As we enter the 2020s, most technology observers are well aware of the tremendous growth and accompanying use of the Internet by people all over the world. The Internet has facilitated a dramatic change in how we live, work, and play. This has never been made more obvious to us than by the circumstances brought on by the COVID-19 pandemic. The entire world has embraced remote work and online schooling in our quest to keep people safe and from spreading this deadly disease. None of these recent dramatic life style changes would have been possible without the technical advances that have taken place since the turn of the century two decades ago. Today, if one does a Google search of the Internet, one typically gets over 5 billion hits. A Google search of the Internet of Things (IoT) will also yield over 5 billion hits due to the high interest in this predicted next big application of the Internet. Likewise, a Google search of wireless technology commonly yields over a billion hits. There is a very high correlation between wireless technology and all things Internet centric. In fact, the only other technology that has matched the world-wide growth of the Internet is cellular telephone technology. Today, more people access the Internet wirelessly from a mobile platform than those that use their PC to do so [1]. To be sure, advances in PC and smartphone hardware and software technology (memory capacity, operating system improvements, display and camera technology, etc.) coupled with Internet access speeds have driven our acceptance and reliance on the Internet. But, to most consumers, the concept of mobility has been the key transformative technology. This mobility paradigm, implemented through wireless technology, is most likely going to be the driving force behind the next generation of Internet applications.

Wireless is not a new technology. It has been with us for well over one hundred years. For a great deal of that time period, it was known as radio and was used to provide human-to-human communications and entertainment and news through the concept of broadcasting (AM and FM technologies). One of the predecessor organizations to the Institute of Electrical and Electronics Engineers (IEEE) was the IRE, the Institute of Radio Engineers, that existed from 1912 to 1962! Cellular technology was introduced in the United States in 1983 using standard FM technology but it wasn't until the third generation (3G) of cellular technology (circa 2000) that we had the real start of data transmission available to the masses (albeit at rather slow rates) over our cellular networks [2]. With the arrival of the fourth generation (4G) of cellular there has been no turning back. As humans living in civilized society, the world's people have embraced wireless technology in all forms. We have now deployed 5G cellular with even faster data rates and new IoT application capabilities and are already actively discussing the next generation of cellular, 6G, for deployment in the 2030s. At the same time, there have been other wireless networking technologies developed and deployed all over the world. The IEEE wireless technologies are the most well known but there are many others that have been developed for various niche application spaces as well as variations of cellular signal formats for specific low-data rate applications. These non-cellular wireless systems have also been developed for various perceived markets/application spaces that need wireless data/networking connectivity. In the free market, which wireless technologies grab the biggest market share and proliferate is up to the consumers of these various technologies. Today, the wireless networking space is one of the fastest changing technology areas and there is no reason to think that it will slow down anytime soon.

A Potential Problem

For most newly emerging technologies a new or upgraded technical workforce is needed to deal with issues surrounding the implementation, installation, maintenance, and upgrading of installed systems in the "field" (i.e. a wireless networking or IoT field service technician). This would seem to be especially necessary today for wireless networking systems given the rapid transformation of this particular field. Since an AS degree is typically associated with the work title of technician, it would seem to be sensible to train workers for the wireless networking industry at the two-year college level. However, one has to ask the question, "is this necessary"? To try to ascertain the answer to this question one should examine use cases for wireless networking systems. Let's start with some familiar territory. Today, most high-speed Internet is delivered over cable networks [3] with the cable modem delivering high-speed Wi-Fi to the residents of the household or apartment. The user's device only needs to look for available wireless networks, provide a passcode for the correct wireless access point and the operating system (OS) of the device will take care of making the connection automatically and in the future (unless something changes with the wireless system). What could be easier? No high-level skill set needed at all. But this use case is for the classic human user Internet connection. By the way, if the wireless networking hardware has any problems the Xfinity or AT&T or Charter cable technician will show up at your door and replace the defective wireless unit! No need for a wireless networking technician! But what about the next big Internet application area – the Internet of Things? Let's examine this use case with some market predictions. Figure #1 below from IOT Analytics indicates the number of IoT devices (in billions) and non-IoT devices that are expected to be connected to the Internet by 2025 [4].

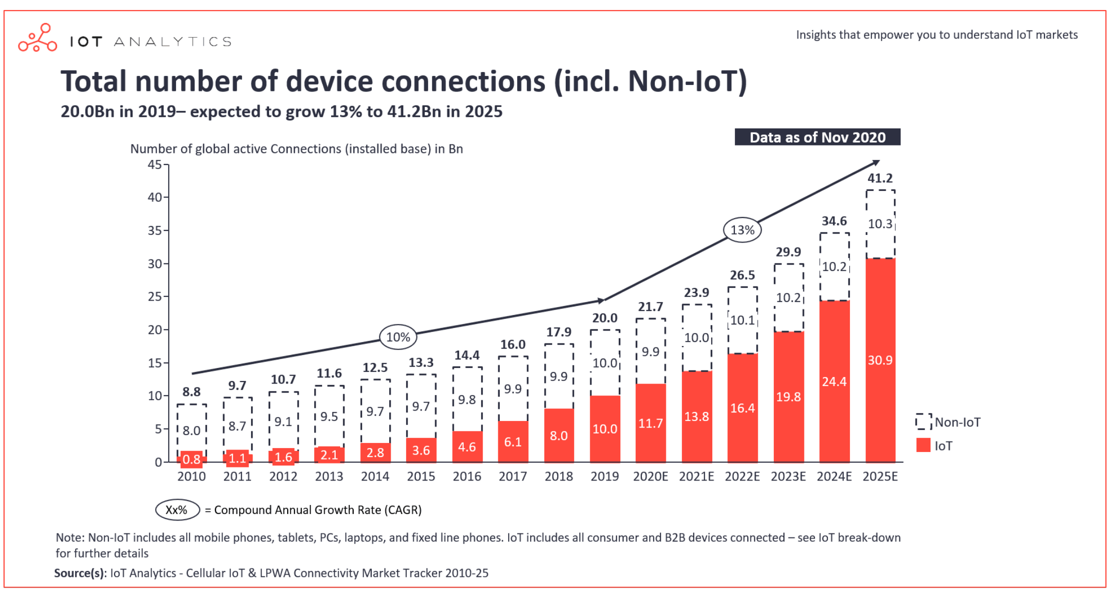

Figure #1 – Global Number of Connected IoT Devices (From IOT Analytics)

As one can see from this chart, it is predicted that over 30 billion IoT devices will be connected to the Internet by the year 2025. Some have predicted more; some have predicted less. However, everyone predicts that this is just the start of this technology trend and they all predict hundreds of billions or trillions of devices only a few more years in the future after 2025. Also, it is useful to look at the anticipated industries/businesses that will employ these IoT devices. Figure 2 from IOT analytics displays information about the markets served by IoT platform vendors [5].

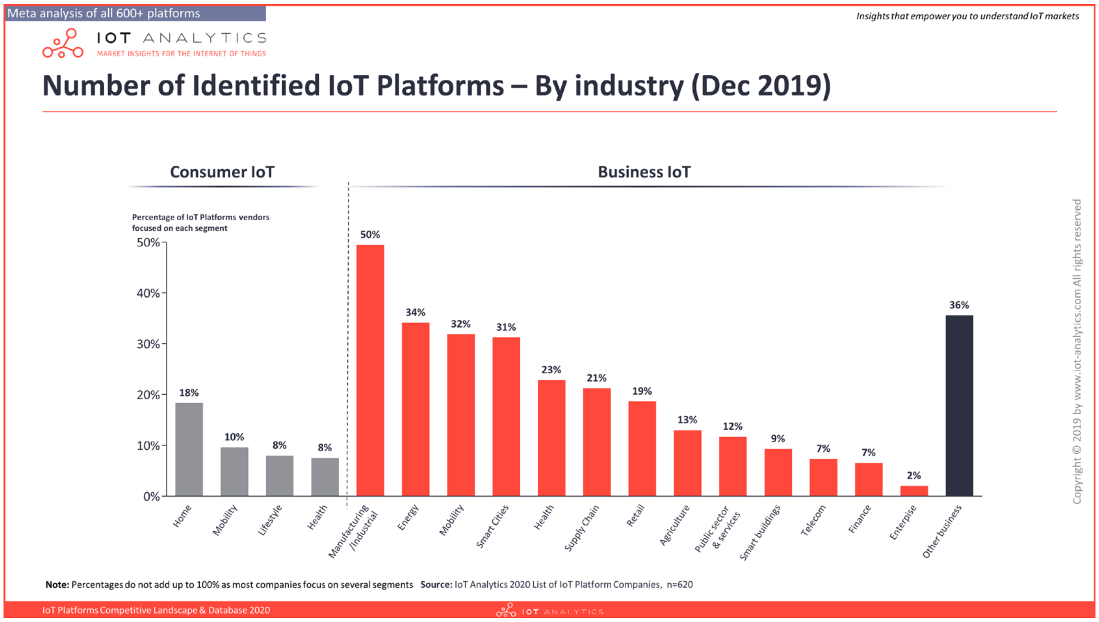

Figure #2 – Breakdown of Business and Consumer IoT Platform Market (From IOT Analytics)

It appears that most of the IoT platform vendors believe that the biggest market for their products is in the manufacturing/industrial space. One last chart, Figure #3 from IOT Analytics, shows the predicted networking technology expected to be used by the installed IoT devices [6].

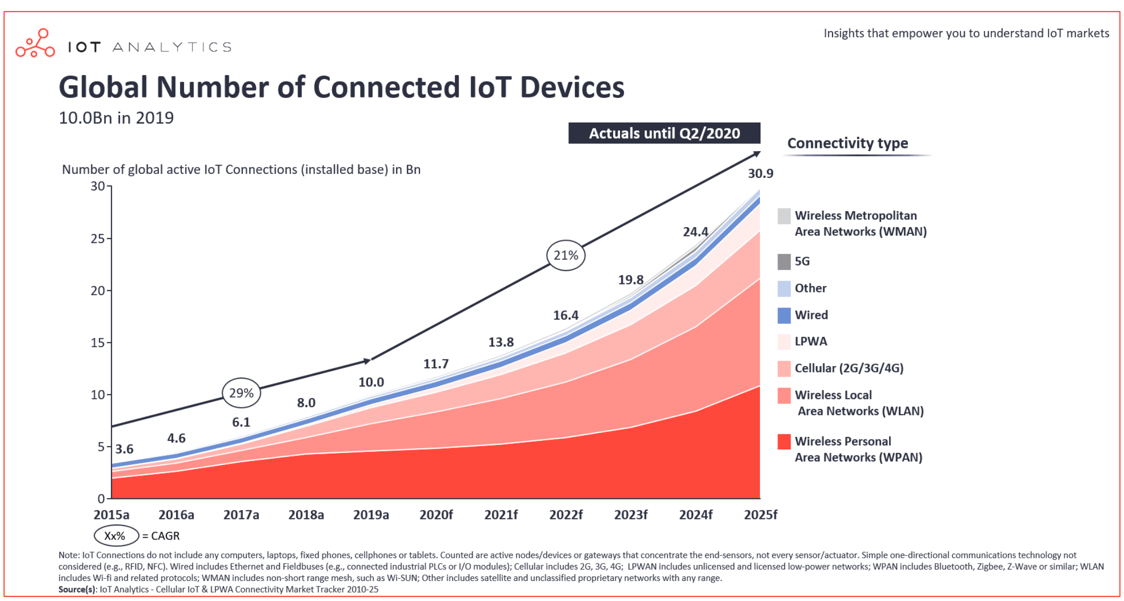

Figure #3 – Type of IoT Network Connectivity (From IOT Analytics)

This last figure is very telling in that the use of hard-wired networking connectivity is extremely small compared to wireless networking. So, putting this all together, one might predict that there will be hundreds of millions if not billions of devices connected to the Internet using numerous different wireless networking technologies. What does that tell us? Any curriculum coverage of wireless networks should be inclusive of the various types of wireless networking and also address the use cases that they were designed for. In all cases, the IoT devices will tend to be throwaway technology and thus there is little need to study radio hardware since it is highly uneconomical to repair such devices. They will typically either work correctly or go into a non-functioning state and need to be replaced.

Wireless Networking Applications

Figure #2 indicates that the application areas for IoT devices is extremely broad-based and could certainly be multidisciplinary in nature. This author has predicted, in agreement with Cisco, that in the future, depending upon the field, there will be a need for an IoT field technician [7]. Any such person should have some training in the particular field that the IoT application is being used in. For instance, an agricultural IoT use case requires some knowledge of topics germane to the agricultural industry while a smart building IoT use case should require some knowledge of building automation technology. It is debatable how much knowledge of the particular use case field is needed but most would agree that depending upon the field, a knowledge range from entry-level to technical expert might be desirable. Cisco has developed some curriculum for the IoT field [8] but seems to think that the Cisco trained networking technician will have the necessary skills from their networking academy experience to deal with wireless networking IoT issues. The problem with Cisco's philosophy is that they emphasis IT (i.e. business or enterprise) networking applications and don't address the very topic that IoT applications are being used for – that of operational technology or OT. For those readers who are unfamiliar with this term the following definition is fairly representative: ***operational technology*** or OT is a category of computing and communication systems to manage, monitor and control industrial operations with a focus on the physical devices and processes that they use [9]. OT is another catch-all term for indicating the use case(s) that the IoT application is addressing or acquiring data about.

The Cisco networking curriculum does address Wi-Fi but it is dated and not very technical (recall the skill set of the cable technician installing a cable modem mentioned previously). It emphasizes enterprise wireless applications of an IT nature. It leaves a great deal to be desired from this author's perspective. Cisco did have a wireless online course leading to a CCNP certification (replaced now by the CCNP Enterprise certification) but it was/is totally Wi-Fi centric [10]. The IEEE 802.11 standard, since its inception, has been continuingly updated by various industry/academic working groups to extend its areas of application as new uses are envisioned and brought to the marketplace. Recently, Wi-Fi has been relabeled with the use of a generation moniker as new frequency bands have been opened for Wi-Fi use (i.e. Wi-Fi 6 or IEEE 802.11ax). See Table 1 below. Cisco has not kept up with these newer versions of IEEE 802.11 since many of the new specialized application areas/spaces for Wi-Fi are not IT applications but instead are for different distance ranges, frequencies, and data rates as shown below in Figure #4.

TABLE 1: COMPARING WI-FI-5 AND WI-FI 6 STANDARDS		
Parameter	**Wi-Fi 5 (802.11ac)**	**Wi-Fi 6 (802.11ax)**
Frequency	5 GHz	2.4 and 5.0 GHz
Bandwidths (channels)	20, 40, 80+80, 160 MHz	20, 40, 80+80, 160 MHz
Access	OFDM	OFDMA
Antennas	MU-MIMO (4 × 4)	MU-MIMO (8 × 8)
Modulation	256QAM	1024QAM
Maximum data rate	3.5 Gb/s	9.6 Gb/s
Maximum users/AP	4	8

Table #1 – Comparison of WI-FI Generation 5 and WI-FI Generation 6

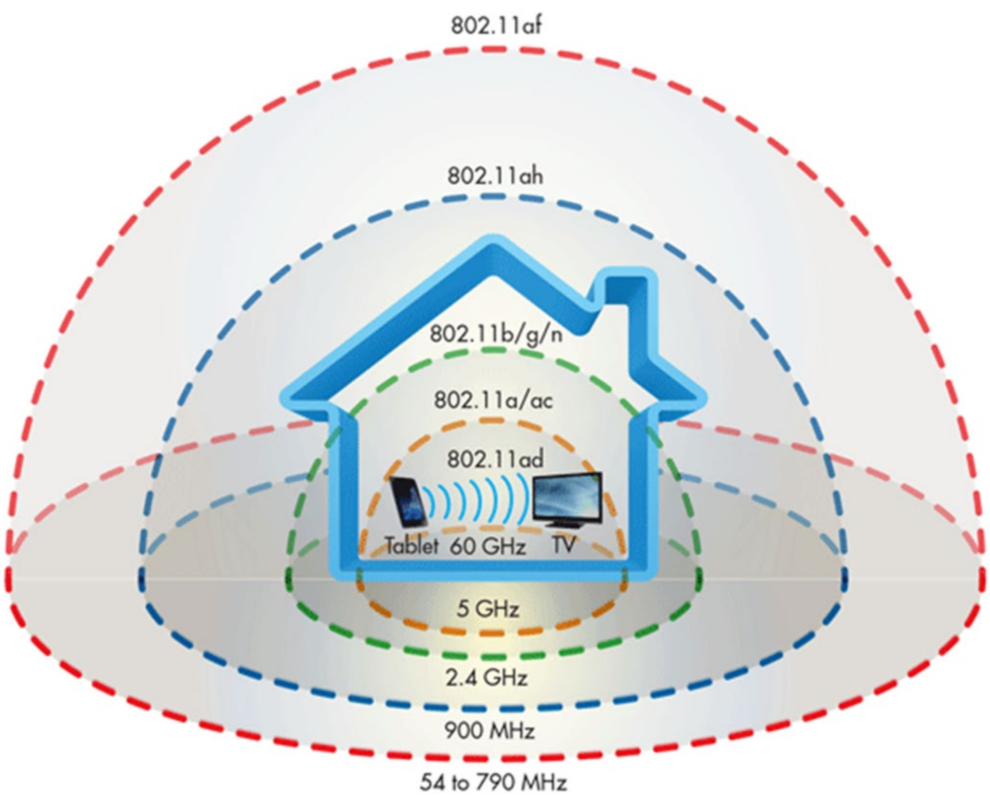

Figure #4 – Diagram of the many IEEE 802.11 extensions and their range

A Wireless Networking Course for Today's Technology

From this author's perspective, what needs to be taught about wireless networking technology is as follows. Either in module or course form, a list of topics from various sub-areas of the enabling technologies: basic computer networking, wireless system fundamentals, cellular technology fundamentals, IEEE wireless technologies, wireless PANs, LPWAN technologies, and a survey of electromagnetic propagation, transmission lines, and antennas. Depending upon a student's background the computer networking material might be omitted if they are already well versed in that area. The idea is not to provide a classic electronic communication system course but an overview of practical topics that explain how things work in simple terms and the practical aspects of locating transmitters/receivers so that propagation conditions to not prevent proper operation.

More detail about the topic areas for a full course are given here:

Topic #1 – Basic Computer Networking – Coverage of basic IPv4 addressing, networking hardware (switches, routers), MAC addressing, and the OSI model

Topic #2 – TCP/IP Protocol Suite – ICMP, ARP, DHCP, Port Numbers, and WireShark

Topic #3 – Introduction to Wireless & Wireless Data Networks

Topic #4 – Typical Wireless Networking System Components – Transmitter, Receiver, Channel, Noise, Modulation, Demodulation, and Encoding and Decoding

Topic #5 – The Language of Wireless Systems and Hardware – dBs, Filters, Test Equipment

Topic #6 – Analog Wireless System Overview – AM, FM, Pulse

Topic #7 – Digital Wireless Systems Overview – Symbols, n-PSK, n-QAM, etc.

Topic #8 – Wireless Receiver Systems Overview

Topic #9 – Wireless Multiplexing and Access Scheme Overview – FDM, TDM, CDM, etc.

Topic #10 – Wireless LANs – Wi-Fi – IEEE 802.11 and the extensions

Topic #11 – Blue Tooth and IEEE 802.15

Topic #12 – Cellular System Technology – 4G, 5G, & 6G

Topic #13 – LPWAN Technologies – LoRa, NB-IoT, MIoTY, etc.

Topic #14 – EM Propagation – Ground, Space, Sky Waves, Polarization

Topic #15 – Transmission Lines – Coaxial Cable, Fiber Optic Cable, Matching, etc.

Topic #16 – Antennas – Basic antennas (i.e. Dipole), MIMO, Arrays, Reflector, etc.

This list of topics is from a two-credit course, ELE-230, and an associated course lab, ELE-230L, that is taught by the author at Springfield Technical Community College both in person and online [11]. Topics #1-#3 deal with basic networking principles, networking hardware, networking protocols, and introduce the various wireless networking technologies available presently. Topics #4-#9 deal with wireless system hardware components and introduce various modulation types and multiplexing access techniques used by wireless systems. Topics #10-#13 provide additional detail about the most popular wireless data systems including Bluetooth and LPWAN technologies. Finally, topics #14-#16 serve as an essential overview of electromagnetic propagation, transmission lines, and antennas. These last topics are fundamental if the technician is going to be able to understand the various nuances of where wireless systems (in particular their antennas) need to be located for proper operation.

Conclusions:

Due to the state of today's electronics, the hardware used to implement IoT devices has become throwaway technology. That said, the technician that might deal with this technology needs to know basic computer networking, have a knowledge of embedded controllers and how to access these devices to update or reload software, and some knowledge of environmental conditions that might preclude or deteriorate system operation due to various propagation impairments (i.e. antenna location, pinched transmission line, metal obstacles, etc.). The technician's goal is to be able to install and maintain IoT devices so that they perform their designated function (usually the collection of data) with a full life-span. Furthermore, the technician should have some knowledge of the use case field so that they are aware of what the physical parameter is that the IoT device is trying to monitor. Certainly, monitoring a patient's vital signs versus sensing and communicating road surface conditions to vehicles are different animals with their individual nuances. Usually requiring some basic understanding of the important principles involved, this knowledge is especially important to the proper placement and location of the IoT device(s) and relates directly to how well it can communicate wirelessly to the gateway or access point that it is tethered to.

Today, to gain this skill set requires some wireless curriculum but certainly not an entire two-year program or even a certificate for that matter. Typically, a single course can provide a good coverage of the needed concepts and in some cases targeted modules can provide the necessary information to gain the skills needed in the field. This may change in the future as we transition to the use of millimeter wave (mm-wave) frequencies for 6G. The use of mm-waves, reconfigurable antennas, meta-materials, and other exotic technologies brings with it a whole host of new issues. Lastly, some practical lab work should be included to familiarize the student with the test equipment typically used in the wireless field. Previously, extremely expensive "boxes" like spectrum analyzers were budget busters and usually not found in electronics labs, today there are many low-cost hand-held devices available that can replace these laboratory quality devices for field work.

References:

1. https://www.broadbandsearch.net/blog/mobile-desktop-internet-usage-statistics
2. *Wireless Telecommunications Networks and Systems*, Gary J. Mullett, Delmar, 2006
3. https://www.cnet.com/how-to/the-best-internet-providers-for-2021-cable-dsl-satellite-more/
4. https://iot-analytics.com/state-of-the-iot-2020-12-billion-iot-connections-surpassing-non-iot-for-the-first-time/
5. https://iot-analytics.com/iot-platform-comparison-how-providers-stack-up/
6. Same as 4.
7. *Who is going to teach the skills needed by the IoT Field Technician?,* by Gary J. Mullett, Proceedings of the 2019 American Society of Engineering Educators Annual Conference and Exposition, Saint Louis, MO
8. https://www.netacad.com/courses/iot/introduction-iot
9. https://www.i-scoop.eu/industry-4-0/operational-technology-ot/
10. https://www.cisco.com/c/en/us/training-events/training-certifications/certifications/professional/ccnp-wireless.html
11. https://www.stcc.edu/explore/descriptions/ele-230/