Artificial Intelligence (AI) for Network Infrastructure and Management

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Abstract

Artificial Intelligence (AI) technology is growing at very fast rate and its use is increasing in various fields day by day. Today, Artificial Intelligence is used in many different fields like self-driven cars, medical field, astronomy, robotics, aviation, computer science, education, finance, human resources, recruiting, marketing, job search, music, algorithmic trading, market analysis, data mining, transportation, and many more. In this paper, research has been done about the use of Artificial Intelligence in Network infrastructure and Management. This paper mainly discusses about how artificial intelligence is currently being used in various computer networking related application or technologies like Network Management, Wireless networking, Software defined networking (SDN), and network security. After that, research has been done about how much value it is currently offering in networking and what improvements are needed. Also, research has been done about what are the different use cases, which new features we can think of adding for performance improvement, if there are any challenges in using Artificial Intelligence in networking, how networking companies like Cisco, Arista, Juniper are currently using Artificial Intelligence or how they are planning to use Artificial Intelligence in the future, how Artificial Intelligence can impact networking related job market, which types of jobs it may add in the future, and which types of jobs it may eliminate in the future. In this research paper investigation has been done about how Artificial Intelligence can help network management, troubleshooting and optimization, what is the impact on network management with the introduction of Artificial Intelligence, and what are the new technologies the network engineers and managers will have to learn. Finally, this paper discusses about future prospective of Artificial Intelligence in network management.

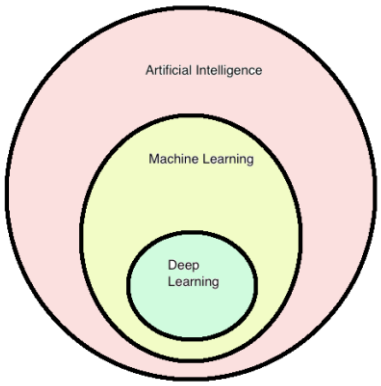
Introduction

The term Artificial Intelligence was first introduced by John McCarthy in 1956 (Smith, 2016). He was a professor of Computer Science at Stanford University and was interested in developing a system which can function like human and act intelligently like humans. John McCarthy's web site defines Artificial Intelligence as "It is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable." (Project JMT Team, 2007). Jonathan Cohen defines Artificial Intelligence as science and engineering of making intelligent machines, especially intelligent computer programs (Singh, Thappa, Singh G., & Singh S, 2010). Machine learning is a science of making computer program intelligent enough that they could take decision (Valente, Ali Imran, Onireti, & Demo Souza, 2017). Artificial Intelligence as it is seen today is the result of the combined efforts of a lot of different scientists and technologists. Artificial Intelligence can perform closely same as human and can learn from experiences and can adjust to various dynamic inputs. Artificial intelligence is based on Natural Language Processing (NLP) and deep learning. NLP is essentially part of Artificial Intelligence which act as an interface between computers and human spoken language. Machine Learning uses algorithm to parse data, learn from that data and make informed decisions based on what it has learned.

Deep Learning structures algorithms in layers to create an artificial neural network that can learn and make intelligent decisions on its own (Grossfeld, 2018). Deep learning allows computational models that are composed of multiple processing layers to learn representation of data with multiple levels of abstraction (LeCun, Bengio, Hinton, 2015)

Today Artificial Intelligence is being used and explored in almost every filed and the reason is the power of Artificial Intelligence is unlimited. Technology in general is growing at very fast rate in all directions and dimensions, which generates huge amount of data. Business requirement are growing at very fast rate and every company wants to be better that other and for that, vendors offers various functions, features and automation to their customers. Technology has become integral part of our lives now and with this growing demand, the people who manages and maintain those technologies are finding it very difficult to keep up with delivering the results and looking for ways to perform the task efficiently with limited resources. As per Cisco document Machine Learning by Network Switches, by 2021 annual IP traffic will reach 3.3 Zettabytes (ZB) every year or 278 Exabytes (EB) per month (Sharma, 2018). That is where artificial intelligence, machine learning, and automation plays very important role. Artificial Intelligence can analyze the data and take action based on defined network policies. Artificial Intelligence might not completely replace Network administrator or engineers, but it will definitely act as a big supporting system. The purpose of this research paper is to study current use of Artificial Intelligence in the field of network management, what are the drawback of using AI, and what is the future of AI in network management field. Currently available traditional network management system can generate various fancy reports showing network availability time, bandwidth usage based on application, and Layer 4 to layer 7 protocol usage. However, the actual analysis and further action on the collected data is done by network administrator. The expert system based on Artificial Intelligence can detect the problem, diagnose the problem and take corrective action. Based on the applications of Artificial Intelligence seen so far, it will not be wrong to say Artificial Intelligence (AI) is going to be the future. Many people interchangeably use the term Artificial Intelligence and Machine Learning.

Figure 1. below shows how these terms are related.



Even though these terms are related, there is some difference between them. Artificial Intelligence is a broad concept having human intelligence in Machines. Machine learning is one of the way Artificial Intelligence can be implemented. Dealing with complex problems and algorithm is one of the most important advantage of Artificial Intelligence and Machine learning. For some tasks that requires complex computation, regression, classification, and decision-making, Artificial Intelligence and Machine learning can perform close to or even better than human. We often come cross complex problem and analysis requirement in networking that demands efficient solutions and network data processing, performance report, automation. In such scenarios it is efficient and effective to bring in Artificial Intelligence and Machine learning (Wang, Cui, Xiao, Jiang ,2018). Artificial Intelligence makes network infrastructure intelligent, improve your network security posture, enrich your network management experience, it transforms your processes and business models. It creates meaningful experience with your data and reinvent the network. As per IDC report global spending on Artificial Intelligence and Cognitive Learning will see 54.2 percent increase in 2018 to $19.1 billion and that number can

increase up to $52.2 billion in 2021 (Shirer, 2018). The increasing deployment of intelligent devices (like smart cars, smart phones and smart home devices), networking technologies (like network virtualization, and cloud computing) the amount of digital data collected has grown very high. In order to manage these devices and optimize the distribution of traffic, today's network is becoming more complex and heterogenous. The heterogenous networking infrastructure increases the complexity of the managed network and creates many challenges in effectively manage the network. To manage such type of infrastructure one way to address the problem is to deploy more intelligence in the network (Xie, Yu, Huang, Xie R, Liu, Wang, & Liu, Y., 2019). Next topic discusses about basics of machine learning.

Basics of Machine Learning

Machine Learning technology applies and powers many aspects of modern technology from internet search to content filtering on social medium, to provide recommendation on various e-commerce business websites and it is increasingly used in consumer product markets such as smart phones and cameras (LeCun, Bengio, Hinton, 2015). In classical approach of programming you will have some type of input, you will have a model or a function, and you do some computation on the input to get the desired output. In machine learning you are provided with some input and some possible output and then you derive a possible model or function that determines the relation between input and output. There are two machine learning algorithms, Supervised Learning and Unsupervised learning. These two algorithms are discussed as below.

Supervised Learning

In supervised learning you have a set of input, say X and set of output say Y and your goal is to come up with a function Y=F(X). For example, if we apply Supervised Machine Learning

method to network monitoring data, we know what type of alerts our network gets, rates at which the alerts are coming, types of alert or failures. Supervised Machine learning method can be applied on this network monitoring data to generate or predict future statistics of events and alerts and can help us plan network management better based on study of the data. Another example can be of retail stores where we know how much sale was done in one day, one week or one month and what items were sold. In this case the data is available and labeled. Now when you apply the machine learning technique to this data, it is called supervised learning. By applying machine learning to this data, retail stores can predict future instances about sale statistics and various other analytical things. If we take example of images of spoon and knife as a labeled data, then in that data, spoon and forks are already labeled and machine learns about these two different item images. If we give spoon images as new data to the system, now the algorithm knows how to label and separate these items automatically.

Supervised learning can be further divided into classification and regression. When the output variable can be categorized into two or more classes For Example, yes / no, or true / false, red/blue/green, or male/female, we use classification method. Example of classification is, identifying SPAM email. SPAM emails are usually we have keywords like lottery, win, money etc. In classification supervised learning, based on the learning about the SPAM keywords and behaviors machine can identify spam emails. Regression algorithm is used when we analyze relation between two or more variables, where a change in one variable is associated with change in another variable. Example can be change in salary is associated with number of years of experience and skills level. In the field of cellular network, supervised learning can be applied in many ways like prediction of mobility, allocation of resources, load balancing, Hand Over (HO) optimization, fault classification and cell outage management (Valente, Ali Imran, Onireti, &

Demo Souza, 2017). We do not have to do any manual computation to come up with these Machine learning functions. There are many libraries available to come up with thse functions. Example popular Machine Learning Libraries are Spark ML, Pytorch, H2O.ai, Keras, Theano, caffe, TensorFlow etc. (Sharma, 2018)

Unsupervised Learning

In unsupervised learning you are not given set of outputs. All we know is set of inputs. Based on that we have to find some sort of relationship between those inputs where you do not even know how the output will look like. In Unsupervised learning, algorithm is trained using data that is unlabeled. There is no supervision and no training will be given to the machine allowing it to act on the data which is not labeled. Hence machine tries to identify patterns and give the responses. For example, if we give input to this machine, number of spoon and fork as one set, then machine will recognize the pattern and will separate spoon and forks based on their patterns, features, similarities and dissimilarities. Unsupervised learning can be further grouped into clustering and association. In clustering, machine will divide the similar objects into one clusters and dissimilar objects into another cluster. Association based unsupervised learning is rule based to discover relationship between variables in large data set. For example, which customer makes similar type product purchase is clustering whereas which type of products were purchased together is association. To understand clustering better we can review some more examples. A telecom company to reduce churn rate of its subscriber can apply clustering unsupervised learning algorithm and the machine may cluster the subscriber based on their data usage and call duration. Based on this clustering, the telecom company may offer promotional offers to customer based on their requirements. They may offer plans which gives more data to the

subscriber who use more data and they may offer plans which gives a greater number of minutes to them who use more minutes. To understand association method of unsupervised learning let's take another example of a customer 1 going to supermarket and purchase bread, milk, fruits and wheats. Customer 2 goes to supermarket and purchase bread, milk, rice and butter. Now when customer 3 goes to supermarket, based on the customer 1 and customer 2 purchase history, an association can be made that when someone goes to super market and buys bread, he or she will also likely to buy milk (Simplilearn, 2019).

Traditional Network Monitoring

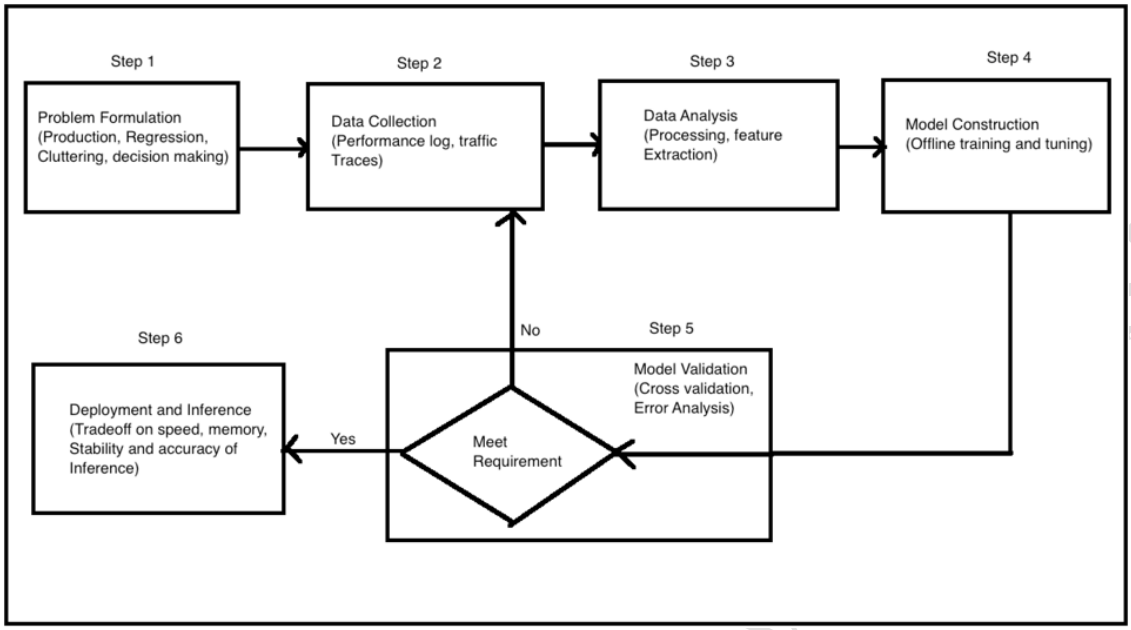
In traditional network monitoring we have a monitoring station or network management system which uses various network monitoring protocol to monitor the network node. It can use various network management protocols like Simple Network Management Protocol (SNMP), ping, telnet, ssh etc. Based on configured parameters the network management system polls the end node or devices and if there is no reply then it can generate alarm. There are many other parameters like latency, utilization, delay, etc. which can be used for monitoring and generate alarms based on configured parameters. Once the Alarm is generated, automated ticket is generated and then the network monitoring station can either generate alarm, call the administrator, email the administrator, and SMS network monitoring / network administrator team. After this, the network monitoring team engineer may have to triage the problem and work towards the resolution of the problem. All these things are manual work. With the increasing network sizes, high cost of network resources, time it takes to resolve the problem from identifying the problem to resolve the problem is very high and time consuming. This is the reason, more and more organizations and trying to automate these processes using some type

software programs or scripting. However, all this needs manual intervention. Think about an automated smart way of doing all this and Artificial Intelligence and Machine learning has the ability to provide us these features.

Machine Learning for Networking [MLN]

Figure 2 below shows basic workflow of applying Machine Learning for Networking. The steps in the workflow are Problem Formulation, Data Collection, Data Analysis, Model Construction, Deployment and Inference, and Model Validation. All these steps are related to each other.

Figure 2. below shows basic workflow of Machine Learning for Networking (Wang, Cui, Xiao, & Jiang, 2018)



In the problem formulation step the problem is correctly understood and abstracted and then categorized as either classification, clustering and decision making. In Data Collection step, basically all related data is collected. This data can be traffic flows, bandwidth utilization reports,

network interface statistics for errors, information about the network topology, etc. In data analysis step the most critical part is identifying the main key factor or also called as feature related to the problem. For example, for the bandwidth utilization data analysis, the key factors are going to be source IP, destination IP, source port, destination port, and protocol. In the model construction phase, an appropriate data analysis model or algorithm is selected based on the type of data involved. For example, for the throughput related data analysis, Hidden Markov model may be selected. Once the algorithm is selected for construction phase and then that model will be provided with historical data pattern and live data pattern in order to train the system. In the model verification steps the algorithm is analyzed against offline data to find if it is generating required result. During this step input data tuning and feature or key tuning modification may be required if the system is not generating required results. If the system is working as expected, then the next step will be executed. The next step in the flow is deployment and inference. In this step the generated model or application is used in live network and performance of the model is analyzed. During this step we may have to modify the system depending on the results. We need to consider various factors like traffic pattern, network performance, if this new model is affecting actual data traffic etc. (Wang, Cui, Xiao, & Jiang, 2018). Machines can learn, analyze, find patterns, detect anomalies, perform root cause analysis for the network. We can use artificial Intelligence and machine learning to predict performance, detect subtle attacks, and make the network reactive to network incidents. Artificial Intelligence provides lots of opportunities for automating network operations and introducing intelligent decision making in network planning, dynamic controller and management of network resources for example connection establishment, self-configuration, and self-optimization, through prediction and estimation by using available

network state information and historic data (Mata, de Miguel, Durán, Merayo, Singh, , Jukan, & Chamania, 2018).

Areas of networking where Machine Learning can be applied are as follows:

1. **Traffic prediction:** The ability to predict traffic pattern, traffic growth and traffic trend is very important for today's complex and incrementally increasing network.
2. **Traffic Analysis:** The ability to analyze traffic using automated method can be very time saving task. Manual traffic analysis needs experts to analyzer the traffic based on their experience and can be time consuming.
3. **Traffic Routing:** When there is a network fault in network path, traffic can be intelligently routed to another path using machine learning technologies.
4. **Congestion Control:** If one path is congested then intelligent system can route the traffic via less congested path.
5. **Resource Management:** With Artificial Intelligence and Machine learning resource utilization can get easier and more affordable as machine can do work of many people.
6. **Fault management:** When there is fault in the network, with ML and AI, we can detect the fault, identify the cause and take corrective action.
7. **QOS management:** Adjustment to QOS queue bandwidth and priority can be intelligently adjusted based on traffic pattern.
8. **Network Security:** AI and ML can be very helpful for identifying threats and taking corrective action to protect network.

As per Ericsson's Mobility report (Ericsson, 2018), "Applying machine intelligence to network management", high powered computer equipment, cloud-based architecture, everything getting digitized and big data analytics are opening great opportunities for Artificial Intelligence. The report says AI is explored in various filed including mimic human behavior and that also includes mobile network operations and maintenance. Mobile network technology is getting advanced and new technologies like 5G and Internet of things are going to increase complexity more and more. To maintain the demand, we are going to need lots of engineer and supports staff. Artificial Intelligence can be very helpful reducing and automating work load. In the next section Artificial Intelligence based Network Management application and tools are explored.

Artificial Intelligence based Network Management application and tools

There are various Artificial Intelligence based Network Management application and tools available in the market by various vendors.

In this topic I have reviewed some of the tools like:

1. Digital Network Architecture (DNA) Center
2. AI for SD-WAN
3. Encrypted Traffic Analytics
4. Cisco Umbrella
5. iCAM
6. Sophie AIOps
7. AI based NOC

8. Intelligent Digital Assistance
9. NetInsight

Detailed information about these tools is as below.

1. Cisco Digital Network Architecture (DNA) Center

Cisco DNA center is Cisco's way of implementing Intent based Networking. In the traditional way of networking all the processes were mainly manual. For example, you design your network, then you implement it and make changes to the network as needed by your business. Intent based networking basically means an intelligent way of understanding what your organization needs are and automatically make it happen. Intent Based Network and Cisco DNA is a way of automating your network management related task based on Artificial Intelligence and Machine Learning. Cisco DNA Center lets organization predict performance through ML to correlate user device and application data for contextual business and application data [7].

Cisco DNA architecture product includes following products (Cisco System, 2018):

a) Cisco IOS XE software
b) Cisco DNA center,
c) Cisco Software-Defined access (SD-Access)
d) Cisco Software Defined WAN (SD-WAN)
e) Cisco DNA Security
f) Cisco DNA Assurance
g) Digital Ready Infrastructure

2. AI for SD-WAN

SD-WAN is a Software Defined approach for managing the Wide-Area Network based on 4G, LTE, or MPLS. Traditionally WANs are based on private links or leased lines and then we used to manage every link and then connected device individually. SD-WAN uses internet based private network and it separates management of WAN link and hardware devices from traffic management and monitoring of that traffic. SD-WAN software component can intelligently identify traffic pattern and divert your flow or traffic as per your requirement. With SD-WAN, traffic is coming from multiple branch office sites and it is very important to provide security for that dynamic traffic pattern. With SD-WAN we need some intelligent way of protecting data and have some way to correct the fault automatically and optimization with very less interaction from network administrator. For this self-healing requirement and intelligent traffic management we need something that can act on information like traffic pattern, network statistics, and Artificial Intelligence is the solution for this requirement.

3. Encrypted Traffic Analytics

Encrypted Traffic Analytics is a network-based security solution that can analyze encrypted packets for any kind of threat or anomaly in the traffic without decrypting it. This technology identify anomaly in the traffic for example ransomware attack, malware detection and advanced persistent threats using Machine Learning and advanced analytics (Cisco, 2019)

4. Cisco Umbrella

Following Security products from Cisco uses Machine Learning and Artificial intelligence. Cisco Umbrella is a security product for multi-cloud environment.

Cloudlock

Cloudlock is cloud based application tool that is used to secure cloud users, protecting against account compromises, data breaches. This application tool uses advanced Machine Learning and Artificial Intelligence to detect anomalies in the cloud environment.

Cognitive thread analytics

Cognitive thread analytics is another Cisco tool that can be used in cloud infrastructure. This tool makes baseline of network behavior and user data traffic and then analyses it against abnormal behavior identify potential threat.

Cisco Advanced Malware Protection (AMP)

Cisco Advanced Malware Protection (AMP) is a tool used to identify malicious software and blocks them. It used advanced Machine Learning techniques for doing so.

5. iCAM

iCAM is Cisco's Intelligent CAM (Content Addressable Memory) analytics and Machine Learning feature. It is also called as iCAM. This feature is supported on Cisco Nexus 9000 Data Center switching platform. Machine Learning is natively running on this platform. This feature shows you traffic utilization per feature like Router access control list (RACL), VLAN ACL, Port ACL, Policy Based Routing, Quality of Service (QOS), Network Address Translation (NAT) etc. In real time network some of these features may be over utilized or some of them are underutilized. iCAM features provides monitoring of utilization of these features and help use available Ternary Content Addressable Memory (TCAM) effectively. With this iCAM feature

you can view what was the utilization (per subnet based, per application based, top heavy heater of the traffic) of these features in the past and current date. This monitoring data provides prediction of traffic pattern for future use, can be used to predict how much the hardware and software tables will be utilized in the future. The iCAM feature uses Machine Learning Algorithm to analyze the historical data and an tell us what the utilization of these feature in the future will be (Cisco, 2018).

6. **Sophie AIOps**

Sophie AIOps is Artificial Intelligence based Network Monitoring application from Loom System. It can collect the logs and parse them and detect anomaly. It can corelate logs with inbuilt intelligence and diagnose the problem, correct fault based and perform automated root cause analysis. Sophie AIOps monitors the network for logs continuously and predict possible incident and it can alert you in advanced. It can provide you detailed information about the analysis of the incident and information about how it can fix the problem (Loop System, 2019).

7. **AI based NOC**

The traditional way of troubleshooting mobile network or any network, involves looking at the logs of the system, verifying the configurations of the network devices, verifying the health status of the devices and then coming to action plan. All these steps are either based on configuration guides of the product we are troubleshooting, datasheet of the product, some kind of technical database and support engineer's previous knowledge. These are the information which needs to be converted to machine readable format and data structure so that it can be used as input to the machine. Based on these inputs and machine intelligence algorithms, an intelligent Network Operation center can be created. The artificial intelligence based automated Network

Operation Center (NOC) can monitor fault, detect fault and correct machine correctable fault. The prototype NOC software enables mapping multiple composite conditions from historical information in database. Basically, intelligently groups cross domain alarms for identification using pattern mining techniques. It forms rule from the composite conditions using ML and then detect the incidents based on those rules. The prototype rules which are developed are not depending on one technology and they are general logic and can apply to any network topology and architecture. The AI based NOC software is independent and can keep learning incidents and patterns ongoing basis and take intelligent decisions based on the learning.

8. Intelligent digital assistance

Another application of AI as suggested by Ericsson report, is Intelligent digital assistance to guide field technicians about fault resolution for hardware related error at radio base station sites. The hardware installation, configuration and maintenance related task can be time consuming at times. Technicians may face various difficulties in the processes. The intelligent digital assistance can assist technician make his or her job easier. The prototype of Intelligent digital assistance includes visual object detection and steps and procedures from product documentation displayed for assistance. For troubleshooting fault related to faulty cable adapter, visual object detection and augmented reality application can help identify the object, identify if the port is faulty and steps to resolve the fault. The intelligent digital assistance can take photo of the radio base station and then technician can tap on any part of equipment and retrieve more information about the part and get statistics and perform health check. The visual object detection in this system was based on Convolutional Neural Network (CNN) architecture (Ericsson, 2018).

9. **NetInsight**

Aruba (a Hewlett Packard Enterprise company) has come up with an AI powered analytics and assurance tool called NetInsight (Network Asia, 2018). This Aruba's tool can help IT organization experience better user experience and getter results as organization continue to add new technologies like Internet of Things (IoT) and cloud-based networking. NetInsight uses Machine Learning (ML) to continuously monitor the network, provide details about the network status and anomalies found, and then recommend how best to optimize the network. The Next step would be to automatically take corrective action. And then we can say, AI will be said as truly integrated

Drawback of AI and Required Improvement

Artificial Intelligence for network infrastructure management is still in its initial development phase and it will need lots of work get some more meaningful product which is really useful to the extent that it can fully take over without any human intervention. Based on the power of artificial intelligence and its unlimited capabilities, it is possible that in next few years Artificial intelligence may truly become useful. When it will become really useful, it is sure that AI will have very high capacity and can do the jobs of multiple people. Hence, it creates the risk of eliminating jobs of network operation engineer, level 1 and 2 engineers and reduce the headcount for other level of engineers like the one who troubleshoot and do planning jobs. Since every company design their network in their own way and according to their own requirement, every network is different and when we apply Artificial Intelligence and Machine learning techniques to individual network it will be different for every network and will not be something like cookie cutter. Along with that new network technologies are coming in the market every few months

and with that kind of dynamic change, it will be very different and difficult machine learning experience with every new technology. When Machine Leaning algorithms are used for Malware detection, basically machine learning algorithm learns the behavior based on sampling. Attacker can easily manipulate the sampling process and the attacker may invade detection no mater which machine learning algorithm is used (Gardiner & Nagaraja, 2017).

Future of AI in Networking:

Due to the extensive power and capabilities of Artificial Intelligence, in near future applications of AI will be all over in networking. This includes network design and capacity planning. These two tasks are very important and needs expert Network Engineer. Automating tasks like root cause analysis which is very time consuming can be a great help for network engineers to save their valuable time. Another task on which we can apply AI and ML is analyzing packet capture from capturing tools like Wireshark. With numerous technologies becoming available day by day, it is very difficult to have one network engineer who can have knowledge in all those new technologies. AI is a machine based and can have that power of leaning all the new technologies based on input data and algorithms. Today's networks are changing its type from traditional network to cloud based networks and software defined networking (controller) based network. AI is going to be key player in enabling the power of these technologies. AI is already there in these fields in the initial stages and its use is expected to grow high.

Conclusion:

Artificial Intelligence concept is there from long time and its use is slowly increasing in various fields. Although the concepts of Artificial Intelligence and machine learning are there for long time, these concepts and its use was not generalized so far. In recent years, organizations have started using Artificial intelligence, machine learning and its applications in various products. With increase in data, new technologies, Internet of things and everything getting digitized, the number of networks connected devices has grown a lot, application of artificial Intelligence and machine Learning to Network Management has started increasing. Currently there are many Network management applications available which are Artificial Intelligence based and networking organizations are trying more and more to make use of Artificial Intelligence. As the use of this technology will grow in network management, this technology will become more mature. Once the use of AI and ML becomes more mature, we will start see huge advantages like the AI based network application can perform work of multiple network engineers or administrative and will save lots of cost to the company. Organizations will still need technical staff but the expectation from technical staff would be different. It could be related to managing new technologies that have just arrived, designing and troubleshooting more complex technologies, and automating the network management using Artificial Intelligence and machine learning techniques.

Reference:

1. Smith, C. (2006, December). The History of Artificial Intelligence. Retrieved February 19, 2019, from https://courses.cs.washington.edu/courses/csep590/06au/projects/history-ai.pdf

2. Project JMC Team (Ed.). (2007, November). Retrieved from http://jmc.stanford.edu/artificial-intelligence/what-is-ai/index.html

3. Singh, S., Thappa, M., Singh, G., Singh, S., & Singh, S. (2010). Artificial intelligence and neural network. International Journal of Advanced Research in Computer Science, *1*(3) Retrieved from http://search.proquest.com.jproxy.lib.ecu.edu/docview/1443702162?accountid=10639

4. Wang, M., Cui, Y., Wang, X., Xiao, S., & Jiang, J. (2018;2017;). Machine learning for networking: Workflow, advances and opportunities. IEEE Network, 32(2), 92-99. doi:10.1109/MNET.2017.1700200

5. Grossfeld, B. (Ed.). (2018, July 18). A simple way to understand machine learning vs deep learning. Retrieved February 19, 2019, from https://www.zendesk.com/blog/machine-learning-and-deep-learning/

6. Cisco. C. (2018). ICAM Configuration Guide. Retrieved February 19, 2019, from https://www.cisco.com/c/en/us/td/docs/switches/datacenter/nexus9000/sw/7-x/iCAM/configuration/guide/b_Cisco_Nexus_9000_Series_NX-OS_iCAM_Configuration_Guide_7x/b_Cisco_Nexus_9000_Series_NX-OS_iCAM_Configuration_Guide_7x_chapter_010.html

7. Cisco Sys, C. (2019). Transforming Businesses with Artificial Intelligence. Retrieved February 20, 2019, from https://www.cisco.com/c/dam/en/us/solutions/collateral/digital-transformation/ai-whitepaper.pdf

8. Cisco System, C. (2018). Cisco DNA Architecture. Retrieved February 20, 2019, from https://www.cisco.com/c/dam/en/us/solutions/collateral/enterprise-networks/cisco-digital-network-architecture/solution-overview-c22-736580.pdf

9. Loom Systems, L. (2019). Retrieved February 21, 2019, from https://www.loomsystems.com/solutions/network-monitoring

10. Ericsson, E. (2018). Applying machine intelligence to network management. Retrieved March 3, 2019, from https://www.ericsson.com/assets/local/mobility-report/documents/2018/emr-june-2018-applying-machine-intelligence-to-network-management.pdf

11. Aruba's AI-powered analytics enables autonomous networking. (2018). *Networks Asia*, Retrieved from http://search.proquest.com.jproxy.lib.ecu.edu/docview/2021099784?accountid=10639

12. Shirer, M. (2018). Worldwide Spending on Cognitive and Artificial Intelligence Systems Will Grow to $19.1 Billion in 2018, According to New IDC Spending Guide. *IDC*. Retrieved March 14, 2019, from https://www.idc.com/getdoc.jsp?containerId=prUS43662418

13. Sharma, S. (2018, June 10). *Machine Learning on Network Switches CTHRST-2694*. Lecture presented at Cisco Live in Florida, Orlando.

14. LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature*, *521*(7553), 436+. Retrieved from http://link.galegroup.com.jproxy.lib.ecu.edu/apps/doc/A415563174/AONE?u=ncliveecu&sid=AONE&xid=085d1dc8

15. Simplilearn. (2019, September 11). *Supervised and Unsupervised Learning In Machine Learning*. Speech. Retrieved March 17, 2019, from https://www.youtube.com/watch?v=kE5QZ8G_78c&t=475s

16. Gardiner, J., & Nagaraja, S. (2016;2017;). On the security of machine learning in malware C&C detection: A survey. *ACM Computing Surveys (CSUR), 49*(3), 1-39. doi:10.1145/3003816

17. Xie, J., Yu, F. R., Huang, T., Xie, R., Liu, J., Wang, C., & Liu, Y. (2019;2018;). A survey of machine learning techniques applied to software defined networking (SDN): Research issues and challenges. *IEEE Communications Surveys & Tutorials, 21*(1), 393-430. doi:10.1109/COMST.2018.2866942

18. Valente Klaine, P., Ali Imran, M., Onireti, O., & Demo Souza, R. (2017). A survey of machine learning techniques applied to self-organizing cellular networks. *IEEE Communications Surveys & Tutorials, 19*(4), 2392-2431. doi:10.1109/COMST.2017.2727878

19. Mata, J., de Miguel, I., Durán, R. J., Merayo, N., Singh, S. K., Jukan, A., & Chamania, M. (2018). Artificial intelligence (AI) methods in optical networks: A comprehensive survey. *Optical Switching and Networking, 28*, 43-57. doi:10.1016/j.osn.2017.12.006