Software-Defined Network and Cloud-Edge Collaboration for Smart and Connected Vehicles

Raj Mani Shukla
University of Nevada, Reno
Reno, Nevada, USA
rshukla@unr.edu

Shamik Sengupta
University of Nevada, Reno
Reno, Nevada, USA
ssengupta@unr.edu

Mainak Chatterjee
University of Central Florida
Orlando, Florida, USA
mainak@eecs.ucf.edu

ABSTRACT

Smart and connected communities are envisioned to include millions of sensors and devices tied together through the Internet. This has ushered the demand to investigate intensive communication and computing solutions for their realization to facilitate human life. Connected vehicles can be considered as a significant realm of the smart and connected communities. This paper presents the importance and challenges of Software-Defined Networks (SDN) for providing better network management in smart and connected vehicles. We also describe the significance and challenges in embracing cloud, edge and fog computing for processing enormous amount of data generated from the network of interconnected vehicles. Further, a portrayal of some of the open research issues for better realization of the connected world is provided.

KEYWORDS

Smart and Connected Communities, Connected Vehicles, Software-Defined Network, Cloud Computing, Edge Computing, Cloudlet, Cascade Failure, Adversarial Attack

1 INTRODUCTION

The concept of smart cities is evolving to the new idea of Smart and Connected Communities (SCC) that incorporate smart homes, smart transportation systems, smart grids, health-care services, smart learning, all tied together through the Internet connection. The integration assists in various forms like crowd management in cities, reducing greenhouse gases, promoting new business models, making government agencies responsive and efficient, improving livability and quality of life. For instance, in a connected community, the appliances in smart homes can take the information from user's travel patterns and switch on (or off) the appliances like HVAC system [19]. The smart grid uses traffic information in the city and helps in demand-side management (DSM) of electric supply. Smart transportation assists local authorities in traffic management and helps people adopt safe driving practices in cities. Farmers can be provided information about weather, crop conditions, and market price which may help them decide the best time to harvest their crops and best place to sell them for maximum profit. The SCC foster sustainability and quality of life, enhances security and safety of people and environment, and promote a better quality of life [32]. It also boosts profit for businesses, aids in reducing losses, and advocates better health-care and emergency services.

The smart and connected vehicles are one of the significant components in a smart and connected community. Business Insider (BI) estimates that the 94 million connected cars to be shipped in by 2021 [16]. Thus, an estimated annual growth of connected vehicles is around 35% from 21 million connected cars in 2016. With the recent advancement in Plugged-in Electric Vehicle (PEV), the smart and green transport is also gaining a lot of interest for researchers and businesses [18]. Several auto companies like Tesla, Nissan and Chevrolet have started PEV production and it is expected that others will also expand their market share of PEV production [5].

Connected vehicles woven together in the ecosystem of road-side units, pedestrian devices, utilities and charging points generate an enormous amount of data which need to be efficiently transmitted from one place to another place through the communication network. Due to the large volume of this data, network management in the domain of connected vehicles appeals for efficient and scalable solutions. Fortunately, the advances in SDN have enabled network elements like switches, routers and end devices to be easily added or configured, thus imparting scalability to network management. SDN also assist in facile network monitoring and resource distribution because of its centralized architecture and global view of the network. Due to its simplified design, SDN paradigm provides ideal network management solution to large-scale and dynamically connected vehicular networks.

The huge amount of data generated from connected vehicles also need to be stored and processed for making analytical decisions. Although cloud computing has been used for remote storage and processing of data, it cannot sufficiently process all of the data generated from connected vehicles [2]. Therefore, computing solutions for smart and connected vehicles also require better and efficient techniques. The advent of edge computing, fog computing, and cloudlets provide an immense pool of computational resource for data processing. Therefore, traditional cloud computing technology coupled with the edge, fog, and cloudlets have the potential to provide scalable computing solution to smart and connected vehicles. The ecosystem of cloud, edge and SDN controller can be envisioned as in Figure 1.

This paper presents the discussion on Software-defined Networks (SDN) which have the potential to provide flexibility to large and dynamic networks. Regarding computation techniques, we describe the importance of cloud, edge, and fog computing technologies. Throughout the discussion, we present the importance of these technologies in the context of connected vehicles. We discuss

Workshops ICDCN '18, January 4–7, 2018, Varanasi, India

ACM ISBN 978-1-4503-6397-6/18/01…$15.00
https://doi.org/10.1145/3170521.3170527

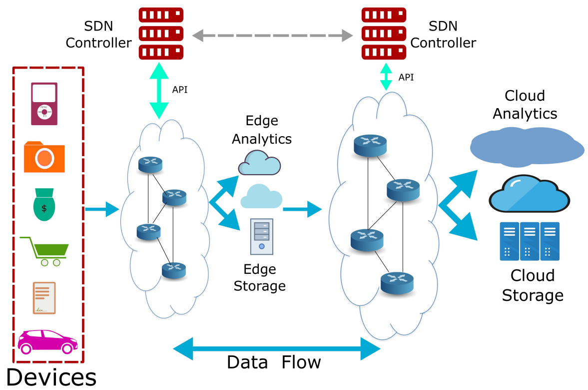

Figure 1: Integrated device, edge and cloud ecosystem

the challenges while adopting these technologies in the realm of connected vehicles. Further, we present some of the open research issues relevant to connected vehicles and their integration with utilities like smart grids.

2 CONNECTED VEHICLES FOR SMART AND CONNECTED COMMUNITIES

Vehicular networks are characterized by a highly dynamic topology with the nodes (vehicles) moving at high speeds. The vehicles also move in different network conditions which include interstate highways with lower Internet coverage, congested traffic conditions, with network becoming slower due to a large number of connected vehicles. Traffic in cities with tall buildings or severe weather conditions may also affect network connectivity.

The connected vehicle architecture which was presumed to offer seamless connectivity for vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) is evolving towards the seamless connectivity between vehicle to pedestrian devices, vehicle to charging stations and vehicle to smart grid network. Today's connected cars include either an on-board connection to the network or connection is through a remote device like smart-phone. Also, tools like GPS are now built-in the car itself. Applications like *GasBuddy* or *Spotify* are further enhancing the driving experience [3]. Although the connected electric vehicles are primarily concerned with bringing safety for drivers, there are several driving forces for bringing Internet connection in vehicles as outlined below.

Safety: Car crashes are one of the major concerns in today's world. A study done by National Highway Traffic Safety Administration (NHTSA) estimates that about 80% of car crashes can be prevented by adopting connected vehicles [30]. Connected vehicles ameliorate safety of vehicles by the use of adaptive cruise control and warning systems. Warnings about the speed limit, red light crossings, and lane change can be issued to the drivers in real-time. The turn assistance and movement near stop or yield sign can be made easier using vehicular networks [31].

Emergency services: If a collision occurs, the emergency services like ambulance and police are informed immediately. Vehicles near the place of emergency are directed to divert or clear the path. This helps in avoiding congestion near the accident site. The evacuation team or fire services can coordinate better to make things faster. Thus, the time for emergency services to reach accident site can be drastically reduced in the system of connected vehicles.

Location based services: Location-based services can help both drivers and businesses. Services like information about nearby hotels, restaurants or shopping places, parking places for electric vehicle can be quickly provided to drivers. Location-based services are also beneficial for businesses as they can advertise to nearby drivers about the available resources and their cost.

Energy management: A vehicular network inter-connected to smart grids helps in better energy management as the grid can predict the traffic conditions in cities and based on that appropriate amount of energy can be generated for electric vehicle charging. Rather than charging all the vehicles at the same time in residential area or office parking lots, vehicles can be scheduled for charging to improve the electric load profile.

Charging services: The route of a vehicle can be optimized thus avoiding congested traffic route to save electric vehicle's battery. Information from vehicle's status of charge (SOC) can be used to decide whether to charge it using AC or DC voltage level at a parking place thus optimizing time and cost of the user. Also, charging station allocation to en-route vehicles based on their status of charge (SOC) can reduce their charging time and minimize cost [29].

Cognitive assistance: Cognitive assistance help drivers to apply brakes or slow down depending upon real-time information [4]. It can assist drivers in avoiding any risky situation. It can also help new or student drivers by guiding them to control vehicles based on the real-time information from nearby vehicles and environments.

It is expected that the future of transportation will be governed by self-driving or autonomous cars [7]. Self-driving cars will require seamless Internet connectivity for its realization. Further, cars with solar roof have the potential to provide green and cheaper transport. Solar roofs can enable the flow of electricity from the car to the grid, thus the fleet of cars can act as an energy source supplying electricity to the grid while they are not in use.

However, the wide-scale adoption of the connected cars and its advancement towards self-driving cars is still evolving and presents various challenges. The following sections discuss the communication and computational needs that can enable scalable solutions to the connected vehicles.

3 SDN FOR CONNECTED VEHICLES

The network solutions for connected vehicles are required to be flexible, adaptable and scalable. In traditional networks, the intelligence was distributed throughout the routers and switches [12]. Thus it was difficult to alter network policies because every router and switch need to be reconfigured individually. It also hinders scalability because it was difficult to manage and monitor a large number of routers and switches. Vehicular networks have dynamic topology, with vehicles connecting and disconnecting intermittently. The network policy for connected vehicles may require changing frequently because of the dynamic nature of the network. Furthermore, the interconnection of electric vehicles, with smart grids and charging stations makes network to be geographically distributed over a vast area. Thus traditional network solutions do not fit well for large-scale, geographically distributed and dynamically connected vehicular network. The SDN paradigm can solve the mentioned problems of traditional networks by decoupling the control plane

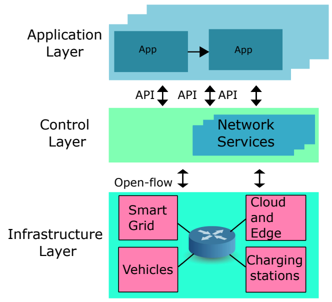

Figure 2: SDN architecture

and the data plane as shown in Figure 2. In SDN based networking, the routers and switches have very low level of intelligence and act as dumb devices for forwarding the packets only. The intelligence is shifted to a logically centralized but physically distributed SDN controller which directs routers and switches about what to do with the packets [12]. Thus network policy change, network up-gradation and network monitoring have become very easy in the SDN domain. The SDN paradigm which was conceived for only wired networks has evolved to benefit both wired and wireless networks [21]. Connected vehicles which have both wired connection, between road side units (RSUs), and wireless connections, between vehicles and vehicle to RSU, can benefit from SDN based network management solutions. SDN has the potential to solve scalability issues in vehicular networks. However, there are also several challenges while adopting SDN as an enabling technology for connected vehicles.

3.1 SDN as an enabling technology

SDN is poised to be enabling technology for connected vehicles because of its global view of the network. Some of the benefits while adopting SDN for connected vehicles are outlined below.

Heterogeneous resources: In vehicular networks, the nodes are equipped with heterogeneous radio services. The SDN can consider them in a unified framework. The selection between different radio technologies like Dedicated Short Range Communication (DSRC), Wi-Fi, LTE or Zigbee can be easily made by SDN because it is aware of the network topology and the available radio service at each node. The SDN can assist in deciding about which radio service is required at which time for communication between nodes depending upon the availability and dynamics of the network. For example, if DSRC becomes congested then SDN can ask some nodes to enable Zigbee connection thus reducing congestion in DSRC.

Resource management: In a connected vehicle scenario, the services may require different types and capacities of communication resources depending on the roadside traffic congestion. Since the logically centralized architecture of SDN has a global view of the network, it can dynamically allocate bandwidth depending on the en-route traffic. For example, a region with more vehicles can be dynamically allocated more bandwidth compared to a region with fewer vehicles. Safety services requiring strict real-time response can be allocated more bandwidth on demand. For instance, emergency services need not be required to have a dedicated frequency band. SDN can allocate high-frequency bands on-demand, thus assisting better resource management [13].

Smart grid integration: Smart grid, charging stations, and vehicles are typically scattered over a vast geographical region. Vehicular mobility makes the problem of charging station selection for electric vehicles complex since wait time, charging rate, and charging cost vary for different charging stations. SDN can help share real-time data between vehicles, charging stations, and smart grid to enable vehicles to make their optimal charging decision.

Transmission power: For the case of vehicular networks, SDN controller can also efficiently assist in deciding the transmission power depending on vehicular density. If the traffic density is high, then transmission power can be set low. On the other hand, lower traffic density require the vehicles to send the signal to a larger distance and thus transmission power is set higher [13]. Similarly, data rate or inter-packet interval can be set based upon the global view of the network rather than the local information from the vehicles.

3.2 Challenges while adopting SDN

Adoption of SDN as a network management solution has several challenges due to its centralized and layered architecture as mentioned below.

Reliability: Since SDN is a logically centralized controller, a compromised SDN controller can affect a large number of nodes in the network. The SDN is prone to reliability issues because of a single point of failure. Clustering of SDN controllers or hierarchical SDN controllers can mitigate these reliability issues. However, the problem of memory synchronization and data exchange between controllers in a clustered or hierarchical structure is a challenging problem. It also increases the initial cost of setup as extra resources are required.

Security: The layered SDN architecture poses several security challenges which need to be carefully considered before its wide-scale adoption. In SDN architecture, application layer, control layer, and infrastructure layer interact with each other (Figure 2). Security vulnerability arises due to interactions between application and control layer, control layer and infrastructure layer, between two application layer or between two control layers. Although open-flow which is one of the well-known APIs for SDN specifies the use of transport layer security (TLS) mechanisms, the adoption of these security mechanisms is only optional and depend upon the user [15]. Thus SDN paradigm requires rigorous security solutions.

Controller placement problem:The optimal placement of the SDN controller for any arbitrary network topology is an important concern for the adoption of the technology [10]. The logically centralized controllers are required to serve all the nodes in the network fairly. The delay between controller to nodes and other controllers is one of the crucial factors in placing the SDN controllers. The placement of SDN controllers becomes even more critical for efficient load distribution for a highly dynamic network topology such as that of connected vehicles.

Performance: In the SDN paradigm, decoupling of control and data plane has its own disadvantages. As the number of switches or routers in the data plane increases, the control plane may have performance issues with its limited computing capabilities [27]. Thus the SDN controller in the data plane gets overloaded once the number of nodes in data plane increases. At some point in the day, the traffic congestion can overload the SDN controller while at other times the controller may not be used to its full potential. Similarly, at the same time of the day traffic conditions can make some SDN controllers overwhelmed with requests while other may become underloaded. Load balancing in SDN controllers is an essential concern since controllers are also spatially located and communication between them incurs some delay.

Delay: In the SDN realm, the switches and routers forward packets according to the entries in the flow table. The flow table is nothing but a table containing entries about what to do with a packet once it arrives at a certain switch or router. The SDN controller dispatches flow table entries to every switch and router according to the network policy. However, once a packet whose information is not available in flow tables arrives at a node, then that node asks the SDN controller about what to do with this new packet. The SDN controller then sends the new table entries associated with that flow. This process to fill the table for new flows takes some time and induces latency [9]. The flow set-up time affects the communication between nodes which require exchanging delay sensitive data between them. The problem becomes severe when new kind of flow is requested frequently to the SDN controller.

4 CLOUD, EDGE, AND FOG COMPUTING FOR CONNECTED VEHICLES

This section delineates the concept of cloud, edge and fog computing technologies in the context of connected vehicles. The sensors and devices in vehicles, at the road side units, and with pedestrians have limited computing capabilities. They also generate enormous amount of data which need to be stored and processed for making analytical decisions [2]. Various researchers are poised to bring the cloud computing capabilities near the end user because of latency issues and location-aware computing. The idea of edge computing [20] developed by European Telecommunications Standards Institute (ETSI), fog computing [2] by Cisco Systems Inc., and cloudlets [26] by the researchers from Carnegie Mellon University (CMU) have similar underlying principles that bring cloud computing facilities near the user. This has latency advantages, and the data can be processed near the user using location-based information. Thus actual value of the data is not lost while it travels to the cloud and processed remotely. Besides, it also improves network performance because the data need not be downloaded or uploaded every time from the cloud which requires more network resources. In this paper, for the sake of convenience, we discuss the importance of edge computing and its challenges in connected vehicle scenarios. However, the discussion also applies to fog computing or cloudlets because the inherent idea behind these concepts is same. It should also be noted that the edge computing, fog computing or cloudlet does not replace clouds or provide a better alternative. They augment the cloud computing infrastructure and assist in better storage, processing or analysis of data by providing an immense pool of computing resources near the user.

4.1 Cloud and Edge computing as an enabling technology

Scalable video streaming: Edge computing can scale up video streaming for connected vehicles. Rather than having the estimated traffic through the navigation tool, the user can see the actual traffic via the camera installed on the vehicle. This can be made possible due to the large-scale deployment of edge servers. The video signals from the camera can be uploaded to the edge servers and the user can download them to see the actual traffic at important locations in city in real-time. The advantage with edge computing is that the delay can be reduced since edge servers are located near the users [14].

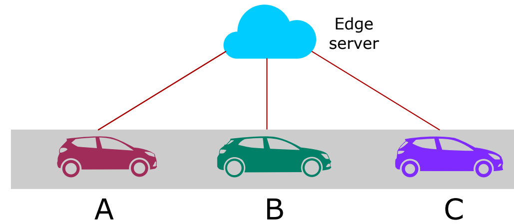

Figure 3: Road-side computing

Internet based services: Edge computing enables Internet based services like live music, video or web-pages to be distributed between cloud and edge servers [22] rather than putting all services in cloud. For example, Netflix or Amazon service require high bandwidth therefore it can be hosted at the edge to avoid video buffering. Since web pages use less resource they can be hosted at cloud.

Roadside computing: Roadside computing can assist preventing accidents by providing user an immediate warning. For example, consider a scenario shown Figure 3 where three cars are moving [11]. If due to an emergency car C brakes, then edge server can warn car A immediately and car A does not have to wait for car B to apply brakes. In connected vehicles, road safety can be better implemented using roadside computing in edge servers because it can process the data in real-time.

Electric vehicle charging: Cloud and edge can collaborate for making charging decisions for electric vehicles. The real-time information about electric vehicle's status of charge (SOC), charging cost at different charging points and information about available charging spots can be stored at the edge server. Information about charging decision can be provided to the car user by integrating car apps to edge server. The hourly average of city traffic, travel pattern of vehicles, and average charging need of vehicles per day can be stored in cloud for making long-term analytical decision and planning.

Energy management: Energy management can be both real-time or non real-time. Microgrids and charging stations can be connected to edge servers which makes short-term energy prediction and planning allowing real-time energy management. Day ahead charging requirement can be made at the cloud helping the main grid to generate appropriate amount of energy.

4.2 Challenges while adopting cloud/edge computing for vehicular networks

A hybrid system of cloud and edge computing has several challenges outlined below which need to be explored for enabling efficient computing architecture for connected vehicles.

Application placement problem: The location where an application should be executed is an important concern in an ecosystem of multiple edge and cloud servers. For the case of connected vehicles, the problem becomes complex because the vehicle location is not fixed and status of executing application need to migrate from one edge (or cloud) to another edge (or cloud). Also, if all the latency sensitive services are placed at the edge, then the performance of edge may degrade. On the contrary, if more services are migrated to the cloud then the resources may not be utilized efficiently. Therefore, the decision about application placement is complex in hybrid of edge and cloud infrastructure.

Fast virtual machine installation: In edge computing scenario, user application can be encapsulated in a Virtual Machine (VM), which is then synthesized at the edge. The advantage of this approach is that user program cannot infect host software running on edge server. To migrate an application from one edge to another edge, the technique of VM migration is adopted [25]. In this technique, VM status is saved on current edge and it is restarted from the saved state in the new edge. However, both VM synthesis and migration are slow processes. The investigation of VMs with low synthesis and migration time is yet to be explored. Also, VM development for executing applications in edge servers need standardization to make them compatible with edge servers which are hosted by different providers.

Application partitioning problem: Application partitioning, which is useful for cloud computing scenario, divides a program into two parts. The component which requires less resource is executed in the local device while one requiring more resource executes at the cloud [6]. The aforementioned solution, though useful in cloud computing scenario, can not directly apply to hybrid of edge and cloud systems because an optimum performance may require partitioning the application in multiple parts. Henceforth, rigorous application partitioning methods are required for improving the performance of the vehicle's hardware resource and minimizing delay in processing application.

Collaboration between edges and clouds: For connected vehicles, the coordination between cloud and edge, which are scattered geographically, is required because vehicle mobility requires services to migrate from one place to another. The orchestration between multiple clouds and edges guaranteeing seamless access of service to user is a complex problem in the integrated system of edge and cloud. Also, different edge and cloud facilities are provided by different vendors [28]. In such cases, a collaboration between them requires a common host software, APIs, and protocol. Collaboration also helps in load balancing and resource management. For instance, services can be shared between multiple edge or between edge and cloud, if some particular edge or cloud are flooded with user requests for processing data.

Security: Security is an important concern in an environment of multiple cloud, and multiple edge servers integrated with connected vehicles and smart grids. Although specific security solutions due to stand-alone cloud or smart grid system exist, the security solutions regarding the integration of these units still need to be explored [23]. Since edge computing is targeted for delay-sensitive applications, the security solutions for it should involve low latency. Also, since en-route vehicle require service migration from edge to edge or edge to cloud an integrated edge cloud systems need a trust model to developed for data sharing.

5 OPEN RESEARCH ISSUES

This section illustrates some of the open research issues concerned with the problem of connected vehicles.

5.1 Impact of cascade failures

Modern smart grid infrastructure consists of communication units and power units; both inter-dependent on each other. The power units generate energy thus providing electricity for running communication units like base station or transmission antennas. Communication units assist power generation units for energy production by sending them control signals through the network. For instance, grid's Supervisory Control and Data Acquisition (SCADA) unit gets electric supply from the grid, and it monitors and manages the grid's power production units. Thus both communication and power units mutually help each other by forming an integrated system. Due to their interdependency, a failure in communication unit can trigger a failure in power unit and vice-versa. The un-operational power unit stops supplying electricity to some communication unit resulting in failure in that unit. This process spreads throughout the integrated smart grid and communication network resulting in a cascade failure. In this phenomena, a failure of a single communication or power unit is propagated to other units very rapidly and disrupts the whole or major part of the smart grid [24].

In the connected vehicle scenario, the impact of cascade failure may be worse because a cascade failure can trigger traffic congestion in cities as the traffic management and traffic control depends upon the network connectivity. Additionally, power outage hinders electric vehicles from getting electricity for charging. The traffic congestion may result in SDN controllers and edge servers flooded with user request thus overloading both of them. This may result in failure of some SDN controllers or edge servers resulting in operation of communication units further getting disrupted. Therefore, the cascade failure in smart grid will have a large impact on the ecosystem of vehicles, smart grids, and communication networks.

Also, recovery from cascade failure will be difficult for such integrated architecture. As some power or communication unit are recovered from failure and become operational, every PEV user will plug in their vehicle for charging thus overloading grid which further induces failures. Therefore, the measures to prevent cascade failure is of utmost importance for the tightly coupled system of connected vehicles and smart grid. Analysis of cascade failure for such kind of integrated system is yet to be explored. Furthermore, if a cascade failure occurs, its mitigation techniques such that it affects very few number of units, and measures for a smooth recovery from such failures is an unexplored research field and requires attention for the better realization of connected vehicles.

5.2 Problem of adversarial attacks

Machine learning algorithms are gaining a lot of importance in today's world because of their ability to learn the patterns based on experience. Image recognition on social networking sites, recommendation systems in Amazon or Netflix, Google search engine's classifier are some of the machine learning applications. Machine learning has also been found useful for communication networks. Google's self-driving car is one of the advancement where a car can be programmed to drive based on machine learning techniques [1].

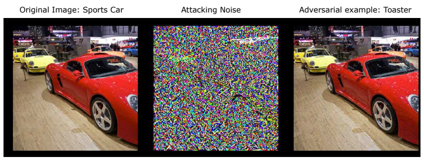

Figure 4: Adversarial attack [17]

However, the researchers from Google Inc. have found that the machine learning algorithms itself can be maliciously attacked [8]. The attack is called an adversarial attack where some small noise or perturbation is added to the input and the expected outcome changes drastically. It is not that every small perturbation will cause undesired result, but there is certain specific pattern in perturbation which results in the undesired outcome. The attacker only has to guess the pattern in noise and can affect outcomes of machine learning algorithms. For example, the two images in Figure 4 are distinguishable from a naked eye. But using machine learning algorithm first one is classified as a car and second one with added noise pattern as a toaster [17]. The attacker has to figure out the pattern in noise and superimpose it with the original image to drastically change the result.

For the case of the connected vehicles or futuristic autonomous vehicles, adversarial attacks are of immense concern since an attacker can make an image of the stop sign to be classified as a yield sign resulting in catastrophic outcomes. Additionally, energy management also requires traffic prediction to estimate both real-time and day ahead energy estimate. In such cases, an adversarial attack will have large impact if energy estimates are incorrect. There has been a little research done on solutions for mitigating adversarial attacks, and they are of concern for adopting machine learning in autonomous systems.

6 CONCLUSIONS

This paper highlighted the importance of connected vehicles for not only ease of driving but also for safety and efficient decision making. We discussed the potential that software-defined networks along with cloud and edge computing have for true realization of connected vehicles. However, adoption of these technologies poses several technical challenges that need to be addressed for successful wide-scale deployment. We also underscored the research needed to mitigate cascade failures and adversarial attacks that connected vehicles are prone to.

REFERENCES

[1] D. Baer. 2016. Machine learning is a revolution as big as the internet or personal computers. (April 2016). http://www.businessinsider.com/machine-learning-as-important-as-the-internet-2016-3

[2] F. Bonomi, R. Milito, J. Zhu, and S. Addepalli. 2012. Fog Computing and Its Role in the Internet of Things. In *Proc. of First Edition of the MCC Workshop on Mobile Cloud Computing*. New York, NY, USA, 13–16.

[3] V. Caswell. 2016. 5 Mobile apps to increase driving experience. (March 2016). http://www.trueautoprotection.com/auto-warranty-and-maintenance-blog/topic/spotify#.Wgk7mcanHIV

[4] Z. Chen, L. Jiang, W. Hu, K. Ha, B. Amos, P. Pillai, A. Hauptmann, and Satyanarayanan Mahadev. 2015. Early Implementation Experience with Wearable Cognitive Assistance Applications. In *Proc. of the Workshop on Wearable Systems and Applications (WearSys) (WearSys '15)*. ACM, New York, NY, USA, 33–38.

[5] Electrification Coalition. 2016. State of the Plug-in Electric Vehicle Market. (2016). http://www.electrificationcoalition.org/sites/default/files/

[6] E. Cuervo, A. Balasubramanian, D. Cho, A. Wolman, S. Saroiu, R. Chandra, and P. Bahl. 2010. MAUI: Making Smartphones Last Longer with Code Offload. In *Proc. of International Conference on Mobile Systems, Applications, and Services*. San Francisco, California, USA, 49–62.

[7] M. Gerla, E. K. Lee, G. Pau, and U. Lee. 2014. Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds. In *IEEE World Forum on Internet of Things (WF-IoT)*. 241–246.

[8] I. Goodfellow, J. Shlens, and C. Szegedy. 2014. Explaining and harnessing adversarial examples. *arXiv preprint arXiv:1412.6572* (2014).

[9] A. Hakiri, A. Gokhale, P. Berthou, D. C. Schmidt, and T. Gayraud. 2014. Software-Defined Networking: Challenges and research opportunities for Future Internet. *Journal of Computer Networks* 75 (2014), 453–471.

[10] B. Heller, R. Sherwood, and N. McKeown. 2012. The Controller Placement Problem. In *Proc. of First Workshop on Hot Topics in Software Defined Networks*. ACM, New York, NY, USA, 7–12.

[11] Y. Hu, M. Patel, D. Sabella, N. Sprecher, and V. Young. 2015. Mobile edge computingâĂŤA key technology towards 5G. *ETSI White Paper* 11, 11 (2015), 1–16.

[12] D. Kreutz, F. M. V. Ramos, P. E. VerÃŋssimo, C. E. Rothenberg, S. Azodolmolky, and S. Uhlig. 2015. Software-Defined Networking: A Comprehensive Survey. *Proc. IEEE* 103, 1 (January 2015), 14–76.

[13] I. Ku, Y. Lu, M. Gerla, R. L. Gomes, F. Ongaro, and E. Cerqueira. 2014. Towards software-defined VANET: Architecture and services. In *Proc. of Annual Mediterranean Ad Hoc Networking Workshop (MED-HOC-NET)*. 103–110.

[14] T. Luan, L. Gao, Z. Li, Y. Xiang, G. Wei, and L. Sun. 2015. Fog computing: Focusing on mobile users at the edge. *arXiv preprint arXiv:1502.01815* (2015).

[15] D. Zhang M. Wasserman, S. Hartman. 2012. Security Analysis of the Open Networking Foundation (ONF) OpenFlow Switch Specification. (April 2012). https://tools.ietf.org/id/draft-mrw-sdnsec-openflow-analysis-00.html

[16] A. Meola. 2016. Automotive Industry Trends: IoT Connected Smart Cars and Vehicles. (December 2016). http://www.businessinsider.com/internet-of-things-connected-smart-cars-2016-10

[17] E. Mikhailov and R. Trusov. 2017. How Adversarial Attacks Work. (2017). http://blog.ycombinator.com/how-adversarial-attacks-work/

[18] F. Mwasilu, J. Justo, E. Kim, T. Do, and J. Jung. 2014. Electric vehicles and smart grid interaction: A review on vehicle to grid and renewable energy sources integration. *Renewable and Sustainable Energy Reviews* 34 (2014), 501 – 516.

[19] J. Pan, R. Jain, S. Paul, T. Vu, A. Saifullah, and M. Sha. 2015. An Internet of Things Framework for Smart Energy in Buildings: Designs, Prototype, and Experiments. *IEEE Internet of Things Journal* 2, 6 (December 2015), 527–537.

[20] M. Patel, Y. Hu, P. Hédé, J. Joubert, C. Thornton, B. Naughton, J .R. Ramos, C. Chan, V. Young, S. .J Tan, D. Lynch, N. Sprecher, T. Musiol, C. Manzanares, U. Rauschenbach, S. Abeta, L. Chen, K. Shimizu, A. Neal, P. Cosimini, A. Pollard, and G. Klas. 2014. Mobile-Edge Computing. In *ETSI White Paper*.

[21] P. Patil, A. Hakiri, Y. Barve, and A. Gokhale. 2016. Enabling Software-Defined Networking for Wireless Mesh Networks in smart environments. In *Proc. of International Symposium on Network Computing and Applications*. 153–157.

[22] M. Rabinovich, Z. Xiao, and A. Aggarwal. 2004. *Computing on the Edge: A Platform for Replicating Internet Applications*. Springer Netherlands, Dordrecht, 57–77.

[23] R. Roman, J. Lopez, and M. Mambo. 2018. Mobile edge computing, fog et al.: A survey and analysis of security threats and challenges. *Journal of Future Generation Computer Systems* 78 (2018), 680–698.

[24] S. Ruj and A. Pal. 2014. Analyzing Cascading Failures in Smart Grids under Random and Targeted Attacks. In *Proc. of IEEE International Conference on Advanced Information Networking and Applications*. 226–233.

[25] M. Satyanarayanan, P. Bahl, R. Caceres, and N. Davies. 2009. The Case for VM-Based Cloudlets in Mobile Computing. *Journal of IEEE Pervasive Computing* 8, 4 (October 2009), 14–23.

[26] M. Satyanarayanan, Z. Chen, K. Ha, W. Hu, W. Richter, and P. Pillai. 2014. Cloudlets: at the Leading Edge of Mobile-Cloud Convergence. In *Proc. of IEEE International Conference on Mobile Computing, Applications and Services (MobiCASE)*. Austin, Texas, 1 – 9.

[27] A. Shapochka. 2015. 4 Challenges Lying in the Wait of SDN. (April 2015). http://www.nojitter.com/post/240169834/4-challenges-lying-in-the-wait-of-sdn

[28] S. K. Sharma and X. Wang. 2017. Live Data Analytics With Collaborative Edge and Cloud Processing in Wireless IoT Networks. *IEEE Access* 5 (March 2017), 4621–4635.

[29] R. Shukla and S.Sengupta. 2017. A Novel Software-defined Network Based Approach for Charging Station Allocation to Plugged-in Electric Vehicles. In *Proc. of IEEE International Symposium on Network Computing and Applications (NCA)*. Boston, Massachusetts, 437–441.

[30] NHTSA study. 2016. "U.S. DOT advances deployment of Connected Vehicle Technology to prevent hundreds of thousands of crashes". (July 2016). "https://www.nhtsa.gov/press-releases"

[31] S. Sultan, M. Al-Doori, A. Al-Bayatti, and H. Zedan. 2014. A comprehensive survey on vehicular Ad Hoc network. *Journal of Network and Computer Applications* 37 (January 2014), 380 – 392.

[32] Y. Sun, H. Song, A. J. Jara, and R. Bie. 2016. Internet of Things and Big Data Analytics for Smart and Connected Communities. *IEEE Access Journal* 4 (February 2016), 766–773.